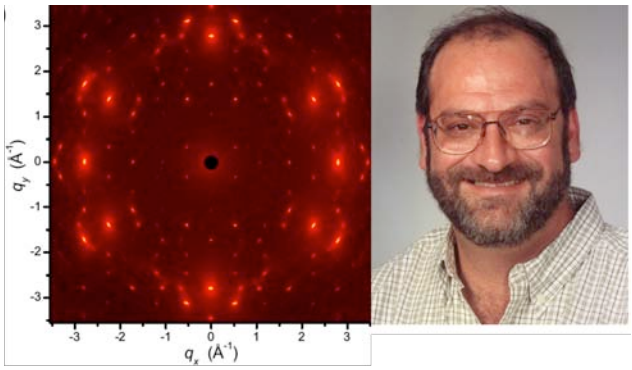
Milestones in Quasicrystal Research at the Ames Laboratory & Iowa State University.

1988 - Alan Goldman joins the Department of Physics & Astronomy, and the Ames Laboratory. (Alan is shown at right, together with an X-ray diffraction pattern of a quasicrystal from a paper he co-authored.[1]) Alan is an expert in scattering and in quasicrystals, having worked on quasicrystals almost since their discovery in 1982 by Danny Shechtman. Alan inspires others in Ames to work on quasicrystals, often via collaborations. Thus the seed is planted.

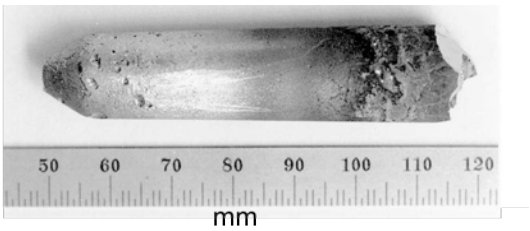


1989 - Alan Goldman, together with his colleagues at SUNY Stony Brook and from Japan, establish that a new class of icosahedral alloys with the face-centered icosahedral (fci) structure do not have the ubiquitous phason disorder found for simple icosahedral (si) structures.[2]

1990-1991 - Scientific efforts in Ames focus on melt spun quasicrystals. The key scientists in this group are Bill McCallum, Alan Goldman, Matthew Kramer, and Jeff Shields.

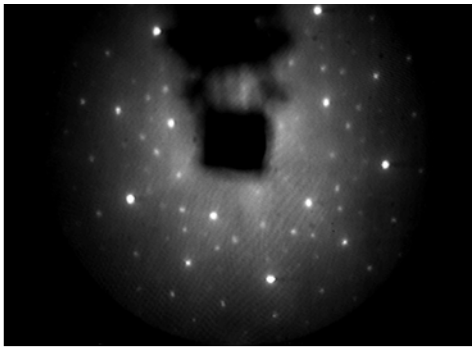
1992 – The Ames Laboratory scattering group and colleagues from Grenoble, France employ inelastic neutron scattering to study phonons in icosahedral alloys.[2]

1992-93 - Synthesis efforts in Tom Lograsso's research group produce macroscopic single grains in several quasicrystalline systems by the Bridgman growth technique, enabling detailed research to advance. (A sample composed of aluminum, palladium, and manganese is shown at right.) Thus, single-grained quasicrystals of several cm^3 are produced for the first time in Ames.[3]



1993 - Alan Goldman and co-workers publish a paper which establishes that quasicrystals can have nearly perfect long-range atomic order, an issue which had been debated until that time.[4]

1995 – Alan Goldman, Matthew Kramer, Bill McCallum and Tom Lograsso win the Department of Energy's Award for Sustained Outstanding Research in Solid State Physics, for their work on "The Structure and Physical Properties of Quasicrystals."



1995 - Ames Laboratory scientists publish their first papers on the surface science of quasicrystals.[5, 6] A low-energy electron diffraction pattern is shown at right.

1995 - An interdisciplinary team at the Ames Laboratory led by Alan Goldman, Dan Sordelet and Pat Thiel is awarded a DOE New Initiative grant (also called a 2% grant) to investigate surface and interface properties of quasicrystals.

1996 - The Ames Laboratory and Iowa State University host an international conference entitled “New Horizons in Quasicrystals: Research and Applications.” Co-chairs are Jean-Marie Dubois (Nancy, France), Alan Goldman, Dan Sordelet, and Pat Thiel. One major outcome of this conference is that Danny Shechtman subsequently receives support from Iowa State University’s Institute for Theoretical and Applied Physics to work with researchers in the Ames Laboratory Plasma Spray Facility. This collaboration leads to a comprehensive survey probing the tribological properties of an unprecedented range of quasicrystalline coatings

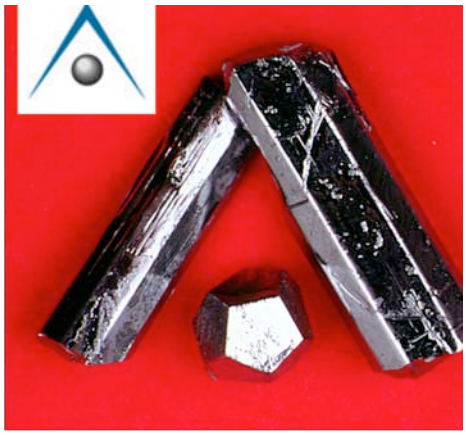
1997 - Alan Goldman and Pat Thiel are invited to organize a session on "Surfaces and Interfaces of Quasicrystals," held at the March Meeting of the American Physical Society, Kansas City.

1997 - Dan Sordelet and Jean Marie Dubois (Nancy, France) organize an issue of the MRS Bulletin devoted to quasicrystals. The cover is shown at right. It depicts, schematically, the thermal spray process for preparing quasicrystalline coatings.

1997 - The Ames Laboratory group, together with two collaborators from Lawrence Berkeley National Laboratory (Martin Gierer and Michel Van Hove), publish the first analysis of the surface structure of an icosahedral quasicrystal using electron diffraction. This result immediately provides a way of understanding and rationalizing important morphological aspects of the clean surface, including step heights and chemical composition of the flat terraces.[7, 8]

1997 - Paul Canfield and Ian Fisher are the first people in the world to grow large, faceted, single grains of quasicrystals. They achieve this using a technique called flux growth. The famous picture at right, showing one of their samples as a beautiful dodecahedron-on-a-penny, is born. Research on rare-earth-bearing quasicrystals begins.[9]

1998 - The Ames Laboratory team (plus a collaborator from Lawrence Berkeley National Laboratory) wins the Department of Energy's Award for Outstanding Scientific Accomplishment in Materials Chemistry. Team members are Cynthia Jenks, Alan Goldman, Matthew Kramer, Dan Sordelet, Pat Thiel, and Michel Van Hove.



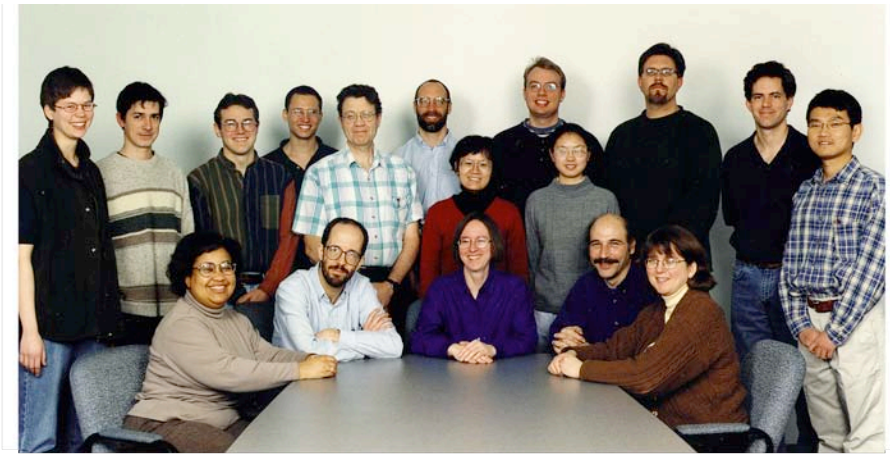
1998-99 - Paul Canfield and Ian Fisher extend flux growth to a wider variety of stable quasicrystals, including an icosahedral phase containing a rare earth, magnesium, and zinc (R-Mg-Zn), a decagonal phase with aluminum, nickel, and cobalt (Al-Ni-Co), as well as the icosahedral phase of aluminum, palladium, and manganese (Al-Pd-Mn).[10, 11] They create a revised Ames Lab Logo, using rod-like samples of decagonal phase, and a dodecahedral sample of icosahedral phase. Their logo is shown at right. The standard Ames Lab logo used at the time is shown in the inset.

1998 - Paul Canfield and Ian Fisher tour Europe, teaching the art of creating quasicrystal samples via flux growth.

1998 – Paul Canfield, Alan Goldman and Ian Fisher show that rare earth moments in R-Mg-Zn quasicrystals are ideal examples of the spin-glass state, a magnetic analogue to window glass.[12, 13]

1998 - Together with French, Japanese, and German colleagues, Pat Thiel co-chairs a Symposium on Quasicrystals at the Fall Meeting of the Materials Research Society.

1999 – An international collaboration, including Ames scientists, explores the structure of Al-Pd-Mn using dynamical X-ray diffraction and X-ray standing waves.[14]



1999 - The Ames Laboratory team, many of whom are shown at right, is featured in C&E News, the primary science news magazine for chemists. Standing, left to right: Barbara Wehner, Vincént Fournée, Paul Bloom, Ian Fisher, James Anderegg, Matthew Kramer, Wen-Jiuan Tsai, Nicholas Spurr, Tanhong Cai, Mark Heinzig, Matthew Besser, Chi-Shen Lee. Seated, left to right: Tamara Bloomer, Paul Canfield, Pat Thiel, Tom Lograsso, Cynthia Jenks.

1999 - A frequent collaborator with the Ames Laboratory team, and a leader in the field of quasicrystals—Jean Marie Dubois (Nancy, France)—is awarded an honorary degree from Iowa State University.

2000 - Together with Japanese, German, and French colleagues, Pat Thiel co-chairs a Symposium on Quasicrystals at the Fall Meeting of the Materials Research Society.

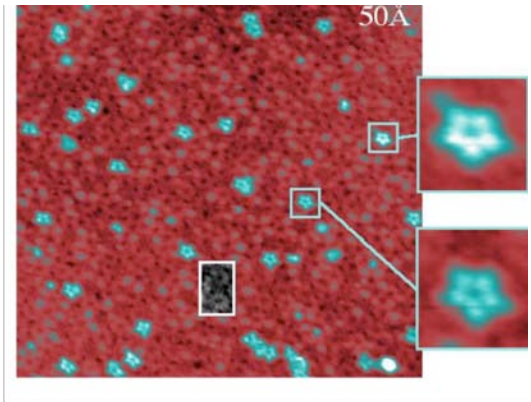
2000 - Pat Thiel organizes a symposium at the National Meeting of the American Chemical Society on *Aperiodic Metals and Metallic Glasses: Surface Properties*.

2001 – Paul Canfield and Ian Fisher (now at Stanford) grow single grains of icosahedral Al-Pd-Re and show that, in this form, it is not a semiconductor or insulator.[15]

2001 - The Jean Marie Dubois Award for Excellence in Quasicrystal Research is established, through an endowment at the Iowa State University Foundation. This is an international award “to recognize important, sustained research on any aspect of quasicrystals within the 10-year period preceding the award.”

2002 - Qisheng Lin and John Corbett discover the Sc-Cu-Zn icosahedral quasicrystal and solve the structures of a series of approximants with support from NSF. This shows how solid state chemists can use structure and bonding analyses, to discover new quasicrystals and approximants.[16]

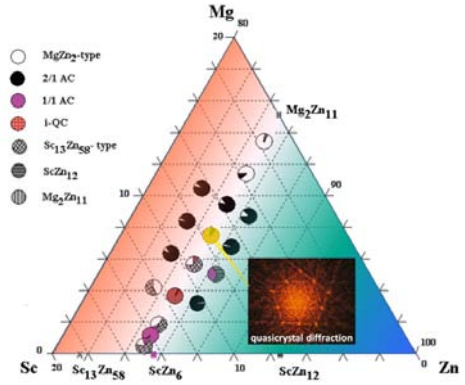
2002 - Tom Lograsso and co-workers synthesize the first macroscopic single grain of a binary quasicrystalline compound, Cd-Yb.[17]



2003 - The Ames Laboratory group publishes its first results concerning atomic-scale structures of metals deposited on quasicrystal surfaces: aluminum on Al-Cu-Fe, and silver on Al-Pd-Mn.[18-20] The work indicates unusual nucleation behavior, and unusual height selection in the growing film. This helps to spur a surge of international research into metal film growth on quasicrystals. The picture at right is a scanning tunneling microscope image, showing starfish-like clusters of aluminum atoms in blue, which have congregated at specific sites on the red quasicrystal surface.[20]

2003 - Together with German, French, and Japanese colleagues, Dan Sordelet co-chairs a Symposium on Quasicrystals at the Fall Meeting of the Materials Research Society.

2003 - An Ames Laboratory team wins Best Poster Award at the 2003 MRS Fall Meeting: "Quasicrystalline $Cd_{84}Yb_{16}$ and its $Cd_{86}Yb_{14}$ Cubic Approximant Phase: A Model System for 3-Dimensional Quasicrystals," by Y.Q. Wu, M.J. Kramer, T.A. Lograsso and D. Wu.



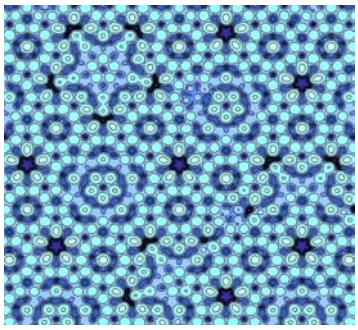
2003 - Qisheng Lin and John Corbett begin to explore quasicrystals and approximants through chemical tuning to pseudo-gaps that are predicted by electronic structure calculations on Mg_2Zn_{11} type (and other) phases. The figure at right shows the phases resulting from their exploration of the Sc-Mg-Zn system. This work eventually leads to the detailed identification of six quasicrystal systems and numerous crystalline approximants.[21, 22]

2004 - Danny Shechtman, who discovered quasicrystals in 1982, joins Iowa State University as a part-time Professor in the Department of Materials Science & Engineering, and he joins the Ames Laboratory as an Associate Scientist. Henceforward, he spends 4 months per year in Ames and 8 months at the Technion in Israel.

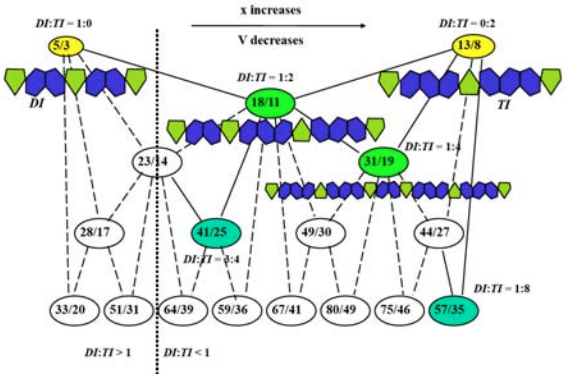
2005 (May) - The Ames Laboratory and Iowa State University host the Ninth International Conference on Quasicrystals (ICQ9). The first Jean Marie Dubois award is presented at ICQ9, to An-Pang Tsai of Tohoku University in Sendai, Japan. The photograph shows the three co-chairs of ICQ9 (left to right): Pat Thiel, Dan Sordelet, and Cynthia Jenks. Pat holds an object that symbolizes the ICQs, passed down from conference to conference: A dodecahedron at the tip of a wand.

2005 - The Ames Laboratory team, together with collaborators at Lawrence Berkeley National Laboratory (Jeong Park, Frank Ogletree, and Miquel Salmeron) publish a paper in *Science* showing anisotropic friction on a clean surface of a decagonal quasicrystal. The anisotropy—a factor of 8 in magnitude—stems from the fact that the surface is periodic in the high-friction direction, and quasiperiodic in the low-friction direction.[23]

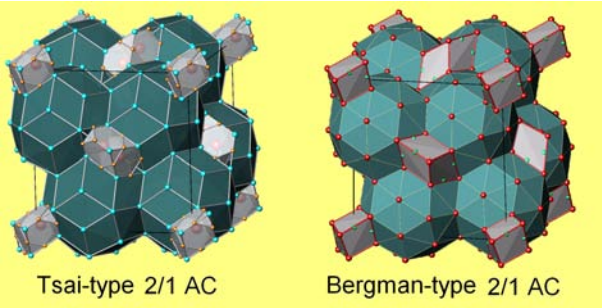
2005 - The Ames Laboratory group, together with collaborators in France and Japan, publishes a paper showing that a quantum size effect can control thin film morphology on quasicrystal surfaces.[24]



2006 - Jim Evans and his group carry out realistic, atomistic-level simulations of metal atoms diffusing and aggregating on a "disordered-bond-network" of neighboring adsorption sites, each of which has a distinct adsorption energy. This is a model for the collective behavior of metal atoms deposited on quasicrystal surfaces. A potential energy surface for one such system is shown at right.[25]

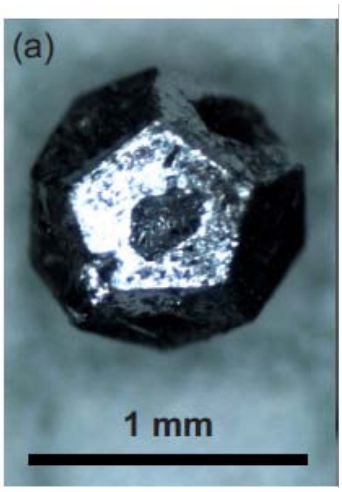


2006 – Olivier Gourdon and Gordon Miller report a series of phases, in a single bimetallic alloy, that are built of chains of two types of atomic clusters (labeled DI and TI at right) separated by a third. The observed phases fit into a Farey tree construction that provides a possible way to predict other one-dimensional quasiperiodic phases. The total Farey tree is shown at right, with the six observed phases represented by colored ovals and schematic chains.[26]



2006 - Qisheng Lin and John Corbett reveal that Bergman- and Tsai-type higher order cubic approximants share a same structural motif: Both exhibit the same long-range orders in terms of giant triacontahedral clusters and prolate rhombohedra, with differences only in short-range-orders.[27] This gives a clearer view for determination and modeling of future quasicrystal structures.

2008-2009 - Baris Ünal, working in Pat Thiel's group, shows that there is a surprising heterogeneity in adsorption sites at surfaces of quasicrystals, and explains why different surface terraces can have different properties.[28, 29]



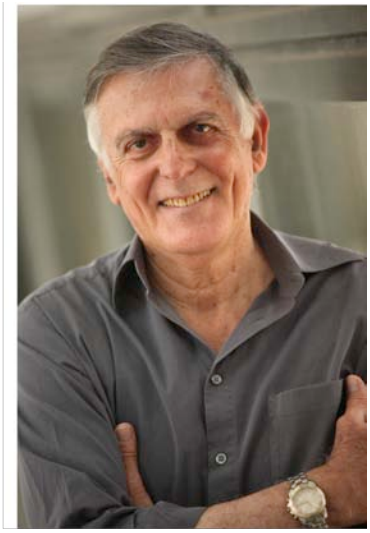
2009 – Paul Canfield, Alan Goldman, and two undergraduate summer students (M. L. Caudle and C.-S. Ho) discover the world's second example of a binary quasicrystal: $Sc_{12}Zn_{88}$. A sample is shown at right. This is the first quasicrystal to be *discovered* in the form of a large single grain, and indicates that there may be many undiscovered, deeply peritectic quasicrystalline phases in binary and ternary systems.[1]

Mid to late-2000's - The focus on quasicrystals shifts to related materials, both internationally and in Ames. One of these, metallic glasses, has strong ties to the atomic structure of quasicrystals, and so the synthesis, characterization and modeling efforts developed through past work with quasicrystals are heavily and successfully leveraged in this new pursuit.

2011 - The ISI Web of Science shows a total of 180 publications on the topic of quasicrystals by authors from Ames Laboratory and/or Iowa State University. The average number of citations per item is 16. The three most-highly-cited papers[7, 8, 30] have more than 100 citations each.

2011 (July) - Iowa State University and Ames Laboratory throw a 70th birthday party for Danny Shechtman. Invited speakers from outside of Ames are Walter Steurer (Switzerland), David Rabson (USA), and Ron Lifshitz (Israel). The lapel pin shown at right is distributed.

2011 (October) - Danny Shechtman wins the Nobel Prize in Chemistry for his 1982 discovery of quasicrystals.



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