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Ernst Zinner, lithic astronomer

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It is a rare privilege to be one of the founders of an entirely new field of science, and it is especially remarkable when that new field belongs to the oldest branch of "natural philosophy." The nature of the stars has perplexed and fascinated humanity for millennia. While the sources of their luminosity and their structures and evolution were revealed over the last century, it is thanks to the pioneering efforts of a rare and remarkable man, Ernst Zinner, as well as his colleagues and students (mostly at the University of Chicago and at Washington University in Saint Louis), that in the last two decades it has become possible to literally hold a piece of a star in one's hand. Armed with sophisticated microscopes and mass spectrometers of various sorts, these "lithic astronomers" are able to reveal stellar processes in exquisite detail by examining the chemical, mineralogical, and especially the nuclear properties of these microscopic grains of stardust. With this special issue of *Meteoritics & Planetary Science*, we honor Ernst Zinner (Fig. 1) and his stellar career achievements on the occasion of his completion of 70 orbits. We cannot here do proper justice to also honoring his admirable personal qualities that have inspired a generation of scientists to follow his lead in studying the death of stars and the birth of our own star. Fortunately, many of us had an opportunity to celebrate Ernst the scientist—and Ernst the man—at the SIMS in the Space Sciences: The Zinner Impact Symposium held at Washington University February 3–4, 2007. This wonderful event, organized by Christine Floss along with Sachiko Amari, Randy Korotev, Frank Stadermann, and Brigitte Wopenka, was attended by about 120 scientists, some of whom have also contributed papers to this volume. This article presents a partial scientific biography and a personal view of the "Zinner impact" by one who was fortunate enough to be involved in a small way in some of the early adventures.

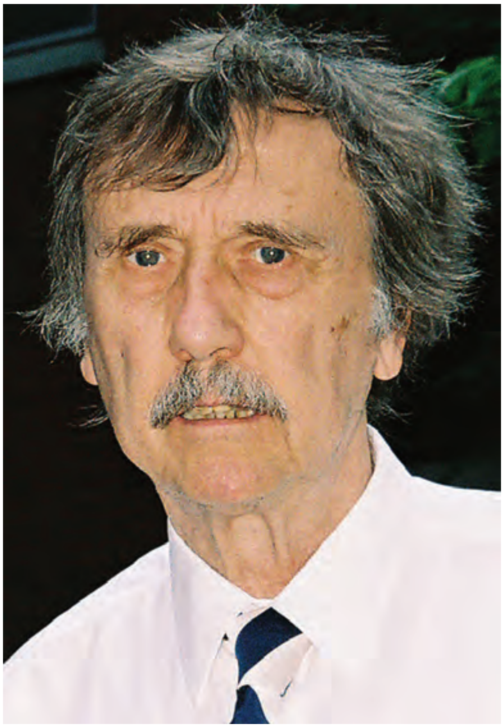

Fig. 1. Ernst K. Zinner, research professor of physics and earth and planetary sciences at Washington University in Saint Louis (2006).

Ernst Zinner was born January 30, 1937, and grew up in a beautiful stone house that was built in 1615 (and still stands) in Saint Peter in der Au, a small town in the Austrian countryside about 100 miles west of Vienna. He is the oldest of five siblings and his father Kunibert was quite a famous sculptor. The history of this setting, their house filled with music, and the mountain hillsides filled with butterflies (which required catching and cataloguing) would all play their role in shaping the boy. A deep appreciation of the beauty of the natural world coupled with a lifelong love of classical music, as well as the occasional frustration at the impermanence of things in the U.S. (particularly the eating establishments in the Houston area), would be a few of the characteristics that would find expression in the man. It was natural that Ernst should study physics, which he did at the Technische Hochschule in Vienna, obtaining his Diplom-Ingenieur in 1960. Following a year of instructing veterinary students in physics, Ernst took a programming job in Switzerland, primarily to avoid mandatory service in the Austrian army. However, he soon decided to resume his graduate studies and applied to various American universities, apparently unaware of that country's interest in a place called Vietnam. He was accepted at Washington University in Saint Louis in 1965 and, ironically, along with

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his green card, he received another welcome package from Uncle Sam in the form of a draft card. Somehow, Ernst managed to escape that ominous path and succeeded in obtaining a Ph.D. in experimental particle physics elucidating aspects of the $K^+ \rightarrow \pi^\circ \mu^+ \nu$ decay. Like the K^+-meson, the experimental particle physics group at Washington University had a short lifetime, and it rapidly disintegrated at the same time that Ernst filed his dissertation in 1972. A now-legendary 2:00 A.M. encounter in the elevator of Compton Hall Laboratory with Bob Walker, the relatively recently ensconced McDonnell Professor of Physics, changed the career direction of the then-35-year-old new Ph.D. and led to a three-decades-long collaboration and friendship. The charismatic Walker charmed Ernst with his enthusiasm for the vast and uncharted scientific opportunities that were available through the analysis of extraterrestrial matter. Zinner bought into the vision and gave up high-energy physics to become a postdoc on the fourth floor of Compton, in the new Laboratory for Space Physics.

At that time, research of Walker's "Fourth Floor Group" mostly focused on understanding and exploiting radiation damage in crystalline solids as a proxy record of thermal histories, exposure ages, and radiation environments. Thus, the first project that Ernst worked on, with Walker as well as Janet Borg and Michel Maurette, involved measurements of the abundance of heavy (Fe-group) ions in the solar wind as recorded by nuclear tracks in mica in an experiment deployed by the Apollo 17 astronauts (Zinner et al. 1974). Two thrusts followed naturally from Zinner's first exposure to space science: recognition of a need for better analytical methods for micro-analysis and germination of an interest in the interplanetary dust particles that caused micro-impact craters on the surfaces of lunar soil crystals. The latter was pursued in collaboration with Donald Morrison of Johnson Space Center in a series of papers (Morrison and Zinner 1977; Poupeau et al. 1975; Zinner and Morrison 1976). To address the former objective, Walker and Zinner set about developing a novel surface analysis technique for quantifying elemental distributions in complex materials like lunar grains. They implanted "marker ions" into the grain surfaces so that isotope analyses could be used to quantify elemental abundances—an innovation on the classic isotope dilution method (Zinner and Walker 1975). To perform the analyses, they turned to secondary ion mass spectrometry (SIMS) because of its inherently high depth resolution.

Important to realize is that in the early to mid-1970s SIMS was a new technology and the first generation of commercial ion probes were already earning a well-deserved reputation for generating unreliable or uninterpretable results (i.e., nonsense). Nevertheless, Walker's considerably gifted intuition led him to believe that the development of new micro-analytical methods would be key to addressing some of the most important large-scale problems in solar system origins and that the ion probe technique could realize its potential with instrumental improvements and appropriate development effort. He also must have had a good hunch that Ernst Zinner possessed the proper blend of skepticism and enthusiasm, as well as the talent, energy, and drive to take on this challenge. Thus began an itinerant existence for Ernst as he spent much of the remainder of the decade and the beginning of the next testing instrumentation and exploring the strengths and limitations of SIMS in several laboratories in the U.S. and Europe. The early development of Ernst's ion microprobe skills was accomplished over dozens of trips to Houston where he had a visiting scientist appointment at the Lunar Science Institute to work on the ARL ion probe at Johnson Space Center. The instrument was housed in a small lab under a stairwell in Building 31. In addition to trying to understand the physics of ion yields and primary beam knock-on effects in depth profiling, Ernst discovered that a correction to count rates had to be made whenever someone walked on the stairs above! While these development efforts were ongoing, Zinner and colleagues continued producing scientific results related to the interplanetary dust flux, the solar wind, and the lunar surface environment (e.g., Crozaz et al. 1977; Zinner 1980b; Zinner et al. 1977).

The early struggles with unknown physics and unreliable instrumentation serve to illustrate several of Ernst's characteristic qualities. The first are dogged determination and perseverance. As usual, this attitude is underpinned by an innate optimism, although in this case, frequently tempered by frustration that scientific progress is slowed by "a stupid machine." No matter how aggravating, all problems from the subtle (e.g., matrix effects, element-dependent dead time, mass fractionation laws) to the absurd (see above!) had to be overcome to assure reliable data. Another characteristic of Ernst's career is that technical development and scientific applications proceed in a synergistic fashion; thus, ion implantation is developed as a means for quantifying matrix effects in depth profiling so that analyses of lunar grains could be accomplished. However, it is important to emphasize that Ernst's ideas regarding technical development have often taken the long view, recognizing that sustained effort is necessary to assure that the tools are made ready, so that when nature cooperates, significant discoveries can be realized. Zinner and Walker had hoped that nature would indeed cooperate by hiding her treasures in small places, and that these secrets could be revealed by SIMS. This was not a radical viewpoint, and in fact others were also developing the ion probe for cosmochemical research—especially Ian Hutcheon, first at Chicago and then with Jerry Wasserburg's group at Caltech, and also Bill Compston and colleagues creating the SHRIMP at the Australian National University. Although not invoking first-hand accounts, I conjecture that none of these pioneers anticipated just how spectacularly successful the ion probe would prove to be in cosmochemistry. Certainly, given the paradigm-shifting discoveries in the mid-1970s of widespread oxygen isotope anomalies (Clayton et al. 1977), the short temporal connection with the presolar molecular cloud indicated by radioisotopes (Lee et al. 1976), and correlated isotopic effects in the enigmatic FUN inclusions (Lee and Papanastassiou 1974), one could well imagine that presolar grains existed in some abundance in meteorites and that new technology would help to uncover them. However, not many dared to express the view that, in little more than a decade, actual grains of stardust could be isolated and that it would be possible to use an ion probe to make correlated isotopic analyses on such rocks weighing only a few picograms.

Zinner and his numerous collaborators have made important contributions to almost all aspects of the broad range of investigations addressed by the ion probe technique. Table 1 enumerates the 178 publications of Ernst according to major area of emphasis (a few entries are repeated because of a large degree of overlap). Fully 10% of these, published over 30 years, report the development of various ion probe methods, ranging from depth profiling (Zinner 1983; Zinner and Walker 1975) to rare earth element (REE) analysis (Crozaz and Zinner 1985; Zinner and Crozaz 1986), isotope analysis (Fahey et al. 1987a; Zinner 1989; Zinner and Grasserbauer 1982), ion imaging (McKeegan et al. 1985; Nguyen et al. 2003; Zinner and Epstein 1987), quantitative aspects of ion detection (Slodzian et al. 2004; Traxlmayr et al. 1984; Zinner et al. 1986a), and new instrument development (Stadermann et al. 2005). Not surprisingly, the category with the most contributions is "Stardust and Nucleosynthesis," but these papers constitute less than half of Ernst's publications. Other areas of cosmochemistry to which Ernst and colleagues contributed significantly, often with founding discoveries, include interplanetary dust particles (IDPs), refractory inclusions in meteorites (CAIs and hibonites), and the abundances of short-lived radionuclides in the early solar system. Missions addressed include Apollo, the Long Duration Exposure Facility (LDEF) (Zinner et al. 1983b), Rosetta (Riedler et al. 1998), and naturally, Stardust (McKeegan et al. 2006). Throughout his career, Ernst has contributed timely and highly influential review papers. These have typically not merely summarized a field, but have also provided new insights and synthesis, often building a foundation for further progress. As a measure of influence, I note that his review papers on stardust grains (Anders and Zinner 1993; Zinner 1998) have been cited about 500 times, the synthesis paper on ^{26}Al distributions in the solar nebula with co-authors Glenn MacPherson and Andy Davis (MacPherson et al. 1995) close to 200 times, and even the early papers delimiting artifacts encountered during depth-profiling of semiconductors and other materials (Zinner 1980a, 1983) total nearly 100 citations.

The in-depth profiling expertise and initial forays into isotope analyses were accomplished at the Technical University in Vienna, where in 1980 Ernst had taken a one-year appointment as visiting professor. There were many reasons why Ernst was happy to be back in his homeland, most of them involving music and Austrian pastries. But his main goal in returning to Vienna was to work out methods for high mass resolution analyses using the Cameca IMS-3f, a next generation ion microscope that the Institute of Analytical Chemistry at the Technical University had acquired primarily for semiconductor applications. At that time, only two such instruments existed in the U.S. for geochemical or cosmochemical research (at MIT and Caltech), but Walker had obtained funding from James McDonnell to purchase an IMS-3f for Washington University. Bob and his wife, Ghislaine Crozaz, met Ernst in Paris for instrument testing, the culmination of which apparently included a late-night victory session with the celebratory atmosphere enhanced by its coincidence with Bastille Day. After concluding a year-long negotiation with Cameca, Ernst had one other important matter to take care of, namely securing the affections of a spirited young chemist, Brigitte Wopenka, who was a junior faculty member at the Institute of Analytical Chemistry, and whom he was introduced to on his very first day in Vienna. So it was that he returned from Austria to Saint Louis in the spring of 1982 with both an ion probe and a wife. Vienna had indeed proved to be a successful sabbatical!

Table 1. Scientific topics addressed in Ernst Zinner's publications.

Topic	Number of publications
Solar wind and lunar space environment	11
Ion microprobe instrumentation and techniques	19
Interplanetary dust and cometary dust	14
LDEF and other missions	7
Rare earth element analysis	7
Isotope anomalies in CAIs and hibonites	19
Short-lived radionuclides	15
Meteorite isotope studies	14
Stardust and nucleosynthesis	69
Reviews and syntheses	21
Other	4

The first year of the ion probe era at Washington University was spent rewriting programs, debugging electronics, and then ultimately building a new ion counting system. Graduate students Kevin McKeegan and Albert Fahey, not knowing any better, were happy to participate in these efforts and to measure the dead time seemingly every day for a year. Ernst also provided training for the two, who must have been slow learners since they continually tested the patience of the master. Once the instrument was functioning properly, deciding what problem to work on first was relatively easy. Bob Walker was convinced that the interplanetary dust particles collected in the stratosphere by Don Brownlee (e.g., Rajan et al. 1977) would prove to be more primitive than any meteorites. The trouble was that these IDPs were rather small (~1 ng) so that a successful measurement would require high sensitivity and a little luck

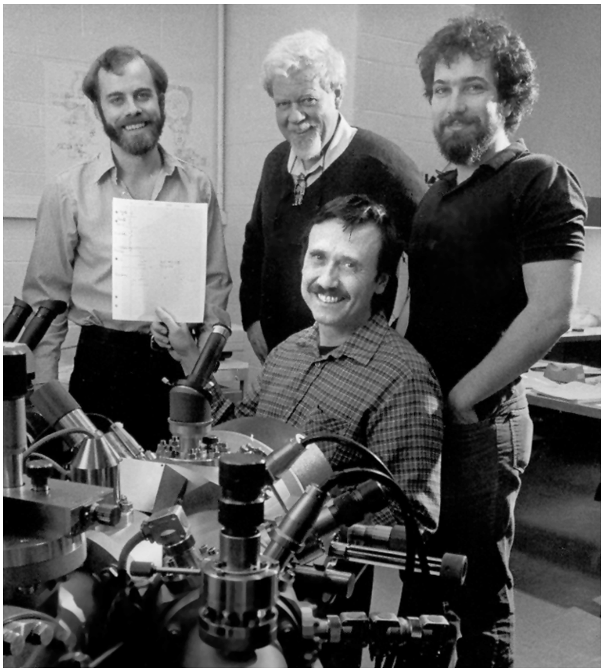

Fig. 2. Ernst Zinner proudly displays the graph showing the first data obtained with the Washington University IMS-3f ion probe to the obvious joy of onlookers (from left) Scott Sandford, Bob Walker, and Kevin McKeegan (1983).

to find large isotope effects that could clearly exceed the modest experimental precision attainable. Hydrogen was a good candidate because large D/H effects had recently been found in chemical separates of primitive carbonaceous and ordinary chondrites by Sam Epstein and others (e.g., Yang and Epstein 1983) pointing to an interstellar inheritance, and a subset of IDPs was known to be relatively rich in hydrogen. Ernst then made the fortuitous discovery that negative ion analysis both increased the sensitivity for D/H in carbonaceous matter and simultaneously reduced molecular ion interference to an essentially negligible level (since H_2^- is not stable). Thus, after working hard to control instrumental parameters closely enough to enable reproducible measurements at high mass resolving power (MRP), it is ironic that the first contribution of the Washington University IMS-3f involved analyses at low MRP. Because IDPs were precious, tests were first conducted on matrix grains ~10 μm in size from the carbonaceous chondrite Renazzo that was known to carry D-enriched material. Early negative results led McKeegan and Walker to finally take dinner, leaving Zinner to carry on with the measurements. Upon returning to the lab, we found a piece of graph paper (in those days, Ernst always hand-plotted data immediately) with a datum circled and “voilà!” boldly written across the page (Fig. 2). Within days, two chondritic IDPs were found to be enriched in deuterium by up to ~1100‰ compared to SMOW with the degree of enrichment heterogeneously distributed among particle fragments at the scale of a few microns, and within a week a letter was sent to *Nature* (Zinner et al. 1983a). This very exciting result has been followed by a large number of other isotopic measurements on IDPs (e.g., Fahey et al. 1984; Floss et al. 2004; Floss et al. 2006; McKeegan et al. 1985; Messenger 2000; Messenger et al. 2003) validating Walker’s hypothesis of their primitive nature by showing that IDPs have a high abundance of materials with molecular cloud affinities (Zinner 1988). Even after his active interests became more directly focused on stardust grains from meteorites, Ernst Zinner played a significant advisory role in all IDP studies. In this regard, I wish the reader to note that it is revealing of Ernst’s character that there exist several high-profile papers on IDPs for which he (and Bob Walker) declined honorary co-authorship, instead allowing their students to develop independence and enjoy greater community exposure (e.g., McKeegan 1987; Messenger 2000).

The interest in IDPs (and the earlier lunar experiences) also led to the idea of capturing particles in space on ultrapure substrates and bringing them back for analysis. The capture cell experiment on NASA’s LDEF mission was constructed at Washington University during this time, but it unfortunately failed to achieve the hoped-for scientific results due to the Challenger accident and subsequent delays in retrieving LDEF (which increased space exposure time well beyond the experiment’s design limits). However, the mission had a lasting impact in that it brought to Saint Louis Frank Stadermann, who would become one of Ernst’s closest long-term collaborators and key in the effort to develop the NanoSIMS (but that’s getting ahead of the story).

Another long-term collaborator was Jitendra Goswami, who came from India for extended visits to the McDonnell Center bearing precious blue gems of hibonite extracted from CM chondrites. The hibonites were in many respects perfect materials for the ion probe; the grains were large enough (~50 μm) for correlated analyses and they exhibited enormous isotopic anomalies in Ti and Ca of clear nucleosynthetic origin, more than an order of magnitude greater than those found previously in FUN inclusions (Fahey et al. 1985; Zinner et al. 1986b). These analyses demanded the utmost performance at high MRP from the ion probe (Fahey et al. 1987a) and the astonishing results showcased the power of the technique. They also represented Ernst’s first ventures into ^{26}Al chronology, which would become an important research focus for the next 15 years (e.g., Fahey et al. 1987a; MacPherson et al. 1995; Podosek et al. 1991; Zinner and Gopel 2002).

The ^{50}Ti enrichments in hibonite had been independently discovered by Trevor Ireland at ANU (Ireland et al. 1985) and large negative δ^{50}Ti values were found soon thereafter by Richard Hinton and colleagues at Chicago (Hinton et al. 1987). Using techniques recently developed for O isotope analyses of IDPs (McKeegan 1987), the Washington University team measured oxygen in hibonites with both positive and negative δ^{50}Ti, providing the first convincing evidence that isotope anomalies in oxygen are not correlated with those in refractory cations and, thus, a late spike from a supernova could not be responsible for the pervasive ^{16}O anomaly (Fahey et al. 1987b). The status of ^{16}O-excesses as the premier nucleogenetic anomaly in the solar system would be further eroded by SIMS analyses of presolar oxide grains discovered by Larry Nittler at Washington University (e.g., Nittler et al. 1997), giving important impetus to current efforts to seek a chemical explanation (e.g., Clayton 2002; Thiemens 1996). The puzzling record of short-lived radioactivity in the hibonite grains was documented by Ireland (Ireland et al. 1988) and interesting correlations between ^{26}Al and ^{41}Ca were later found by Goswami and his students (e.g., Marhas et al. 2002; Sahijpal and Goswami 1998; Srinivasan et al. 1994), although the fundamental chronological relationship of the CM hibonites to other early solar system refractory materials has remained mysterious to this day. Important clues regarding the petrogenesis and inferred solar system origin for the hibonite grains derives from their rare-earth and other trace element abundances, first explored by Fahey et al. (1987a) and then in much greater detail by Ireland who had joined Zinner's team as a postdoc (Ireland et al. 1988).

A pressing need for quantitative microanalysis of rare earth element abundances had been brought to Ernst's attention by his office mate and long-time friend and collaborator, Ghislaine Crozaz. Several SIMS groups had already attempted REE analyses with some success (Metson et al. 1984; Reed 1980; Shimizu et al. 1978), however, the methods were either not fully quantitative or required very intense primary ion beams, resulting in large analytical spots (typically >50 μm), or were prone to potentially large matrix effects, thus requiring very careful standard matching. Ernst realized that most molecular ion interferences in the REE mass region were due to complex species consisting of at least 3 or 4 atoms, and thus could be effectively removed with moderate energy filtering, thereby maintaining high sensitivity. Most remaining interferences (e.g., oxides of the light REE at the mass of the heavy REE) could be corrected for by deconvolution and peak stripping, and moreover, the energy filtering led to rather robust relative sensitivity factors for phosphate, oxide, and silicate matrices (Ireland 1995). The resulting Zinner and Crozaz (1986) contribution is one of the most highly cited SIMS technique papers, with many important applications in geochemistry and cosmochemistry (e.g., Crozaz and Zinner 1985; Wadhwa 2001; Wadhwa et al. 1994).

While the ion probe investigations of CAIs (e.g., Ireland et al. 1991; Podosek et al. 1991; Zinner et al. 1991), REE distributions, and short-lived radioactivity (Endress et al. 1996) proceeded at spatial scales of a few to tens of microns, it was also clear from studies of IDPs, which showed highly deuterium-enriched "hotspots" (McKeegan et al. 1987), that greater isotope anomalies can sometimes be found at the micron or smaller scale. Such high spatial resolution could be achieved by utilizing the ion microscope capabilities of the IMS-3f. In a prescient paper (Zinner and Epstein 1987), Ernst measured carbon isotopes in individual oxide (spinel) grains in an acid residue from the Murchison meteorite that Jongmann Yang and Sam Epstein had shown to contain isotopically heavy hydrogen and carbon. The ion probe data exhibited extremely large ^{13}C enrichments, up to 7000‰, which ion imaging revealed were associated with Si and concentrated in micron-sized subgrains. It was inferred that the carrier phase was small SiC grains that "most likely originated in the circumstellar atmospheres of red giants."

In the same week in 1987 that the Zinner and Epstein paper was submitted, Roy Lewis announced at the Lunar and Planetary Science Conference that a small vial of white powder which he was carrying in his shirt pocket contained interstellar diamonds! Ed Anders, Roy Lewis, Tang Ming, and their colleagues at the University of Chicago had for years been following the tags provided by isotopically exotic noble gases in order to distill down meteorites to isolate chemically resistant presolar carrier phases. Now they had obtained an extract containing huge concentrations of Ne-E and exotic (*s*-process) Xe and displaying an X-ray powder diffraction characteristic of nanoscale diamond. Needing further characterization of this exotic material, Lewis approached Ernst's wife, Brigitte Wopenka, about whether she would be able to use the Raman microprobe at Washington University to confirm that the carrier phase indeed was diamond. So the precious sample went from Lewis' shirt pocket to Brigitte's purse for transport to Saint Louis (in the days before anthrax and heightened airline security). Once Brigitte was done with her (unsuccessful) attempt to obtain a Raman spectrum of the nanometer-sized material, she asked Lewis' and Anders' permission to pass the sample on to the "ion probe folks" who would like to do carbon isotopic analysis on the material. It was clear that if the diamonds really were only nanometers in size, the measurement of individual grains would not be feasible (which is still the case), but that interesting data might still be obtained on "bulk" analyses of micron-sized clumps of the powder. When the sample was prepared for ion probe analysis (following the procedures developed for IDPs), it was discovered that there was more than diamond in the residue and, in fact, grains of SiC large enough for individual measurement were there as well (Bernatowicz et al. 1987). Of course, SiC is a ubiquitous contaminant in many labs (polishing compound), but the ion probe analyses of carbon, nitrogen, and silicon isotopes (Zinner et al. 1987) soon put that possibility to rest and demonstrated that the "contamination" had in fact occurred 4.6 billion years ago! These grains showed isotope anomalies exceeding any previous measurement by up to a factor of 50, and the clear conclusion was that "these phases are circumstellar grains from carbon-rich stars, whose chemical inertness allowed them to survive in exceptionally well-preserved form" (Zinner et al. 1987).

The holy grail of meteorites had been found, but of course, this was just the beginning of the laboratory analysis of stardust. The Chicago-Washington University collaboration flourished as some of the micro-analytical techniques developed by the Fourth Floor Group for the study of IDPs were turned toward characterization of the well-travelled survivors of the Chicago acid treatments. Sachiko Amari moved from Chicago to Saint Louis, and Walker and Zinner with their graduate students, Larry Nittler, Scott Messenger, and Anh Nguyen, and postdoc Conel Alexander searched for new types and locales of presolar grains using novel imaging techniques. Other cosmochemistry groups also redirected their research efforts toward presolar grains, bringing additional ion probes and new techniques like resonant ionization mass spectrometry (e.g., Savina et al. 2003) to bear on the analytical and scientific challenges. With the leadership of emissaries like Don Clayton, Brad Meyer, and Roberto Gallino, nuclear astrophysicists also took notice of the remarkable discoveries in meteorites. Communication and collaboration in the emerging field have been fostered through a series of workshops, especially at Washington University, Clemson University, and in Torino, but in other places as well. Former disciplinary boundaries have been frequently crossed as when, for example, prominent cosmochemists (Fig. 3) made innovations in stellar nucleosynthesis theory based on presolar grain analyses (e.g., Boothroyd et al. 1995; Nollett et al. 2003) and nuclear astrophysicists modeled mineral condensation phenomena in stellar outflows (e.g., Deneault et al. 2003). In addition to diamond and SiC, many other types of presolar grains have been identified up to now, including graphite (Amari et al. 1990), silicon nitride (Nittler et al. 1995), titanium carbide (Bernatowicz et al. 1991), refractory oxides such as corundum, spinel, and hibonite (Choi et al. 1999; Choi et al. 1998; Huss et al. 1994; Hutcheon et al. 1994; Nittler et al. 1994; Nittler et al. 1998), and, more recently, common silicate minerals including olivine, pyroxene, and even amorphous material (so-called "GEMS," Messenger et al. 2003; Nguyen and Zinner 2004). It is not the intention here to review the various subtypes of presolar grains (with clever names like X, Y, Z . . . etc.) and their inferred stellar sources, nor the vast and unique contributions that the study of these remarkable messengers have made to diverse subjects in astrophysics, including stellar evolution and models of nucleosynthesis, galactic chemical evolution, and the physical, chemical, and mineralogical properties of interstellar dust. The interested reader is far better served to consult authoritative reviews done by those directly involved in creating this field, especially of course, Ernst Zinner (e.g., see Anders and Zinner 1993; Clayton and Nittler 2004; Zinner 1998, 2005; Zinner and Amari 1999; Zinner et al. 2006a; Zinner et al. 2006b).

I will, however, make one additional observation that strikes me as particularly fitting given the long and rewarding collaboration that began with that late-night elevator ride. With one of his final scientific contributions, Bob Walker must have been extremely gratified to participate in the discovery of presolar silicate grains in an IDP (Messenger et al. 2003), a discovery made possible only by newest generation ion probe, the NanoSIMS. Taking the long view, Walker and Zinner, along with Stadermann, had worked diligently for many years to help Cameca develop that technology (invented by Georges Slodzian), so that, with the proper tool in hand, nature's secrets were once again unlocked from small hiding places.

The NanoSIMS era is just beginning at the McDonnell Center for the Space Sciences and elsewhere (Fig. 4). As large as the Zinner impact has been, it is sure to grow in the coming years. I count at least 11 ion probe laboratories[1] whose personnel have a close connection with Ernst Zinner either as a former student, postdoc, or one of the many collaborators who have enjoyed extended visits on the Fourth Floor. Clearly, the open laboratory policy and welcoming environment of the McDonnell Center, actively fostered by Walker, Zinner, and all the other denizens of the Fourth Floor, has contributed importantly to the Zinner impact and to the overall advancement of the science (not to mention the betterment of the scientists).

Ernst has received numerous awards in recognition of his many accomplishments. He was honored with the Leonard Medal of the Meteoritical Society in 1997 (Fig. 5) and in the same year received the J. Lawrence Smith Medal of the U.S. National Academy of Sciences. He was elected a Corresponding Member of the Austrian Academy of Sciences in 2002 and is a Fellow of the Meteoritical Society (1988), the American Physical Society (1991), the Geochemical Society and the European Association for Geochemistry (both in 1998). For his work collecting meteorites with Bill Cassidy's team, he received the Antarctic Service Medal of the National Science Foundation. The latter award was given in 1987, the same year in which presolar grains were finally identified.

The period of time during which Ernst was being lauded with awards and recognition has not been without its severe difficulties. For the past dozen years, Ernst has been battling a rare and normally fatal blood cancer and has been in and out of remission several times. In 1999, he survived the cruelest procedure of modern medicine, a bone marrow transplant, in which the former high-energy physicist received a combined 5 times lethal dose of gamma rays. Ernst and his physicians are currently employing new technology (monoclonal antibodies) to keep at bay the disease which relapsed in 2005. Sharing with him an uncommon courage and perseverance on every step of this long battle has been his chief defender, confidante and love of his life, Brigitte (Fig. 6). Ernst, as has already been noted, is a man of many talents—for example, he is not only a

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[1] In approximate chronological order: CNR-IGG (Pavia), the Physical Research Lab (Ahmedabad), UCLA, ANU, NIST, MPI Chemistry (Mainz), CIW (DTM), ASU, JSC, Muséum National d'Histoire Naturelle (Paris), Caltech. My apologies if I've forgotten anyone.

Fig. 3. Two wise men (a.k.a. graybeards) of lithic astronomy: Jerry Wasserburg and Ernst Zinner at the Washington University conference on Astrophysical Implications of the Laboratory Study of Presolar Material in 1996. Wasserburg and Zinner have not directly collaborated on publications (so far), but throughout their careers they have often worked on similar problems in a complementary fashion, thereby engendering a high degree of mutual respect.

Fig. 4. Ernst Zinner, Peter Hoppe (left), and Jitendra Goswami are happy about the data produced by the NanoSIMS at the Max Planck Institute for Chemistry in Mainz (2003).

medal-winning skier (after all, he is Austrian!) and superb ping pong player (second on the Fourth Floor only to Steve Sutton!), but also a truly excellent pianist. A few years ago (during yet another trip to Houston), Ernst explained to me one of the "benefits" of living with a terminal disease: it teaches you the importance of setting your priorities straight and doing some things that you might otherwise not take time for, like learning to play the cello at age 59 in order to share special moments with your son (Fig. 7).

On behalf of the many former students, postdocs, McDonnell Center for the Space Sciences staff, scientific colleagues, and friends, I salute Ernst on this milestone and thank him for enriching our lives and our science. All his many friends, the scientists and many others from different walks of life, wish him more fun with science, lots of happiness for the years to come, and continued success in his battles with both mantle cell lymphoma and the NanoSIMS.

Fig. 5. Ed Anders presented Ernst Zinner for the Leonard Medal of the Meteoritical Society at its 60th annual meeting (1997, Maui, Hawai'i).

Fig. 6. Chemotherapy in 1999 could not dampen the good humor of Brigitte and Ernst.

Acknowledgments–I thank Brigitte Wopenka for helpful factual clarifications and for providing most of the figures. I thank Christine Floss for her tireless organization of the Zinner Impact Symposium and also for her patience.

Fig. 7. Ernst and Max Giacobini Zinner harmonize at their home in 1996. The younger Zinner would far surpass his father on the strings and would play with the Saint Louis Symphony Youth Orchestra; he currently attends Columbia University.

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