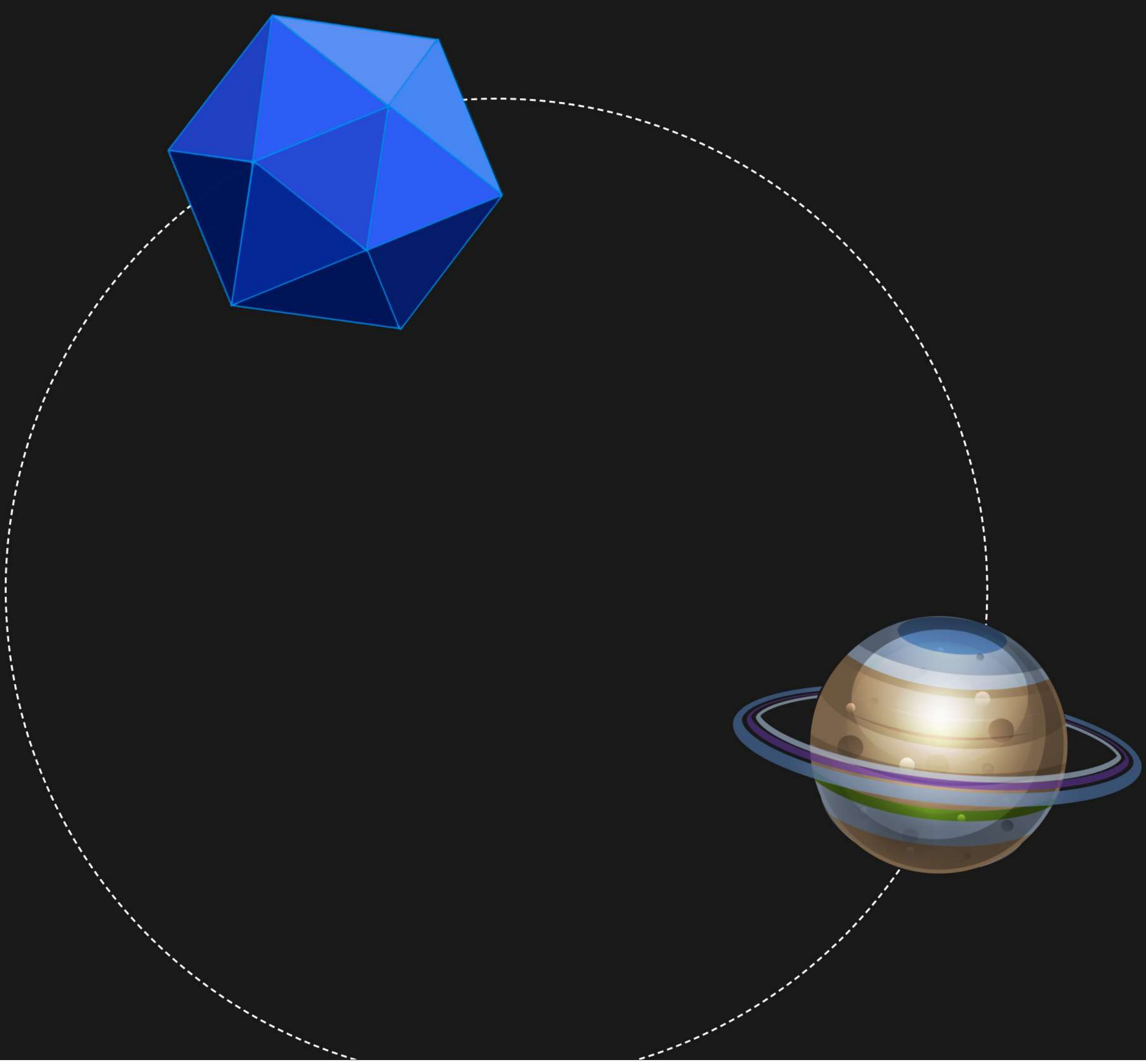
QUASICRYST



Speaker notes

I first heard about quasicrystals when I was applying to PhD schools an was just amazed about their general existence. Not only did they create a parigm shift within the field of crystalography in chemistry but have also had a great impact on astrophysics and mathematics. I actually came to Victoria in a large part because of the work my supervisor does and its connections to quasicrystals.

Dan Schechtman

Chemist
Technion University
On Sabbatical Johns Hopkins

Speaker notes

The story begins with a chemist from Technion University in Israel. He was on sabbatical at Johns Hopkins University in Pennsylvania studying he studied rapidly solidified aluminum transition metal alloys.

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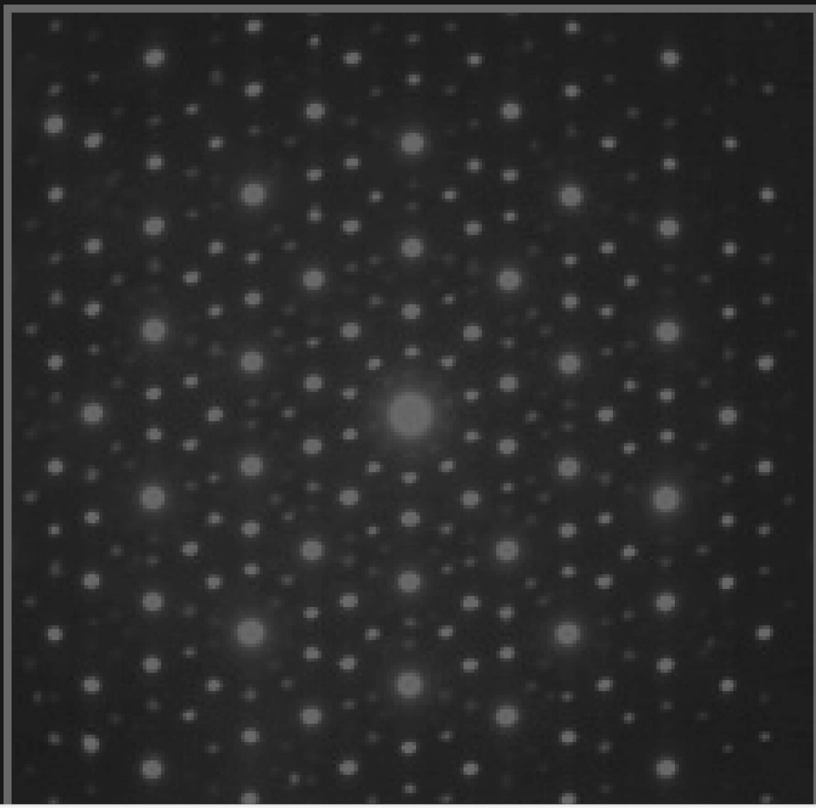

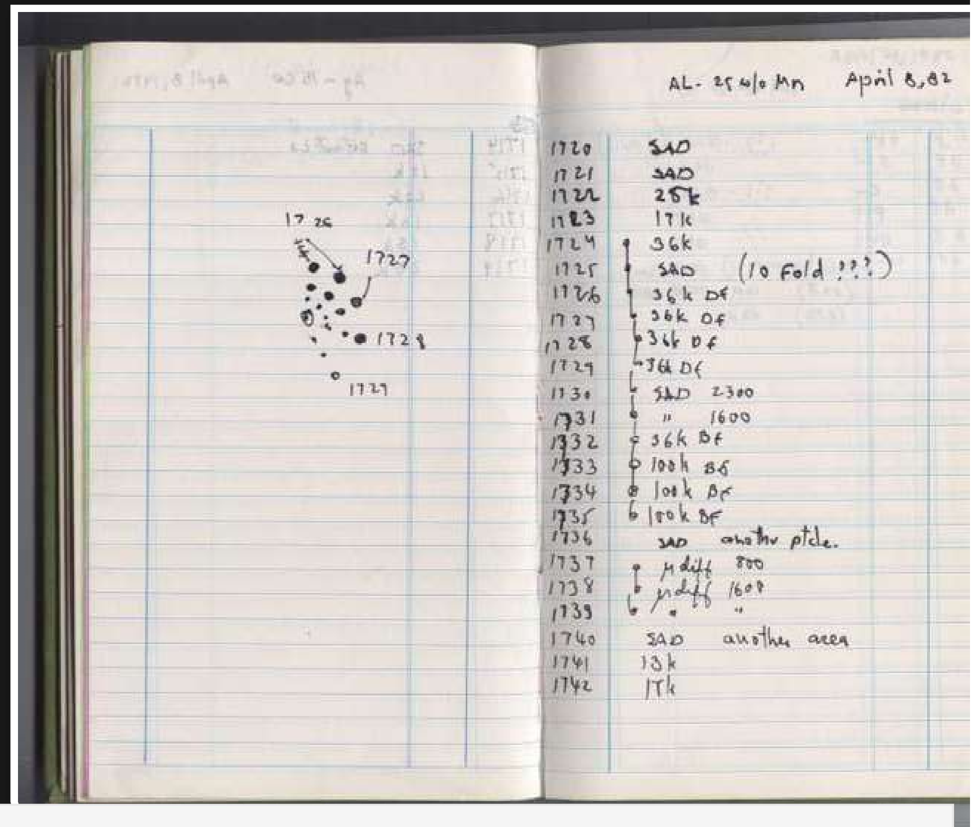

Speaker notes

The main method of studying these materials is through diffraction, where x-rays are passed through the material, and their atomic arrangement is revealed. In 1982, in one of these diffraction patterns, he discovered a regular pattern that did not match any periodically repeated structure. The first impossible thing he noticed is that the pattern had 10 fold symmetry. This means that if the pattern were to be rotated by a whole number multiple of 1/10 of a turn, it would look as if it had not been moved at all. The rotated pattern would fall right on top of the original. For a periodic crystal lattice, 10 fold symmery was forbidden.

Shechtman's results were so out of the ordinary that, even after he had checked his findings several times, it took two years for his work to get published in a peer-reviewed journal. Once it appeared, he says, "all hell broke loose."

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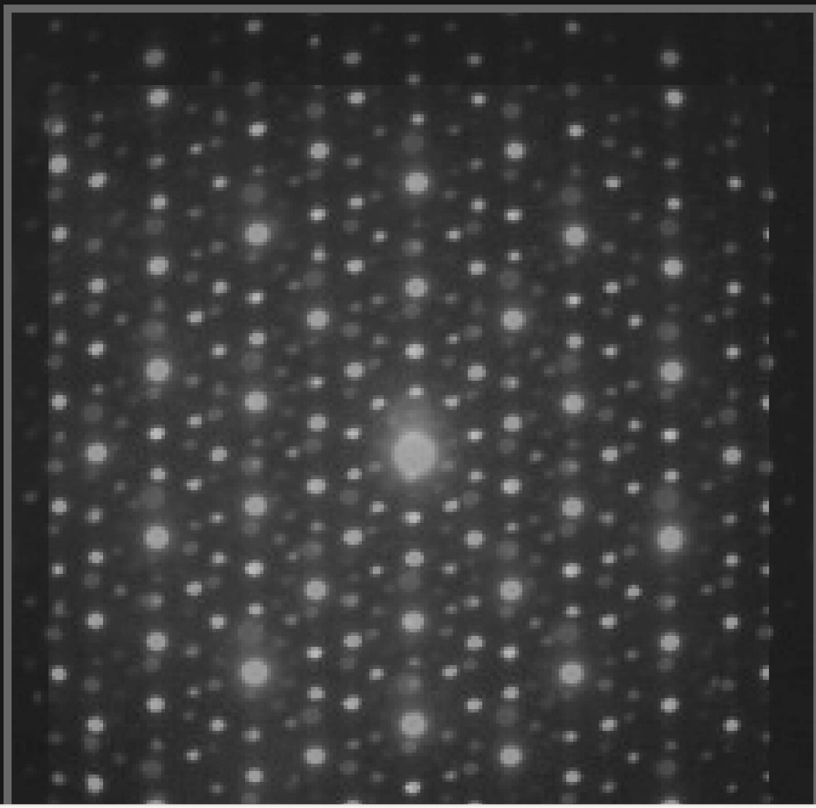

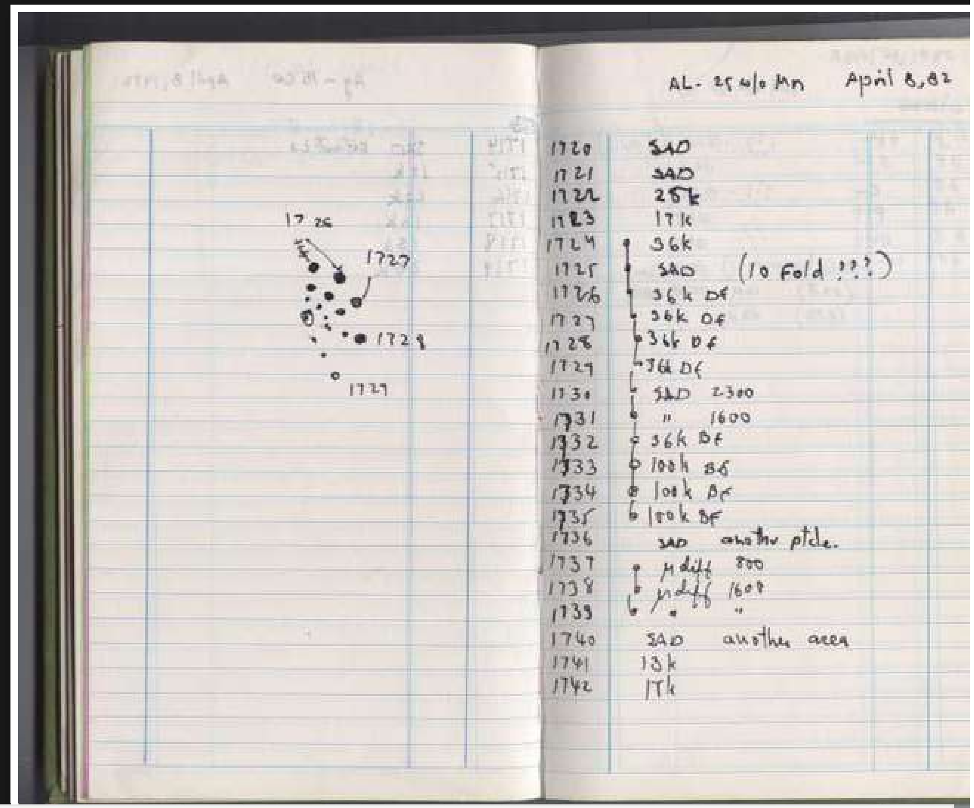

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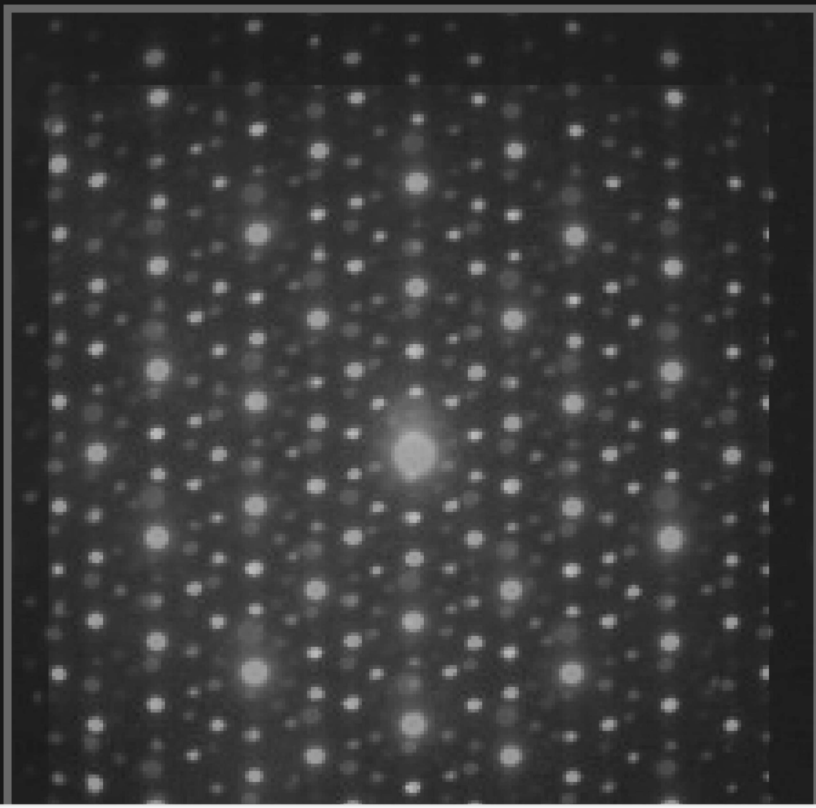

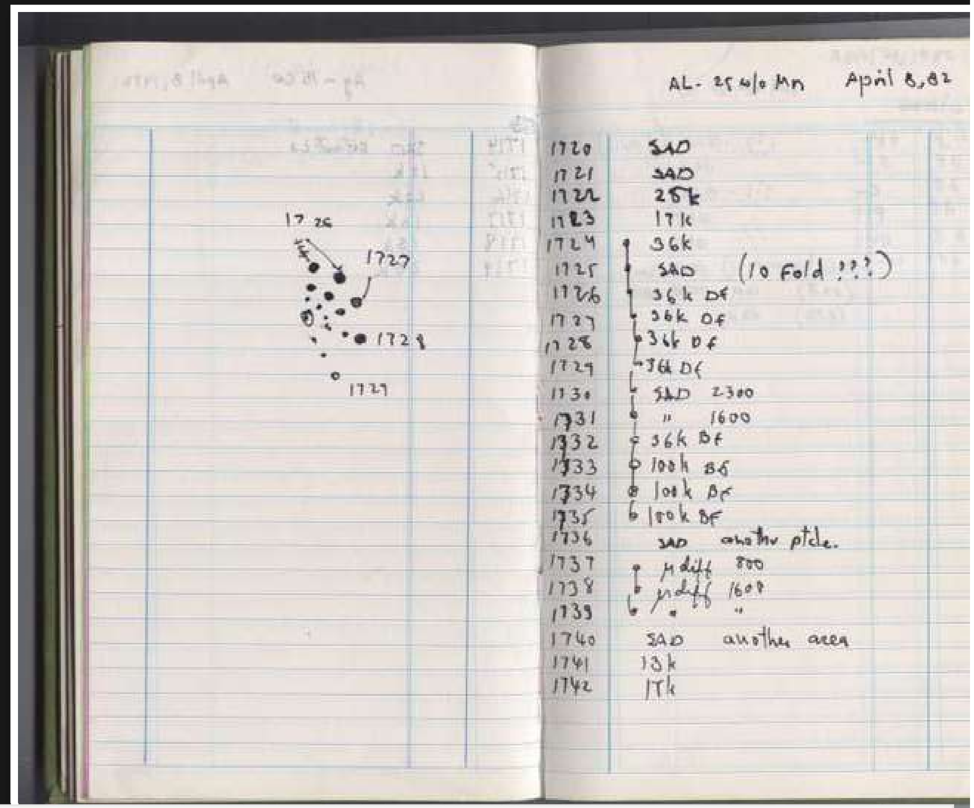

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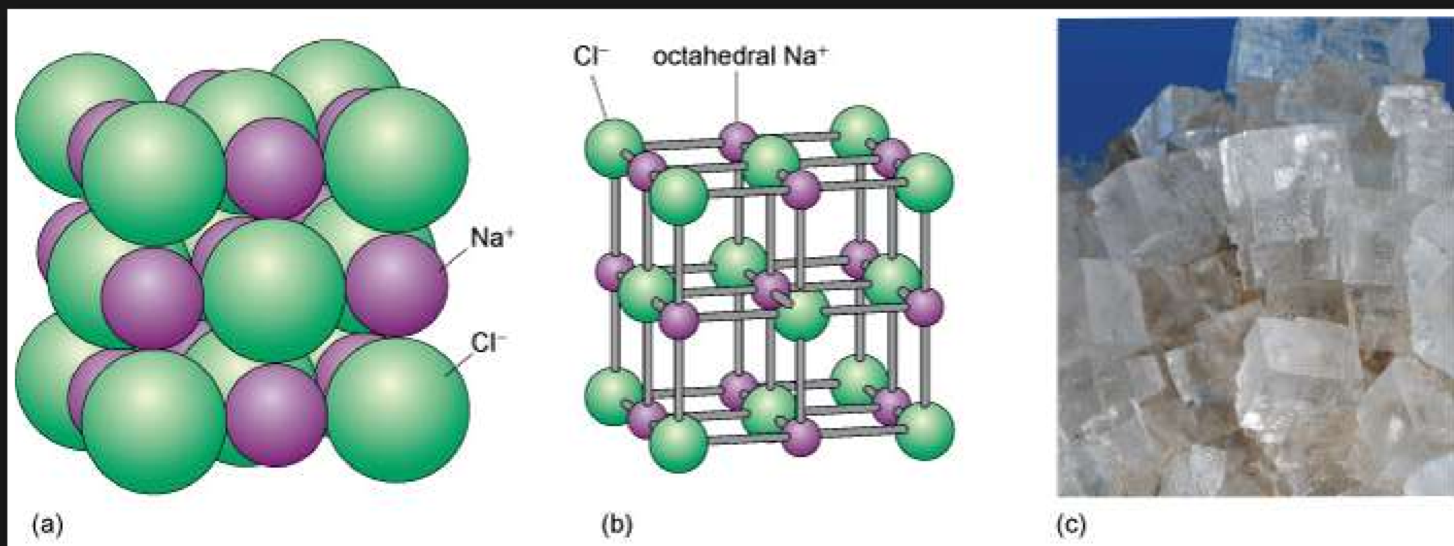
What is a crystal?

"A substance in which the constituent atoms, molecules or ions are packed in a regularly ordered, periodic three-dimensional pattern."

Speaker notes

In order to understand why 10 fold symmetry was forbidden, first we need to define a crystal. Periodic here is very important, this means that the crystal has translational symmetry.

Periodic structure and symmetry

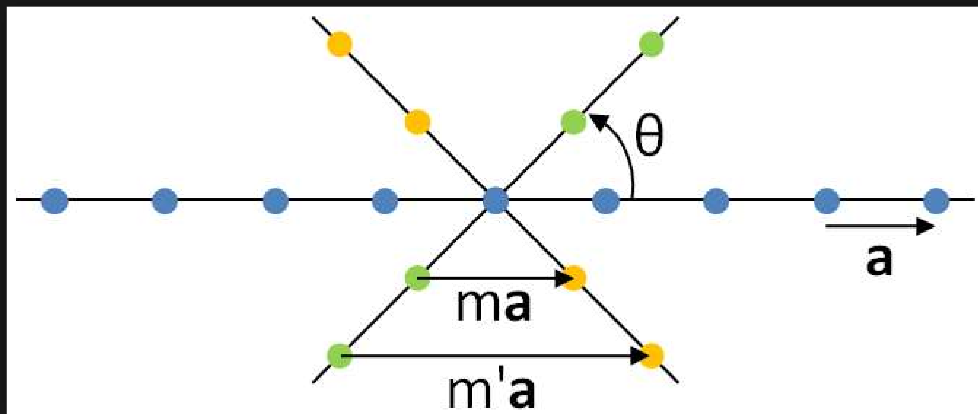


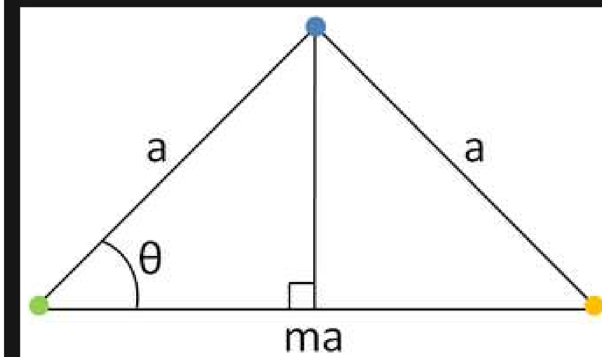
Veronica Burns Chemist "Atomic Size Matters comic"

Speaker notes

Here we see the fundamental region and a periodic lattice of table salt. Veronica Burns, a chemist, explains it beautifully in her comic.

THE ONLY POSSIBLE ROTATIONAL SYMMETRIES OF A CRYSTAL ARE 1,2,3, 4 AND 6.





Rotate one row by $\theta = 2\pi/n$ and the other by $-\theta$.

$$ma = 2a\cos(\theta) \implies m = 2\cos(2\pi/n)$$

$$n = 1, 2, 3, 4, 6$$

Speaker notes

The proof that only the symmetries of 1,2,3, 4 and 5 are possible uses just a bit of trigonometry and some algebra.

"There are no quasicrystals, only quasiscientists."

Linus Pauling

Speaker notes

Shechtman’s research group told him to ”go back and read the textbook” and a couple of days later ”asked him to leave for ’bringing disgrace’ on the team.”
"For a long time it was me against the world," said Dan Shechtman. "I was a subject of ridicule and lectures about the basics of crystallography. The leader of the opposition to my findings was the two-time Nobel Laureate Linus Pauling, the idol of the American Chemical Society and one of the most famous scientists in the world, he was two time nobel laureate once for chemistry and the second time for peace.

A PARADIGM SHIFT

Speaker notes

In spite of all this, he says that the experience was not as traumatic as it sounded. Scientists around the world had quickly replicated Shechtman's discovery and, the field of crystallography was experiencing a paradigm shift and in 1992, the International Union of Crystallography accepted that quasi-periodic materials must exist and altered its definition to the broader "any solid having an essentially discrete diffraction diagram". Meaning that the substance is ordered but may not have translational symmetry. Quasicrystals remained as mysterious as ever. By his collaboraters, Dan Shechtman was urged to dig deeper.

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A PARADIGM SHIFT

"Danny, this material is telling us something and I challenge you to find out what it is." -John W. Cahn

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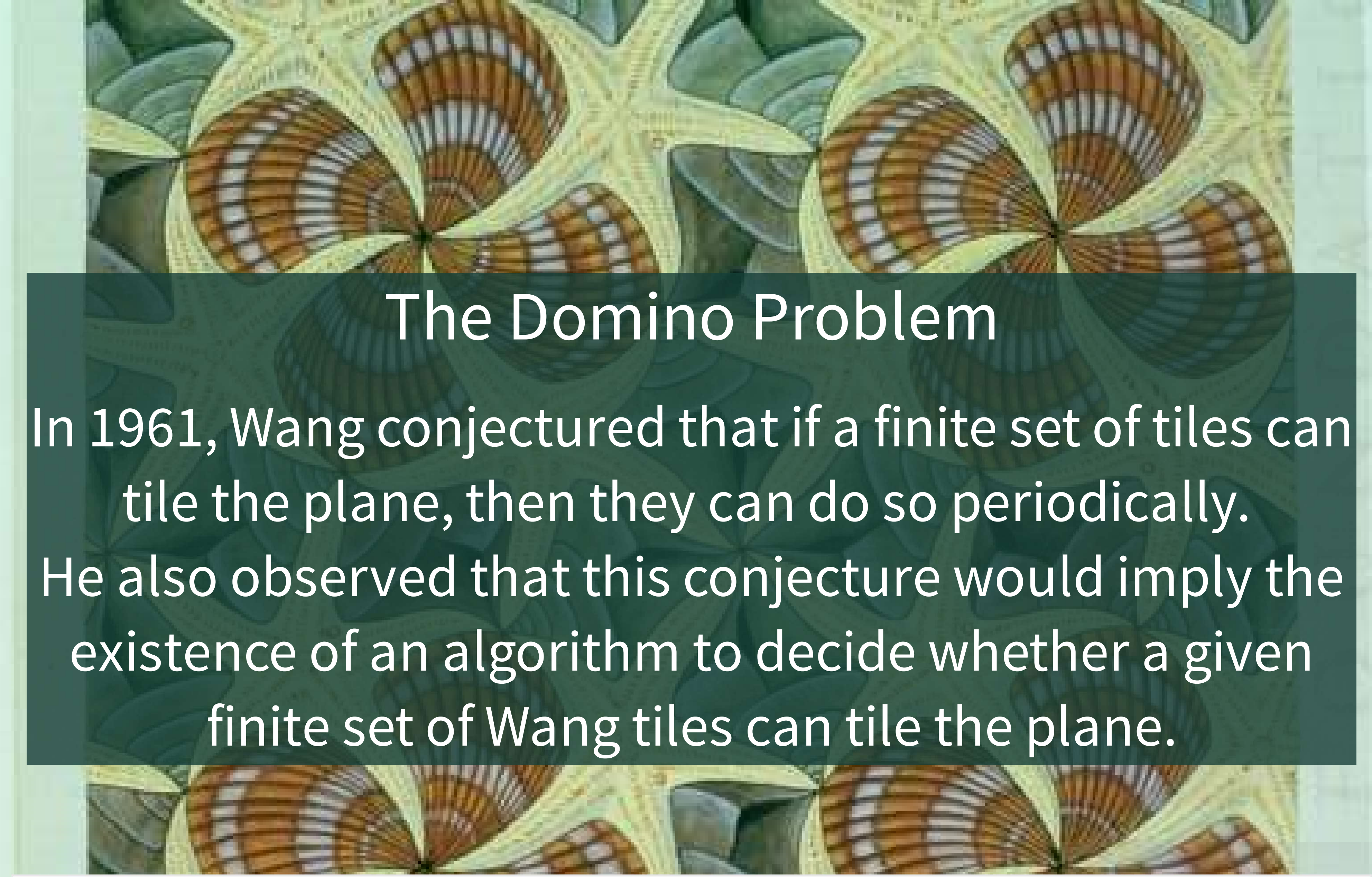
Meanwhile in mathematics...

Speaker notes

In pure mathematics, many mathematicians are very proud to be investigating ideas they deem as not useful to the real world, but somehow regardless of the intentions of mathematicians, down the line, these ideas often times have a way of making themselves useful. This situation is an example of just that.



The Domino Problem

In 1961, Wang conjectured that if a finite set of tiles can tile the plane, then they can do so periodically.
He also observed that this conjecture would imply the existence of an algorithm to decide whether a given finite set of Wang tiles can tile the plane.

Speaker notes

Tiles in this case could be any closed shapes that may be coloured or patterend in some way. An example of a periodic tiling is shown in the background where the shells and starfish repeat periodically.

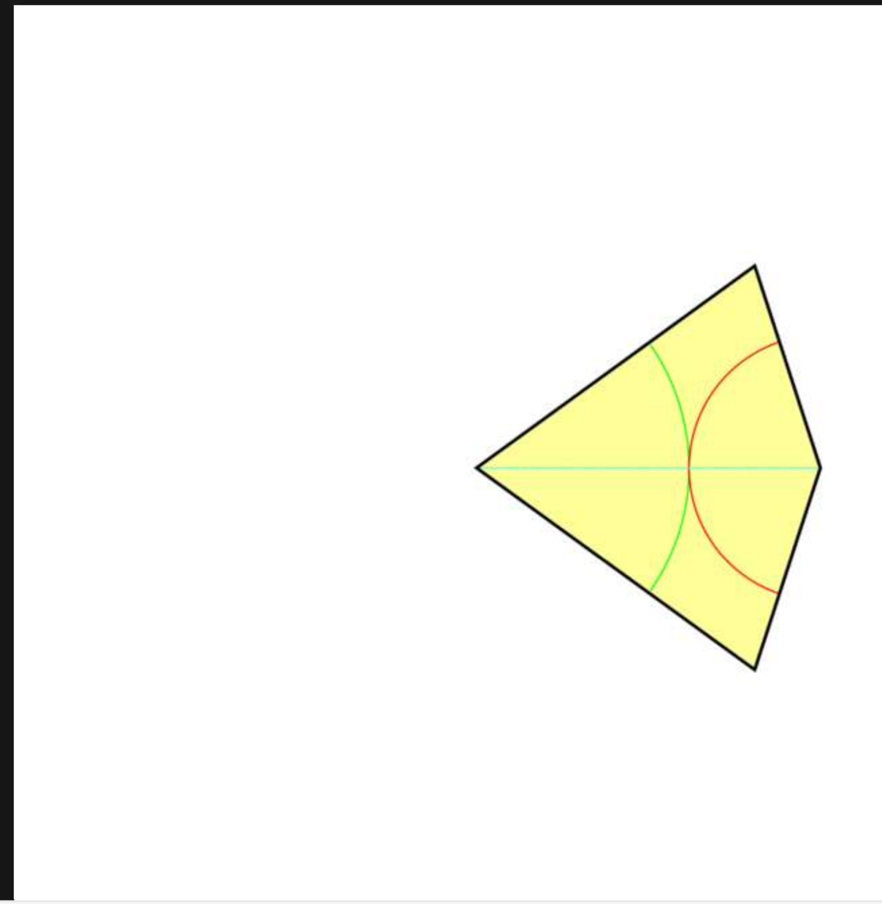
In 1966, Wang's student Robert Berger proved that no algorithm for the problem can exist, by showing its equivalence to the

Speaker notes

There must exist a finite set of tiles that tiles the plane, but only aperiodically. Aperiodically, means that the tiling has some order but it does not have translational order, it does not have translational symmetry.

- Berger's 20,000+tiles
- Berger 104
- Ammann 6
- (1974) Penrose 2

PENROSE'S APERIODIC TILINGS



Speaker notes

The two tiles are called a kite and dart. When given special markings, they will only tile the plane aperiodically. They have the property that any finite pattern in the tiling occurs infinitely often throughout the tiling. Notice that some of the patterns within the tiling have a distinct five fold star rotational symmetry. Wherever there is a five, the golden ratio closely follows. There are many instances of the golden ratio appearing within the tiling, once such instance is in the frequency of kite to dart tiles. The number of kite to dart tiles in a finite pattern within the tiling is given by Fibonacci numbers and so approximates the golden ratio.

Speaker notes

People have become pretty obsessed with the Penrose tiling and have been putting it all over the place. I'm one of these people. One of my projects was to lasercut some penrose tiling coasters. Earlier you saw Roger Penrose standing on a tiling at the mathematics department at the University of Cambridge. Here is a picture of the facade of a TransBay Railroad center in San Francisco. There was even toilet paper made. Unfortunately, Roger Penrose has a patent on the tiling so he sued Kleenex for making it.

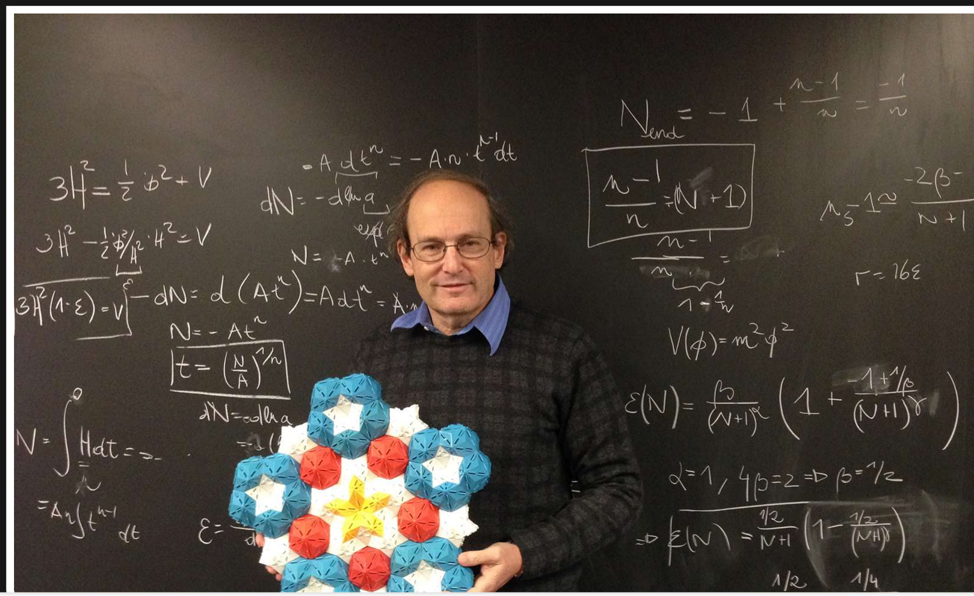
How does this tiling link to quasicrystals?

Speaker notes

So now you may thinking, what do aperiodic tilings have to do with quasicrystals?

1983 Paul Steinhardt and his student Don Levine were inspired by the Penrose tiling and created a theory on a new kind of matter.

"Quasicrystals: A New Class of Ordered Structures."



Speaker notes

Paul Steinhardt astrophysicist, surmised that it was possible to be able to have a crystal tile space aperiodically. Where the penrose tiling is an example of an aperiodic tiling of the plane. Quasicrystals are models of aperiodic tilings of three dimensional space.

The new theory overturned 200 years of scientific dogma. By changing the set of assumptions, quasicrstals went against all of the previously accepted mathematical theorems about the symmetry of matter. Symmetries once thought to be forbidden for solids are actually possible for quasicrystals, including solids with axes of five-fold symmetry. Even more surprisingly, this paper was published a year after Dan Shechtman's discovery and the two researchers were working in the same state. Steinhardt and Levine were shown a preprint of the Shechtman team's paper and immediately recognized that it could be experimental proof of their still-unpublished quasicrystal theory.

Speaker notes

You would think that with these two papers accepted that the alloy Dan Shechtman found would be believed and he would be redeemed for the great research he is. But no. Both papers were accepted with a lot of doubt. Many theories came about to explain Dan Shechtman's discovery as a mistake. Each counter-theory that came about was disproved but sketicism remained. Dan Shechtman discvered an alloy, but it was believed that nature would never construct such a thing. Paul and Dan spent the next 26 years convincing the scientific community that a natural quasicrystal was possible. A little bit before 2009, Paul got lucky. He was contacted by a researcher from Italy with a sample of a rock whose diffraction pattern had five fold symmetry. Paul could not idenfity the origin and formation and the sample was very small. He sent it to several experts with very disappointing answers, the rock was believed to be slag or waste matter from refining metal. He decided to take the matter into his own hands, he and a team travelled to the barren arctic tundra in Russia, on an expedition to find another piece of this rock that could be more clearly identified.

Speaker notes

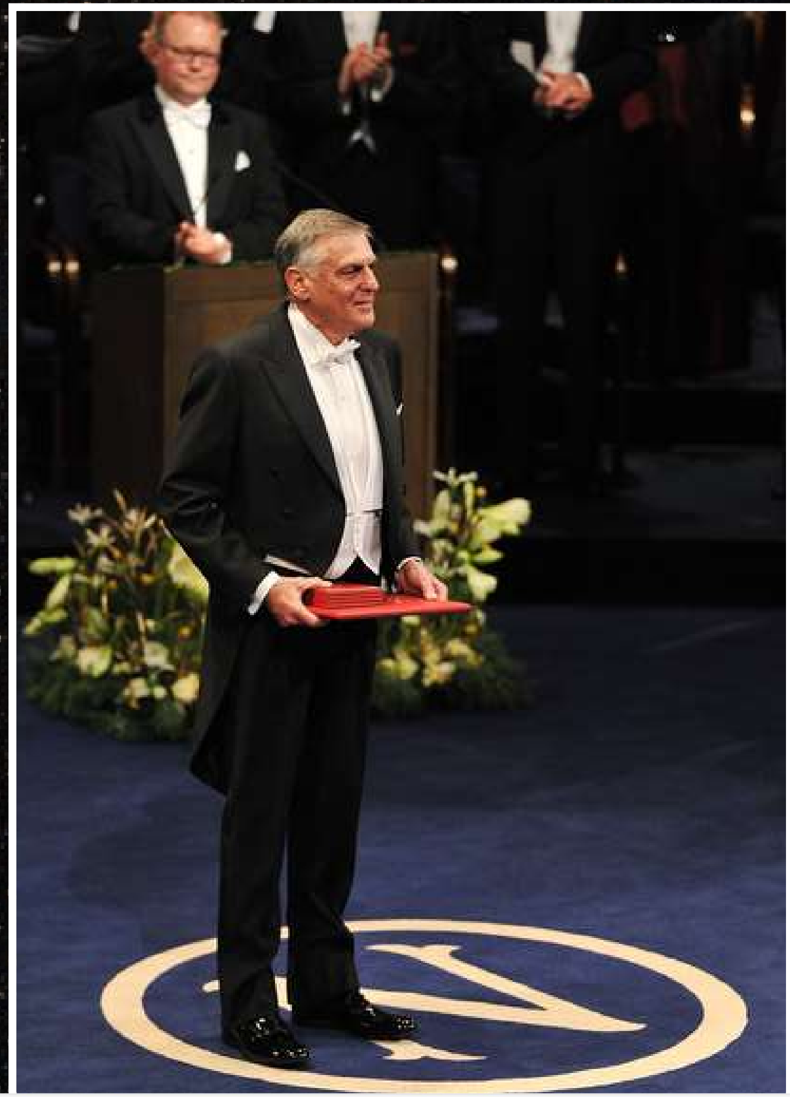
In 2009, his team had found a larger sample in Easern Russia. (Chukotka). A quasicrystal Found in the natural world from a meteorite that is 4.5 billion year old. Not only was this an amazing discover, but this showed that quasicrystals were stable state of matter. Nature was happy to tile things aperiodically.

Khatyrka meteorite

"The quasicrystals and related metallic aluminum minerals found in the meteorite imply the existence of physical process in the early stages of the formation of the solar system that we did not know before; we are still trying to work them out."

Paul Steinhardt

2011



Speaker notes

"Dan Shechtman's Nobel prize celebrated not only a fascinating and beautiful discovery, but also dogged determination against the closed-minded ridicule of his peers, including leading scientists of the day."

- Domino problem
- More on the Domino Problem
- Paul Steinhardt
- Dan Shechtman
- Meteor background
- Star background
- Crystallographic Restriction