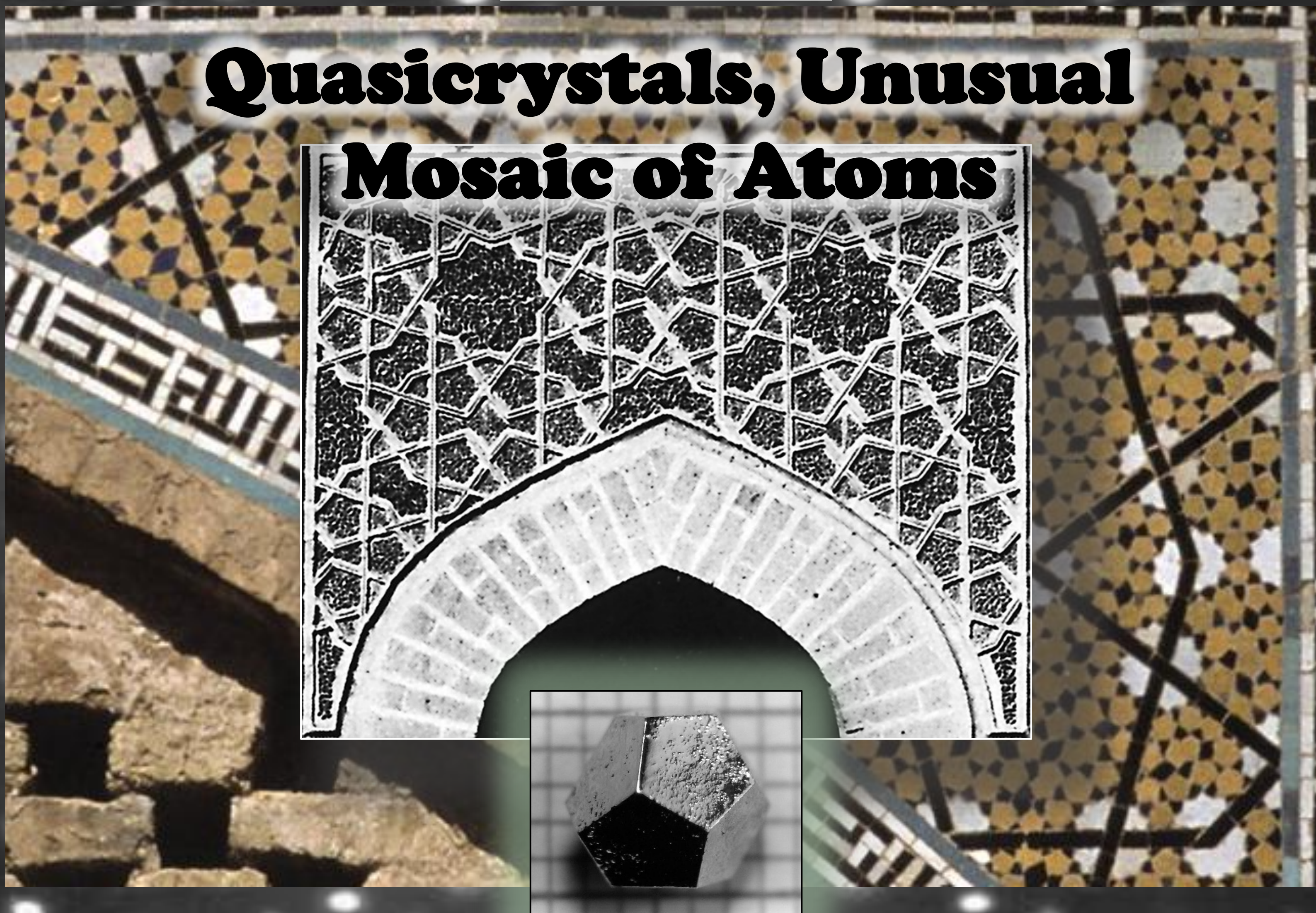
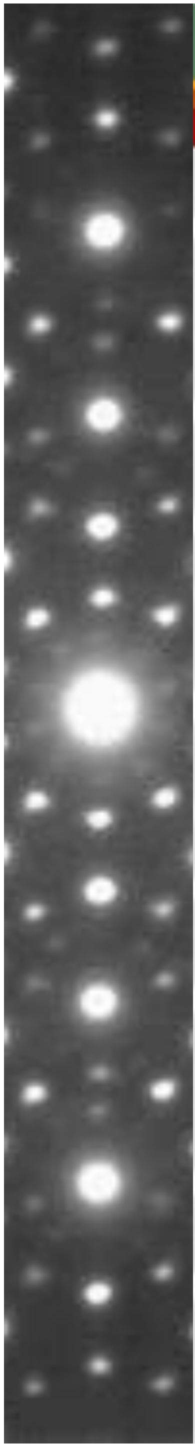
NatureGlo's eScience

Quasicrystals, Unusual Mosaic of Atoms

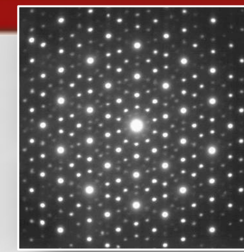


Cover image – Islamic archway, image in the public domain. Background image of a quasicrystal electron microscope diffraction by Materialscientist. Image of the Ho-Mg-Zn (Holmium-Magnesium-Zinc) dodecahedron quasicrystal photographed by AMES lab., US Department of Energy.

You can connect with Natureglo's eScience on Google at gab21921@gmail.com



What is a Quasiperiodic Crystal, or Quasicrystal?

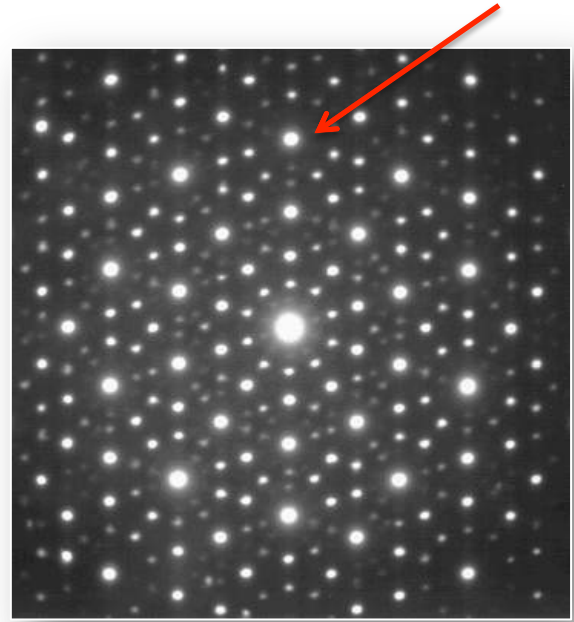


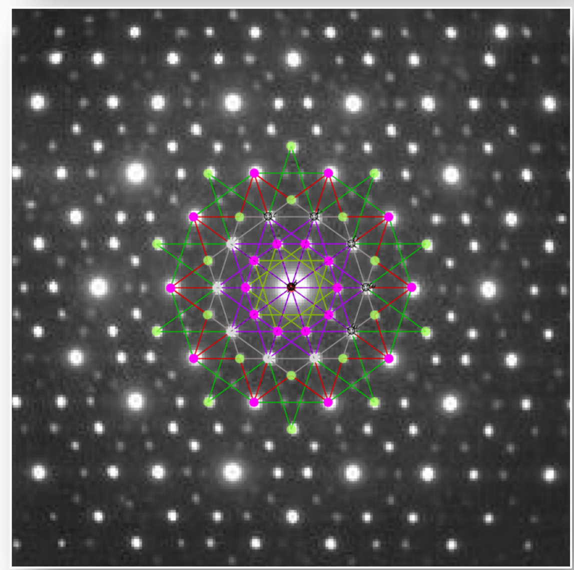
- Unusual atomic crystal arrangements including 5, 8, 10, and 12-fold symmetries found in aluminum alloys & certain polymers (synthetic plastics & resins)
- Atomic pattern fills space without repeating itself
- April 8,1982 – Previously believed impossible, discovered by Israeli materials scientist, Dan Schectman
- Usual crystallographic crystals - only with 2, 3, 4, and 6-fold rotational symmetries; no higher numbers

Images – Aluminum alloy atomic electron microscope diffraction photographed by Materialscientist.

Quasicrystal Atomic Symmetry

- Quasicrystalline pattern - continuously fills plane space; lacks translational symmetry
- Translational symmetry – a figure's symmetry, which quasicrystals lack, when if moved (or copied) in any direction (horizontally, vertically, diagonally) remains same after translated or moved and can be repeated infinitely
- Bragg electron microscope diffraction pattern (see images right) - quasicrystals shows sharp peaks with 5, 8, 10 and even 12-fold symmetries





Images by Materialscientist. Bottom derivative work by Jgmoxness.

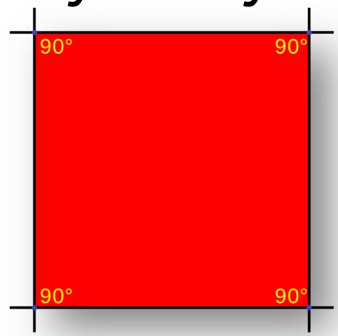
What symmetry is this revealing?

Usual Symmetry Types found in Crystallography

2-fold Symmetry

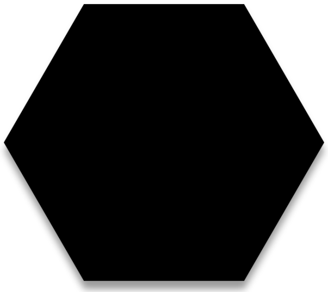
Equilateral triangles can tile the Euclidean plane with 3 around each vertex, with each triangle having an internal angle of 60°.

4-fold Symmetry

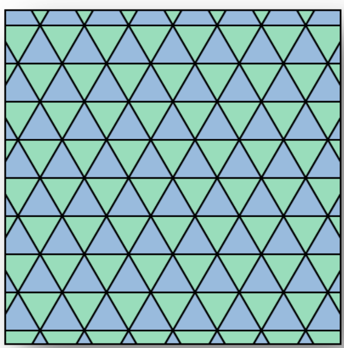


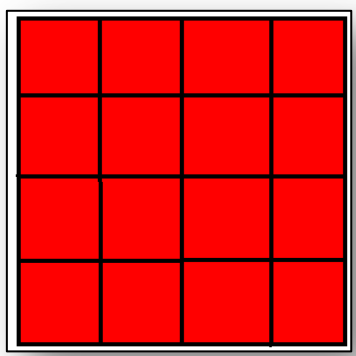
Squares can tile the Euclidean plane with 4 around each vertex, with each square having an internal angle of 90°.

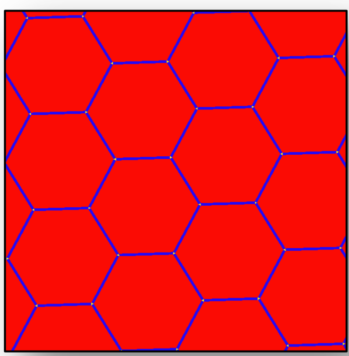
6-fold Symmetry



In geometry, the hexagonal tiling or hexagonal tessellation is a regular tiling of the Euclidean plane, in which three hexagons meet at each vertex.

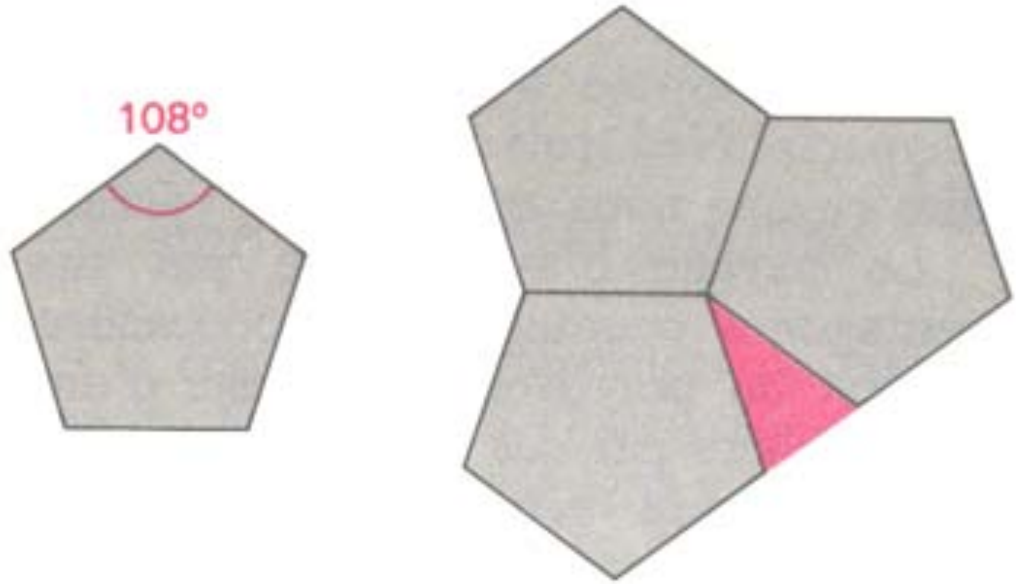






Created by Tomruen

What about 5-fold Symmetry?



- Three pentagons with common vertex don't tile plane
- Plane tiling with pentagons impossible
- How exactly can quasicrystals work with 5, 10 and even 12-fold symmetry?
- Realized on sphere in form of pentagonal dodecahedrons
- More on this later!

Image created by Sadoc JF.

Quasicrystals - Long Road to Discovery & Acceptance

- Early 1960's - aperiodic (or irregular) tilings discovered by mathematicians; some twenty years later, found to apply to quasicrystals study
- Fields of crystallography – changing due to discovery of aperiodic forms in nature
- Quasicrystals investigated & observed earlier, but, until 1980s, were disregarded in favor of prevailing views about atomic structure of matter (with only 2, 3, 4, 6-fold symmetries allowed)
- 2009 – mineral finding, icosahedrite, reveals evidence for quasicrystals natural existence

Background image & sidebar - diffraction pattern of the natural $Al_{63}Cu_{24}Fe_{13}$ quasicrystal found in khatyrkite (a rare mineral). Redrawn after Bindi, Luca; Paul J. Steinhardt, Nan Yao, Peter J. Lu (2009-06-05) created by Materialscientist.

Quasicrystal's Discovery

- 1982 - materials scientist Dan Shechtman observed with electron microscope that certain aluminum-manganese alloys produced unusual diffractograms seen now as revelatory quasicrystal structures
- Took him two years to publish results from scientific community's negative resistance
- 2011 - Dan Shechtman awarded Nobel Prize in chemistry for quasicrystal discovery

Dan Shechtman photographed by by Technion - Israel Institute of Technology

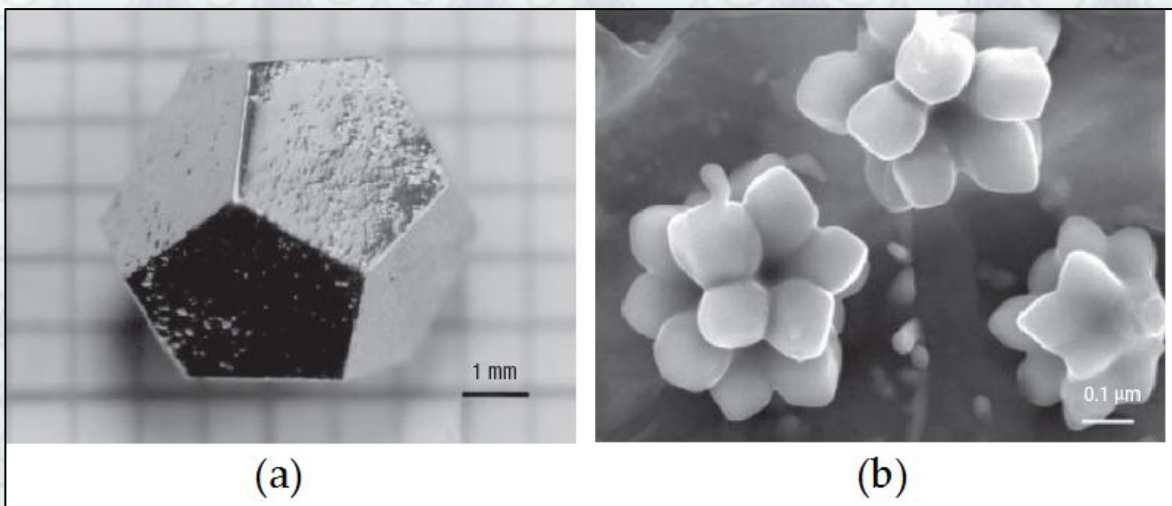
Background image & sidebar: Ho-Mg-Zn (Holmium-Magnesium-Zinc) dodecahedron quasicrystal photographed by AMES lab., US Department of Energy.

The Two Known Quasicrystal Types

- Since Dan Shechtman's discovery, hundreds of quasicrystals reported and confirmed
- Exist universally in many metallic alloys and some polymers (plastics & resins)
- Found most often in aluminum alloys, but numerous other compositions known

The two types of known quasicrystals:

1. **Polygonal (dihedral) - axis of 8, 10 or 12-fold symmetry (octagonal, decagonal, or dodecagonal)**
2. **Icosahedral – aperiodic (irregular) in all directions**

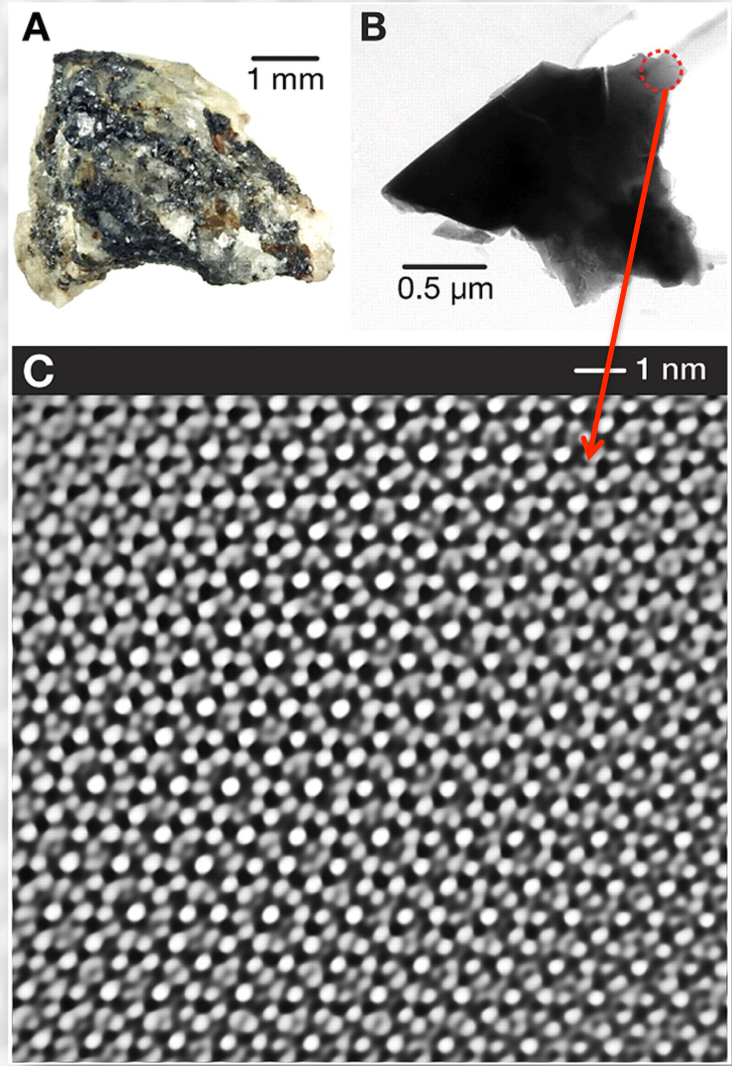


(a) Dodecahedral Zn-Mg-Ho single QC grain (b) Icosahedral Al-Mn QC flowers. Images in the public domain.

Background image & sidebar décor - Atomic model of fivefold icosahedral-Al-Pd-Mn quasicrystal surface created by J.W. Evans, The Ames Laboratory, US Department of Energy.

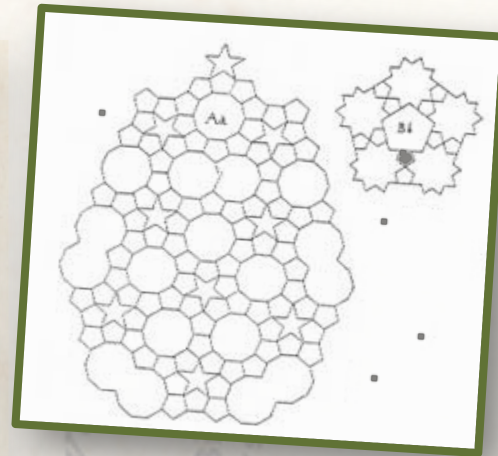
Quasicrystalline Minerals

- Rock sample with mineral khatyrkite
- Atomic diffraction patterns image obtained from thin region of granule with red dashed circle
- Atomic image displays five-fold symmetric, pattern characteristic of quasicrystals

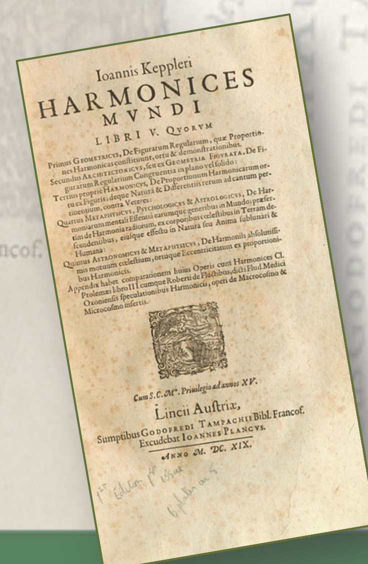


Kepler's Monsters from His Book, *Harmonices Mundi*

- **Kepler usually credited with first systematic explanation of semi-regular or 11 Archimedean tessellations composed of regular polygons**
- **1619 Illustrated plate from *Harmonice Mundi* containing diagrams shown right**



Kepler's "Monsters" (Aa) from his 1619 book, *Harmonice Mundi* (Latin for Harmony of the World).

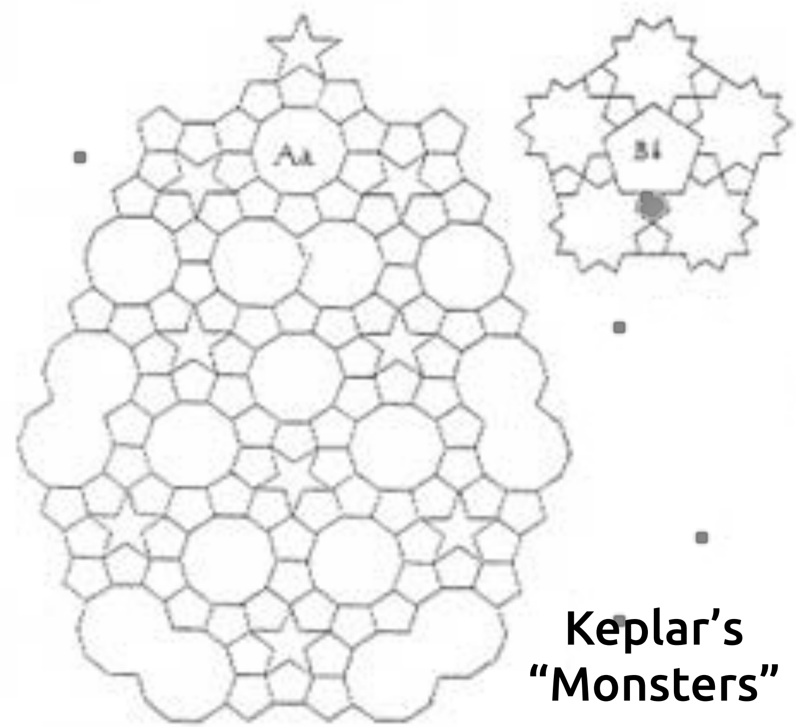

Ioannis Keppleri
HARMONICES
MVNDI
LIBRI V. QVORVM
Lincii Austriæ,
ANNO M. DC. XIX.

Images of pages from *Harmonices Mundi (including thumbnail, frame and background transparencies)* and the diagram, all in the public domain.

Keplar's "Monsters"

- "Monsters" or tilings - Kepler described tiling built with pentagons, pentagrams, decagons, and "fused decagon pairs," in *Harmonice Mundi*

- 1973 - Kepler's diagrams inspired English professor of mathematics & physics, Roger Penrose, to create his "Penrose tiles"

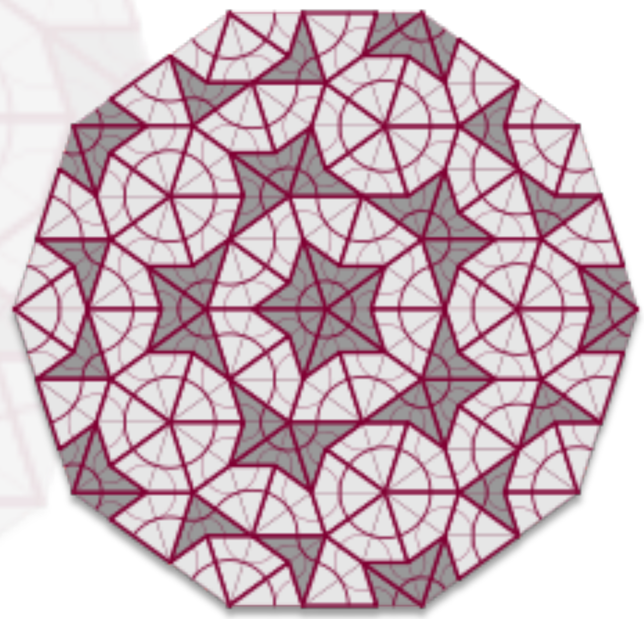


Keplar's "Monsters"

Penrose Tiles

- Roger Penrose created geometric relationship approximately modeling quasicrystals
- What are Penrose tiles? small non-identical shapes arranged to fill a space completely
- Original Penrose tile creation wasn't to describe quasicrystals

Sir Roger Penrose photographed by Biswarup Ganguly.

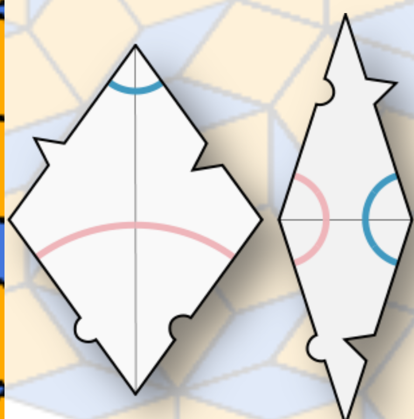


Penrose sun, third generation (background transparency & frame too too) created by GFDL-SELF.

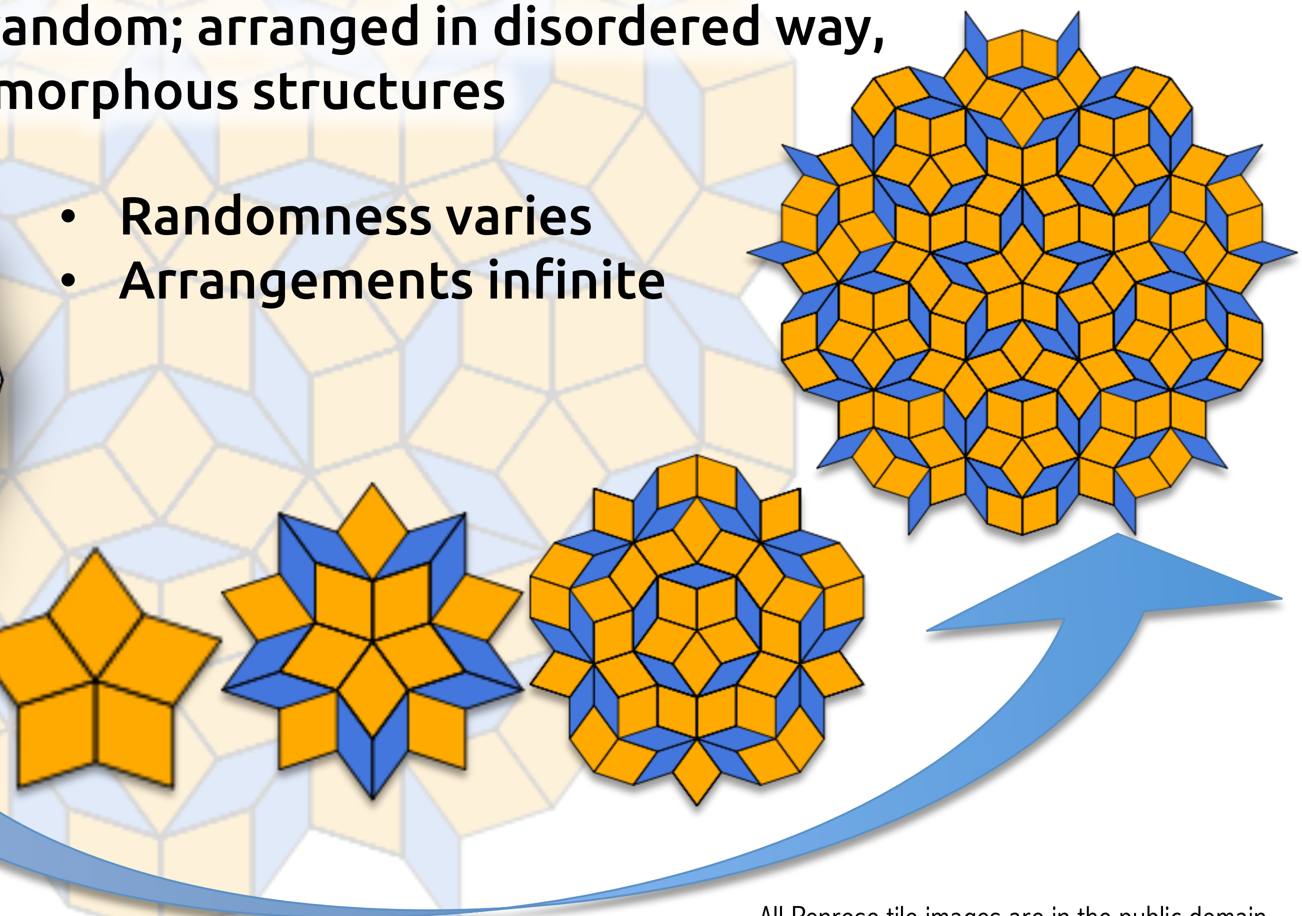
Penrose Tiles

- Simplest Penrose tiling construction – made with two tiles: usually “fat” and “thin” rhombi
- Most tile arrangements either periodic – with definite translational symmetry, resembling a crystalline structure or random; arranged in disordered way, resembling amorphous structures

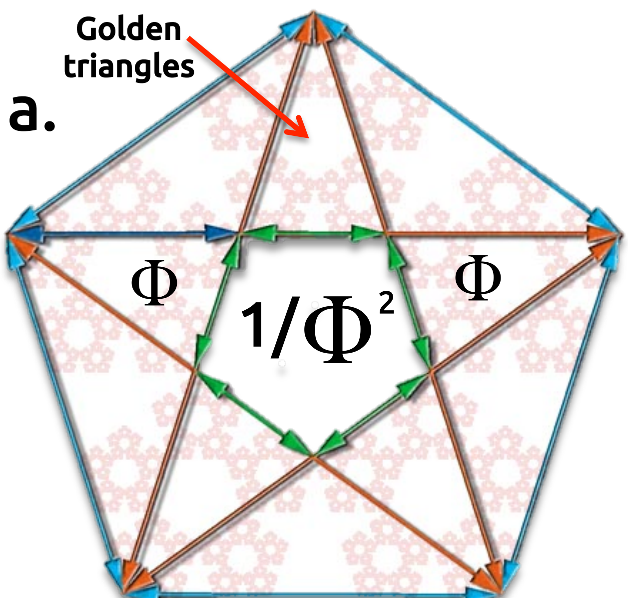
- Randomness varies
- Arrangements infinite



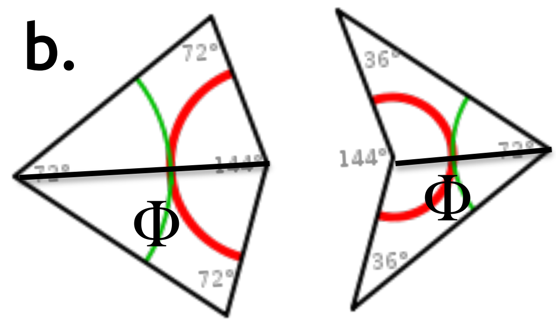
Fat and thin rhombi created by Geometry Guy.



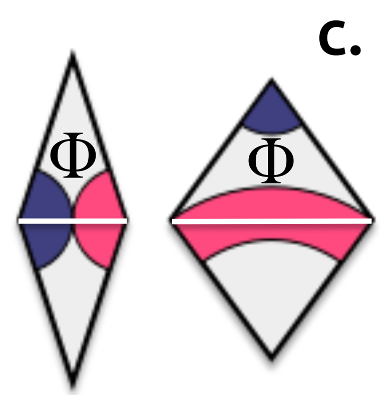
Penrose Tiles & The Golden Ratio



Penrose combined the triangles in a regular pentagon (all sides equal) to create two pair sets of tile types. The relationship of the pentagon sides and the triangles are Phi, 1 and 1/Phi. A public domain image.



Pair set #1: A set of Penrose tiles called the “kite & dart”. Image created by Toon Verstraelen.

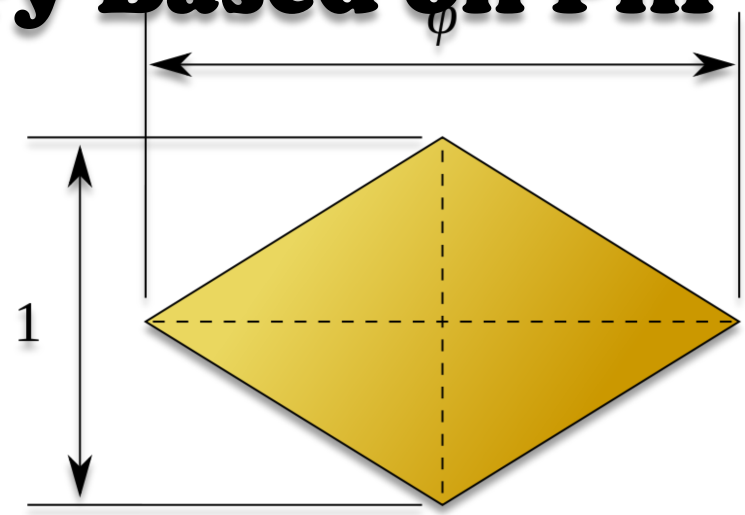


Pair set #2: A set of diamonds also called “fat and thin rhombi”.

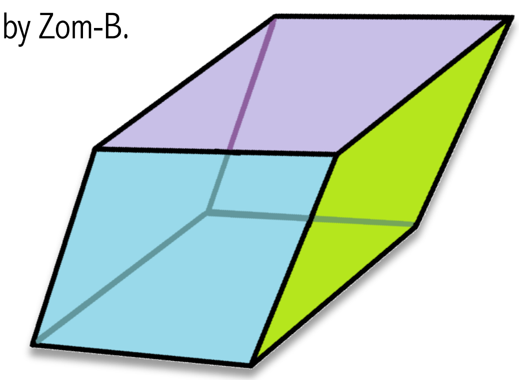
Phi symbols created by Wmayner.

Penrose Tiles fill space with 5-fold Symmetry Based on Phi

- Penrose tiles allow 2-dimensional area to be filled in 5-fold symmetry, using 2 phi-based shapes; previously thought impossible
- Penrose kite and dart create a golden rhombus
- Rhombus diagonals in phi ratio

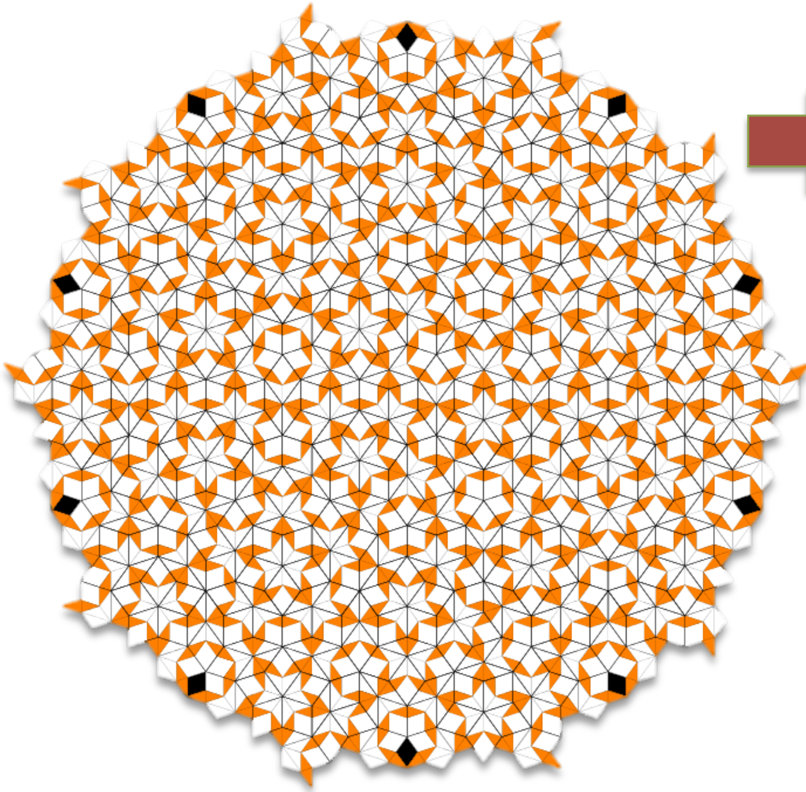


A Golden rhombus by Zom-B.

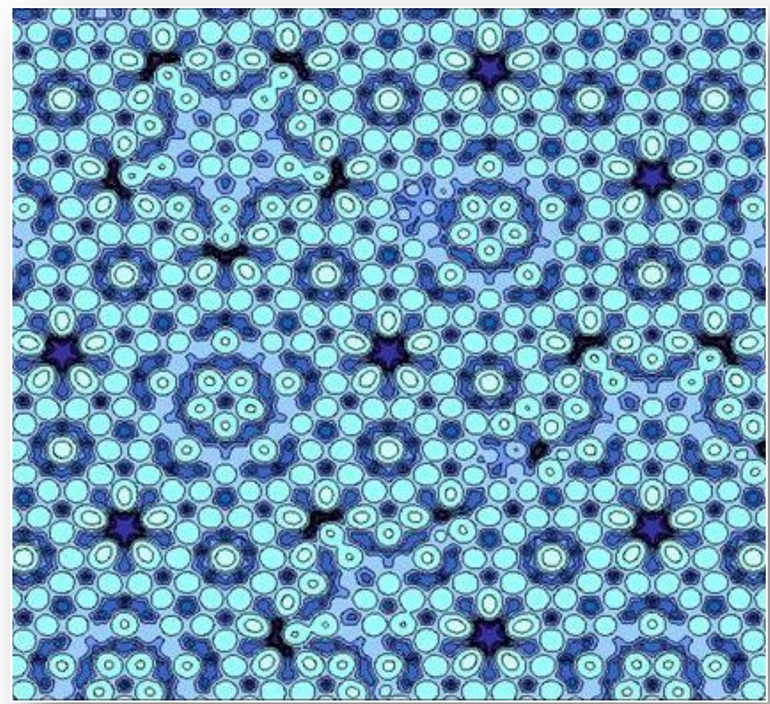


A 3-D Golden rhombus (background & sidebar too) created by Tomruen.

Penrose tiles, made up of Phi, give us a geometric representation of quasicrystal molecules and atoms. Therefore, Phi makes up quasicrystals.



A Penrose tiling with its corresponding inflated tiling overlaid in black created by Sverdrup.



Atomic model of five-fold icosahedral-Al-Pd-Mn quasicrystal surface.

Peter Lu's Girih Tiles with Observations of Islamic Tile Design

- 2007 – Physics graduate student at Harvard, Peter Lu discovered Girih tiles, what Islamic architects most likely used in their designs (pictured right)
- Lu noticed striking similarity between certain Islamic medieval mosque mosaics and quasicrystal atomic structures

The Girih Tiles

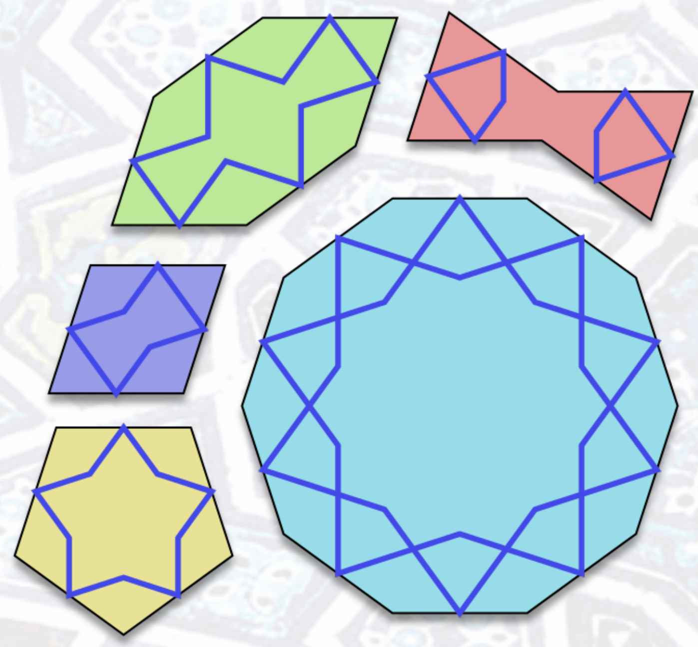
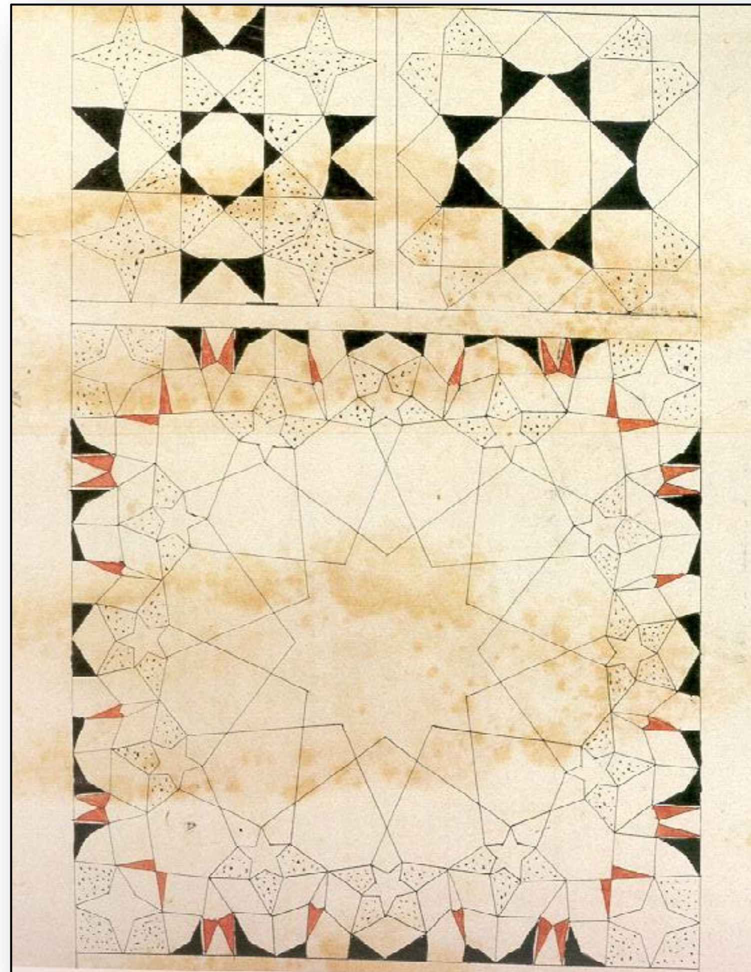


Image created by Cronholm144.

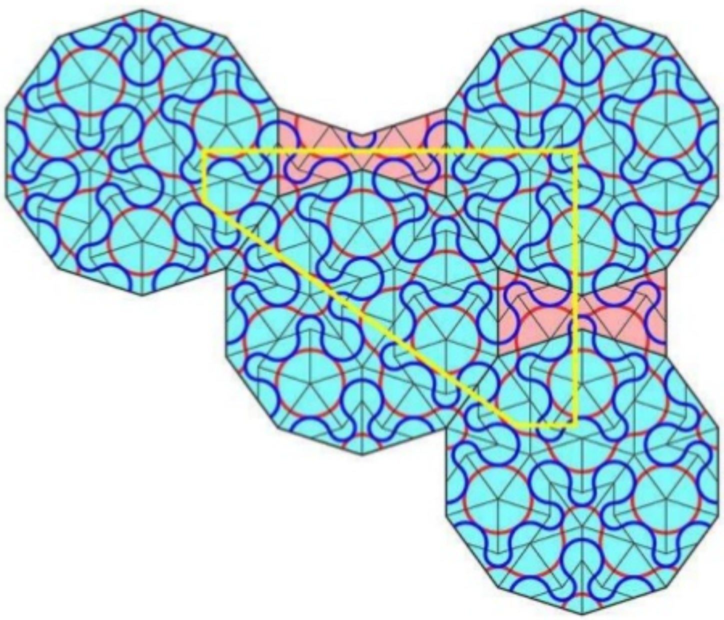
Background & sidebar image – Islamic tilation.

Girih Tiles found in Islamic Topkapi Scroll

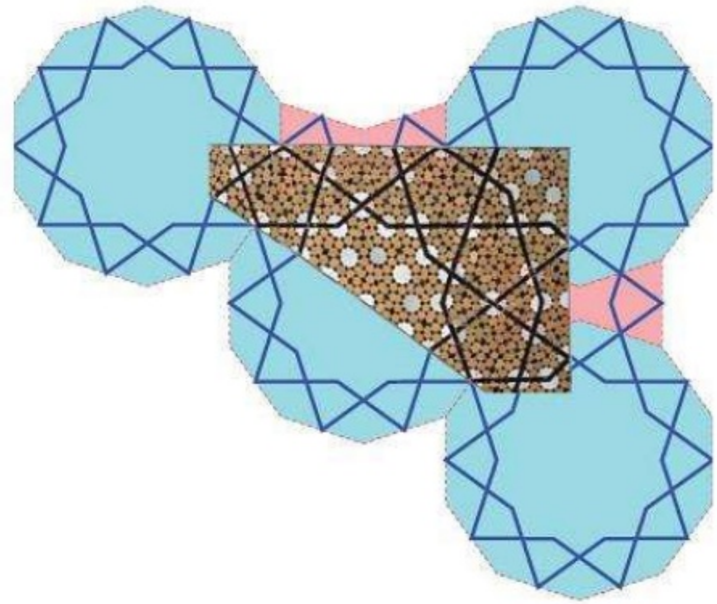
- Girih patterns in medieval Islamic architecture developed by designers as network of zigzagging lines, where lines drafted directly onto tiles with straightedge and compass
- Girih tiles match many Islamic tiling patterns and Penrose tile dart/kites
- Later, Lu found Girih tiles ⟶ matched Topkapi scroll (1500 A.D), a Timurid set of instructions for artisans



Topkapi scroll. Image in the public domain.



The Girih Tiles as a Penrose Tiling



The Girih Tiles fit the tiling of the Darb-i Imam Shrine (and many other tilings)

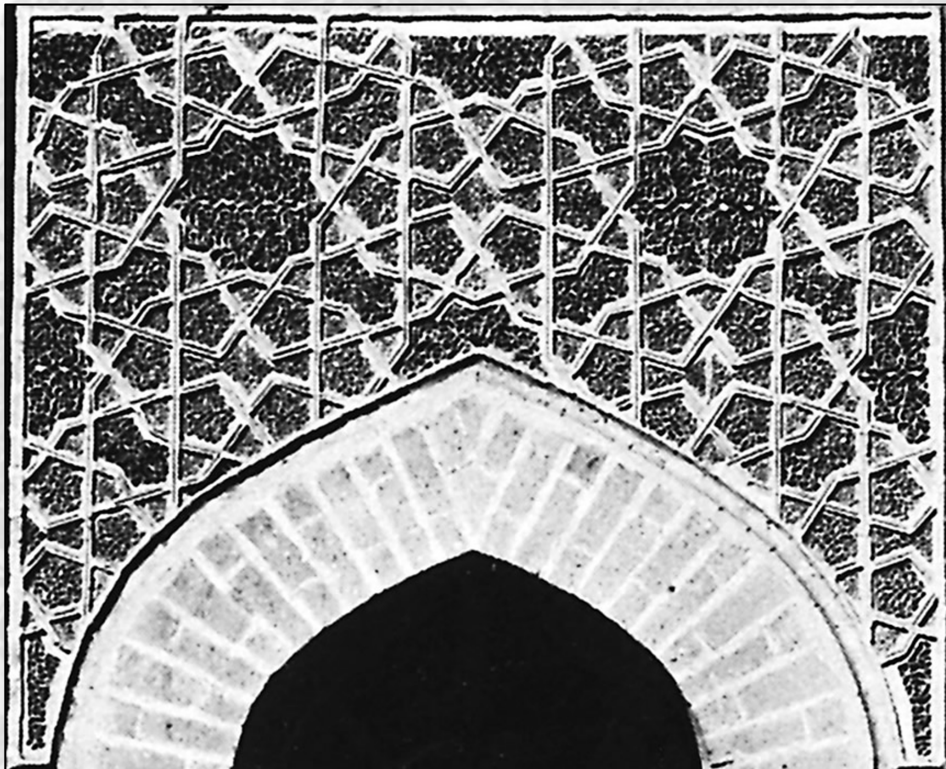
Images created by Peter Lu.

Islamic Tile Design & Quasicrystal Relationship

- 1200 C.E. – girih patterns reconceived as tessellations of special set of equilateral polygons (girih tiles) decorated with lines
- Tiles enabled creation of increasingly complex periodic girih patterns

Islamic tile design exhibiting quasicrystalline behavior. Image in the public domain.

Islamic Mathematicians & Artists Ahead of their Time?

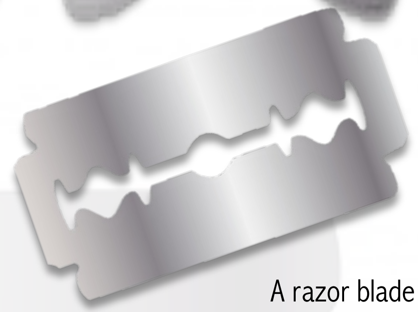


Strong evidence reveals:

- Islamic mathematicians and artists discovered quasicrystalline properties of "Penrose tilings" hundreds of years before Kepler

Quasicrystal type pattern in decagonal strapwork above an arch in the Abbasid al-Mustansiriyya Madrasa in Baghdad, Iraq, which dates to between 1227 and 1234. Image in the public domain.

Quasicrystal Uses



A razor blade by Pixabay and in the public domain.

- Surface coating as aluminum alloys
- Frying pans - coated on inside with Aluminum Nickel Cobalt alloy; high electrical and thermal resistivity
- Steel reinforcement
- Razor blades
- Surgeon’s instruments
- Sandvik, a company in Sweden, produces a precipitation-hardened stainless steel strengthened by small quasicrystalline particles; doesn’t corrode

Image by Cooks & Kitchens.

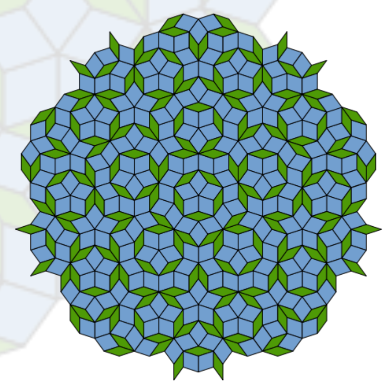
Learn more about quasicrystals by visiting NatureGlo's eScience MathArt Virtual Library link below.

http://hascmathart.weebly.com/quasicrystals.html

A "Girih tile subdivision found in the decagonal girih pattern on a spandrel from the Darb-e Imam shrine." Image in the public domain.

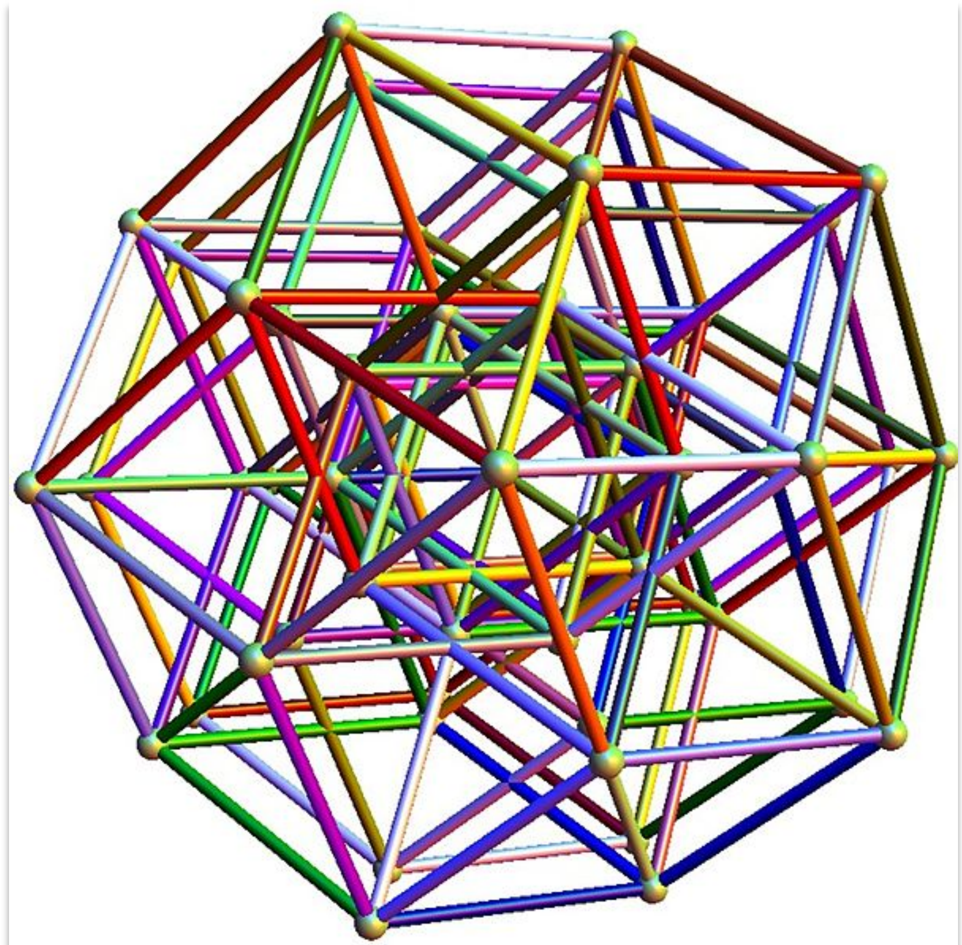
References

1. Wikimedia quasicrystal article: https://en.wikipedia.org/wiki/Quasicrystal
2. Lu, P. J.; Steinhardt, P. J. (2007). "Decagonal and Quasi-Crystalline Tilings in Medieval Islamic Architecture". Science 315 (5815): 1106–1110. Bibcode:2007Sci...315.1106L. doi:10.1126/science.1135491. PMID 17322056
3. Wikipedia Girih Tiles article: https://en.wikipedia.org/wiki/Girih_tiles
4. The Tiles of Infinity: http://www.aramcoworld.com/issue/200905/the.tiles.of.infinity.htm
5. Wikipedia Penrose tiling article: https://en.wikipedia.org/wiki/Penrose_tiling



Images (all the same) – Penrose tiling by Inductiveload and in the public domain.

Thank you for watching!



A 6-Cube-Quasicrystal
created by Jgmoxness.