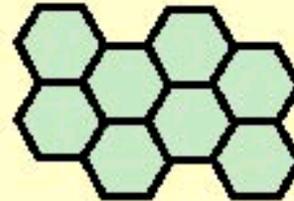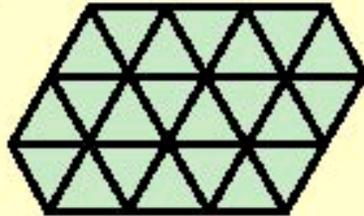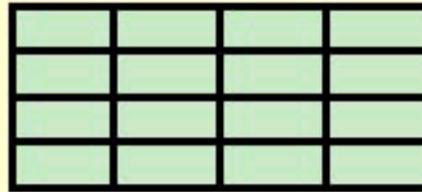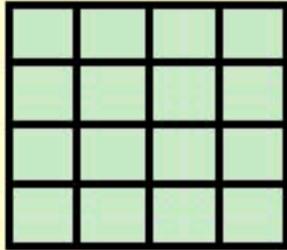# Quasi Images.ppt from Physics Department, Princeton U
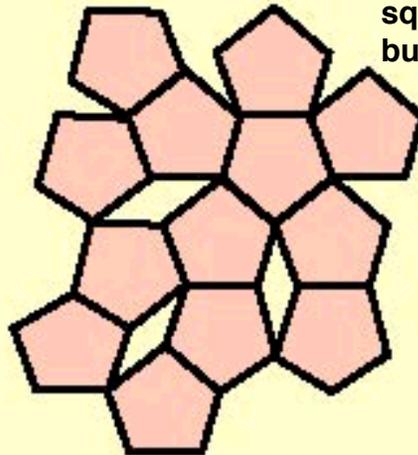
By

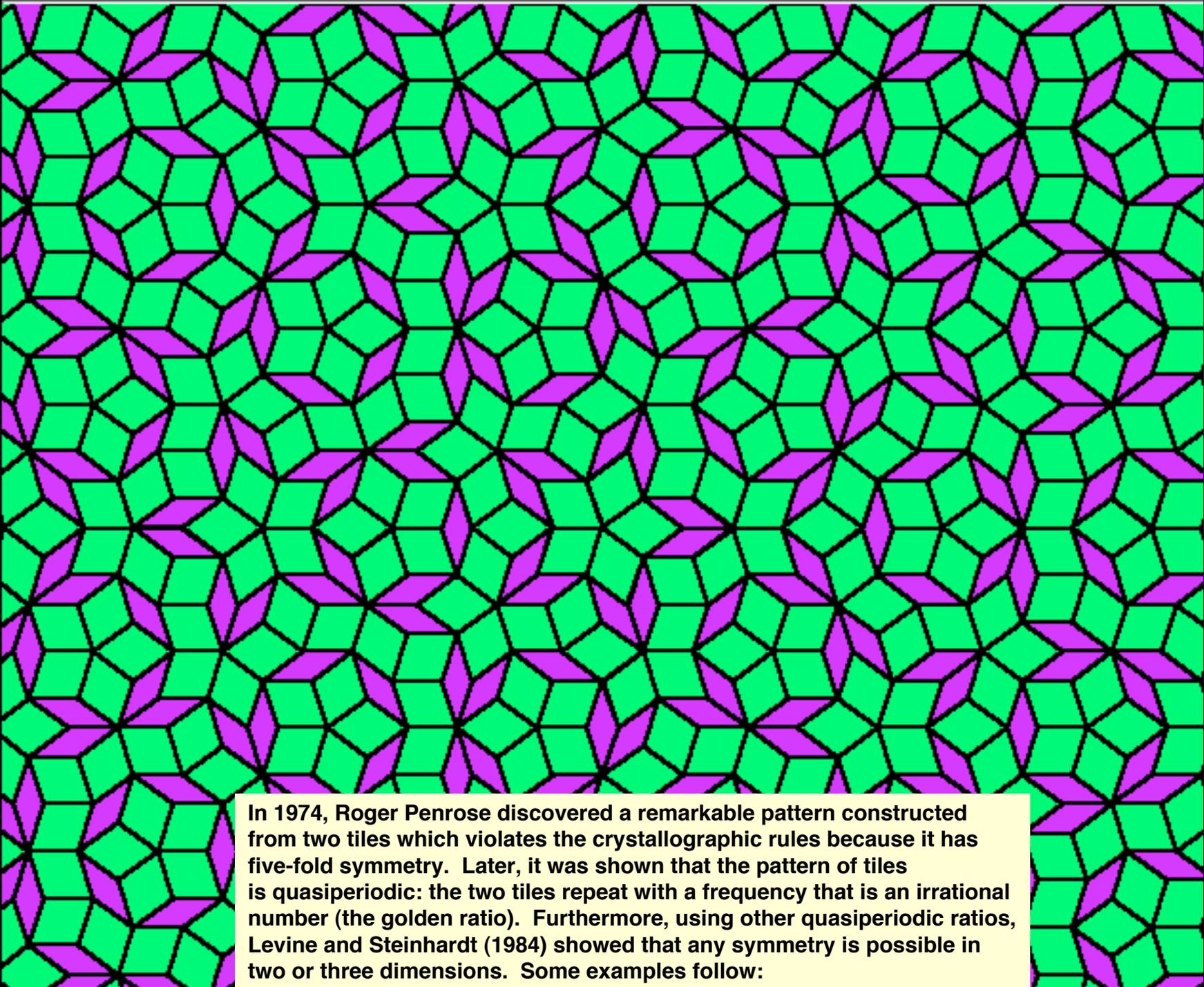Daniel Schechtman

Theorems of Crystallography

Symmetry Axes
Compatible
w / Periodicity

According to the well-known theorems of crystallography, only certain symmetries are allowed: the symmetry of a square, rectangle, parallelogram triangle or hexagon, but not others, such as pentagons.

5-fold
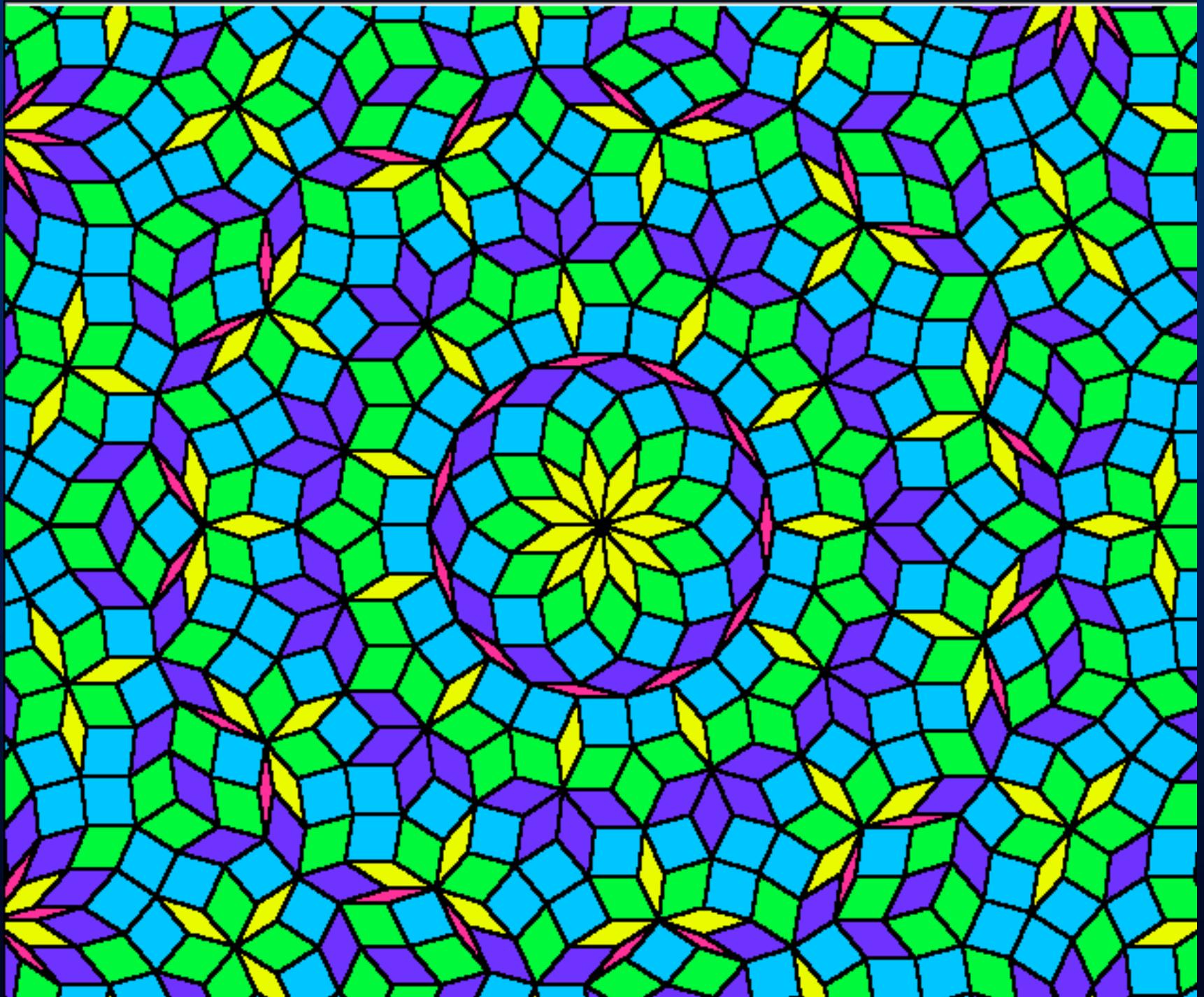Symmetry is
FORBIDDEN

5-fold

In 1974, Roger Penrose discovered a remarkable pattern constructed from two tiles which violates the crystallographic rules because it has five-fold symmetry. Later, it was shown that the pattern of tiles is quasiperiodic: the two tiles repeat with a frequency that is an irrational number (the golden ratio). Furthermore, using other quasiperiodic ratios, Levine and Steinhardt (1984) showed that any symmetry is possible in two or three dimensions. Some examples follow:
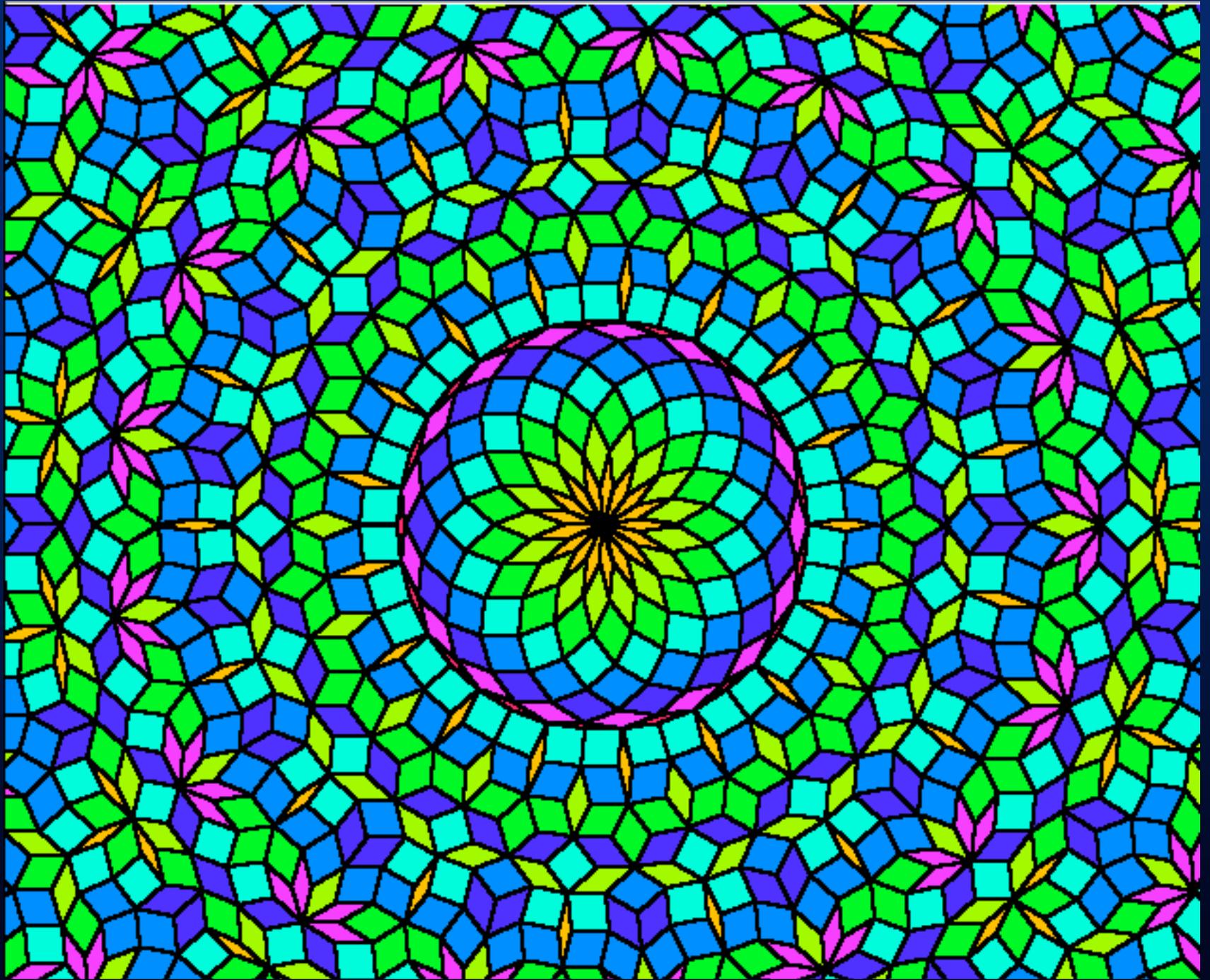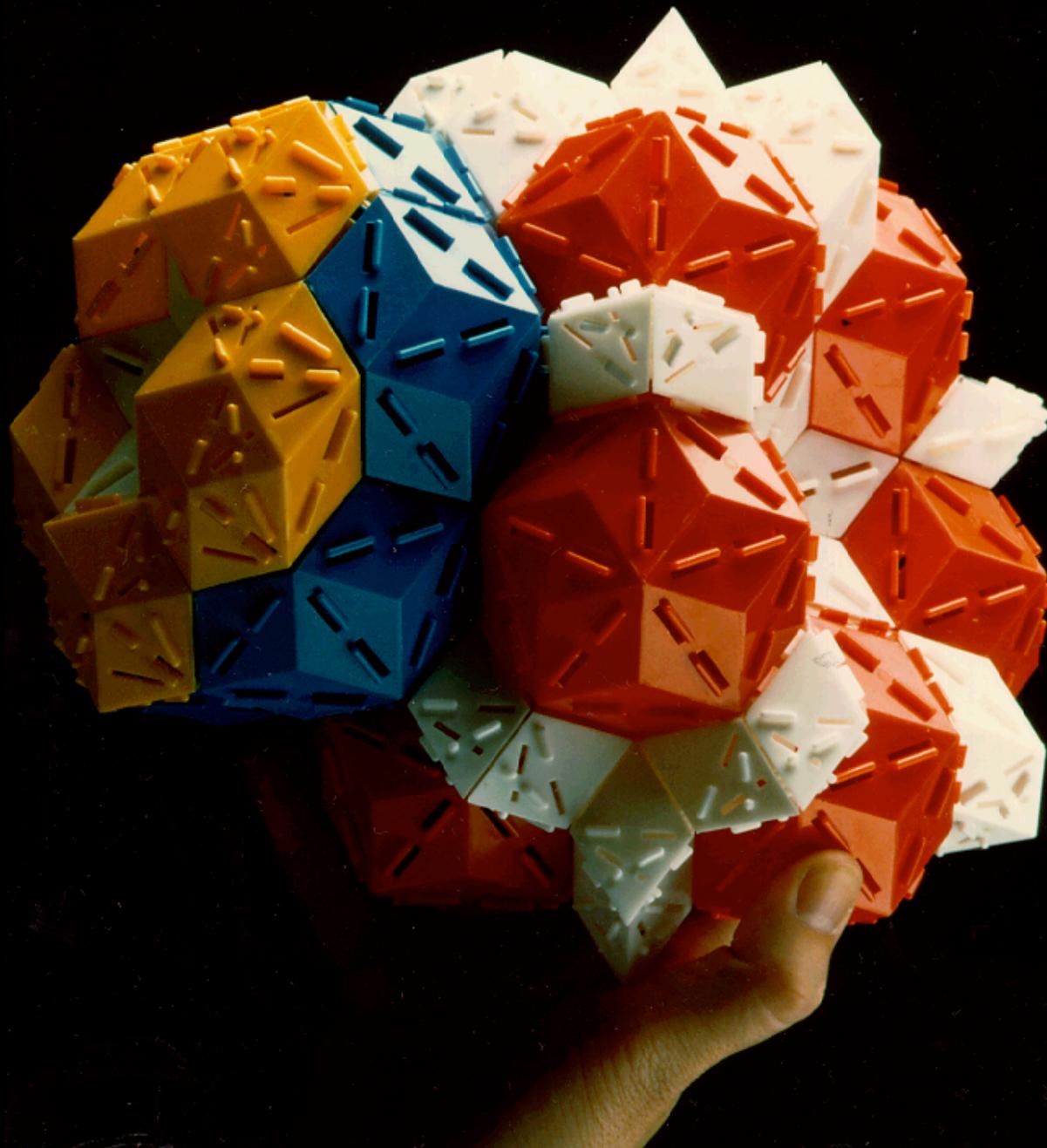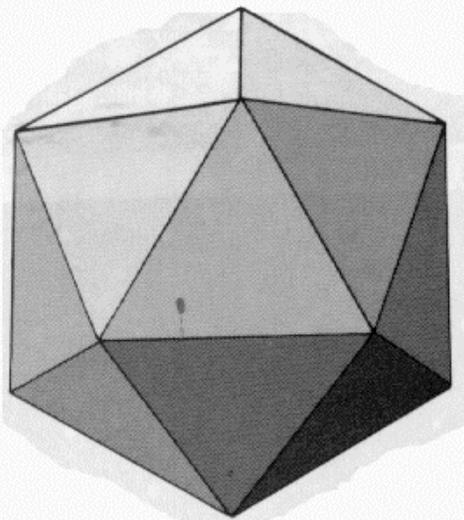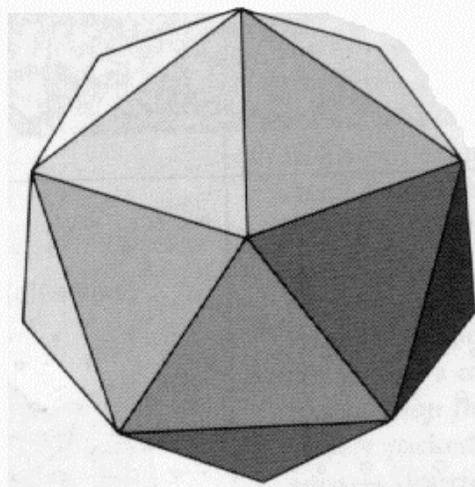
7-fold
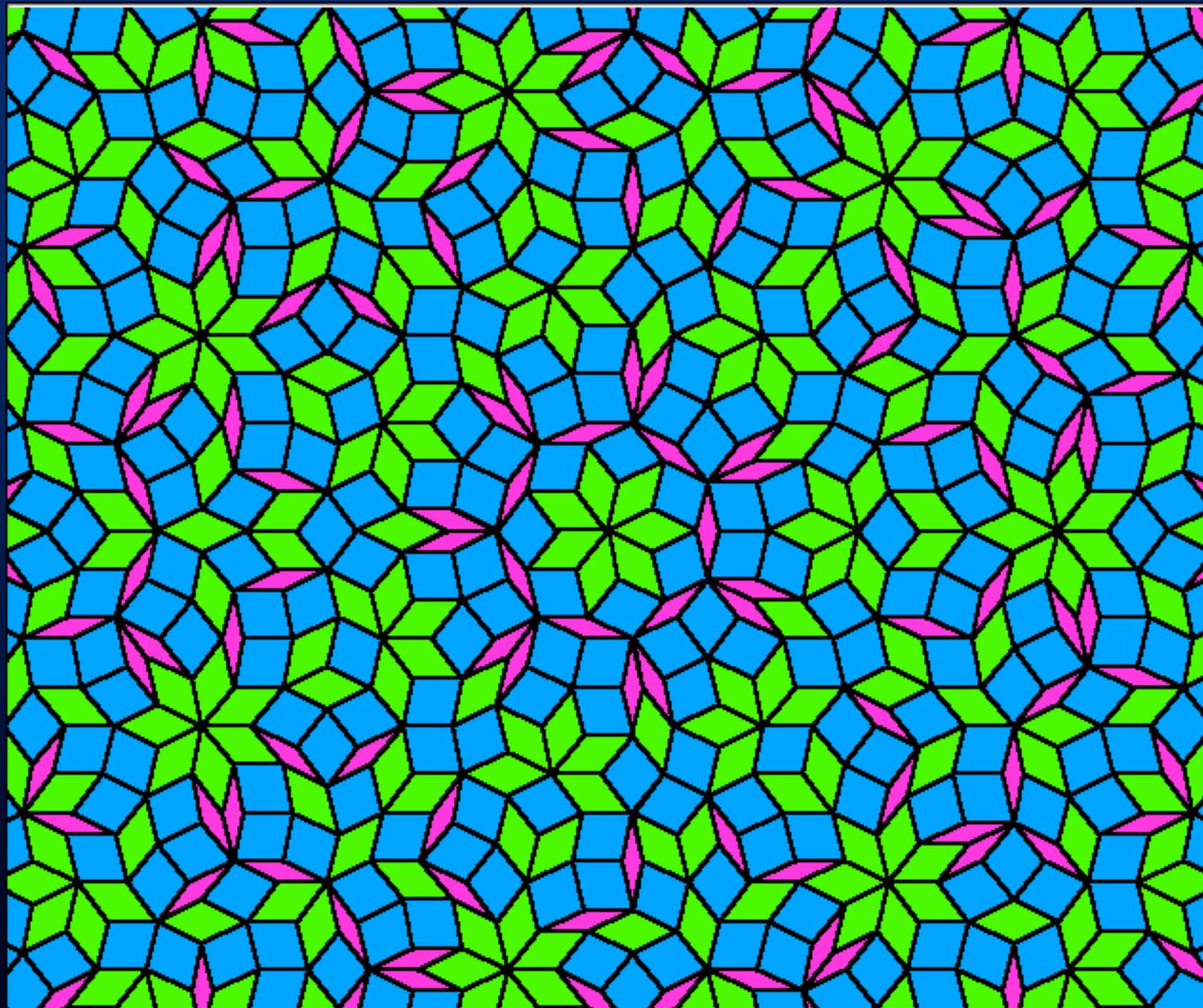
11-fold

17-fold

3d
icosahedral
symmetry
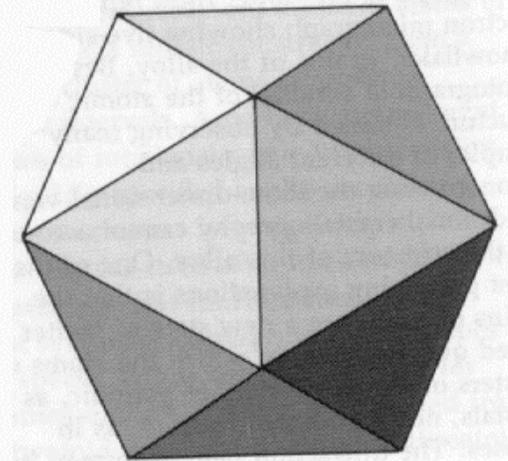
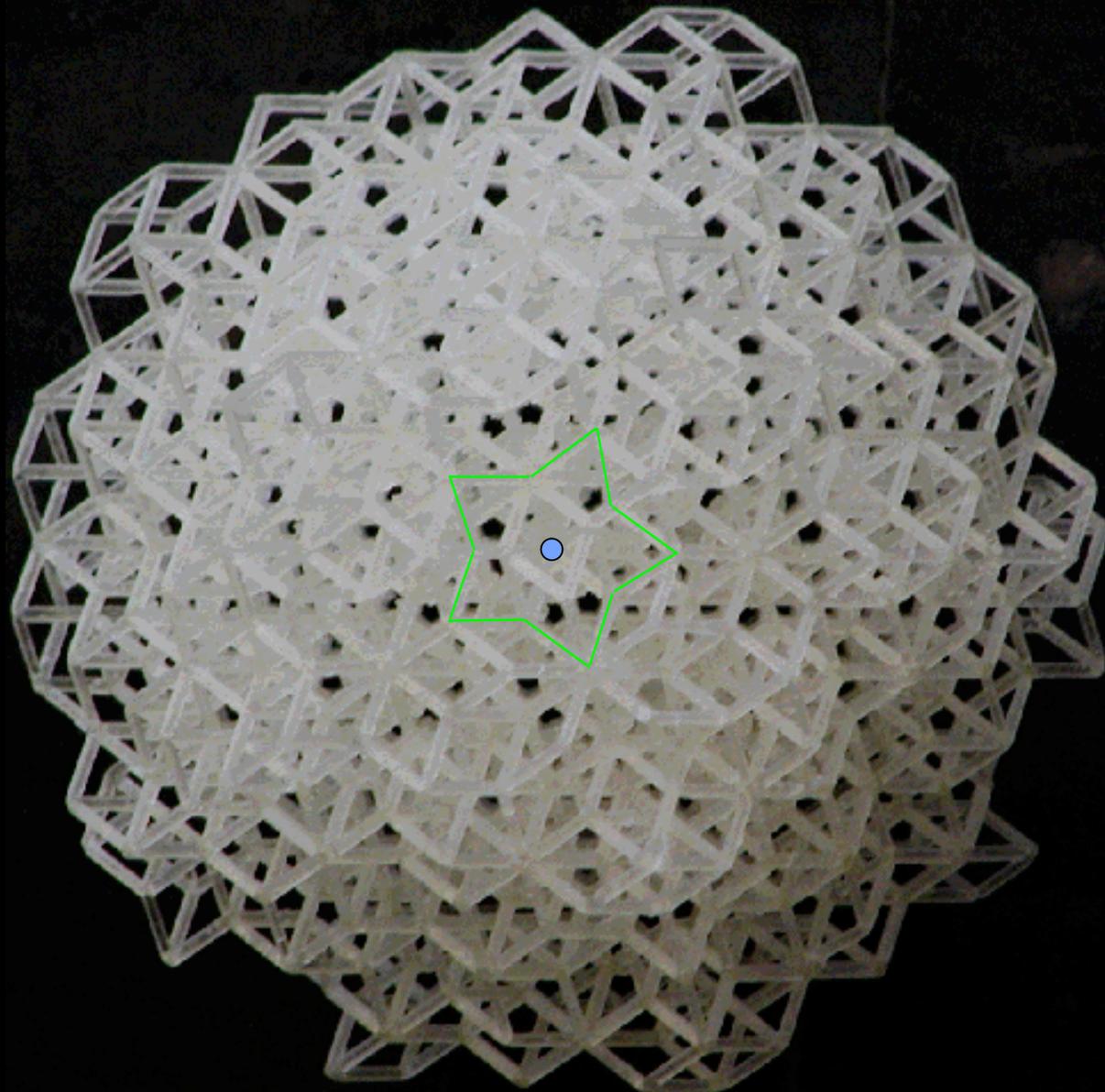**The icosahedron has the symmetry of a soccer ball, with 3, 5 and 2-fold axes**
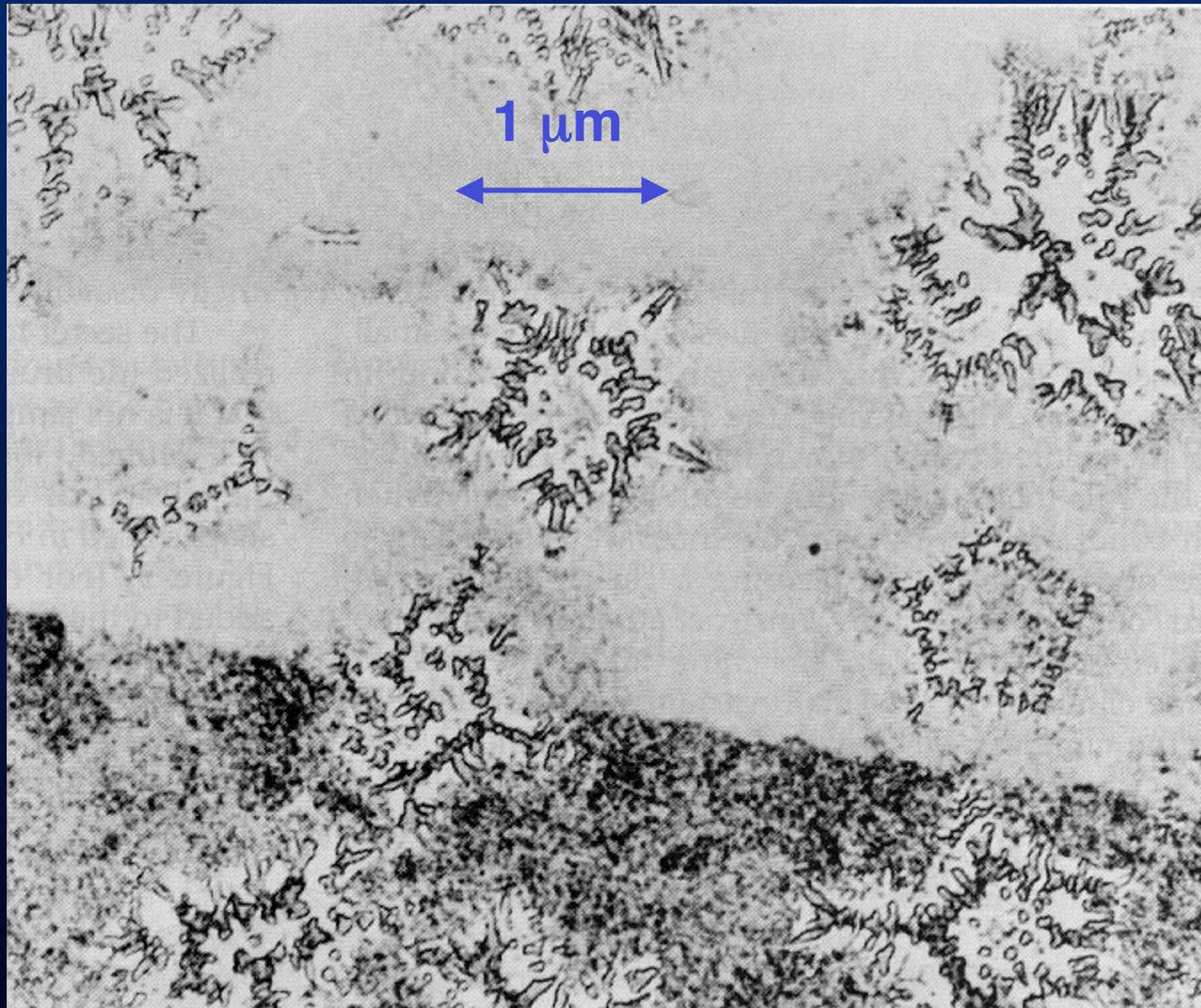
three-fold symmetry axis

five-fold symmetry axis

two-fold symmetry axis

a photonic quasicrystal
constructed from polymer
(see later photos)

A historic breakthrough was the discovery by D. Shechtman, I. Blech, D. Gratias, J.W. Cahn (1984) of icosahedral feathery grains of an Al and Mn alloy:

Al_6Mn

D. Shechtman, I. Blech, D. Gratias, J.W. Cahn (1984) found that each grain (see right hand photo)

"diffracts electrons like a crystal [producing sharp spots]. . .but with a symmetry <u>strictly forbidden</u> for crystals," a profound mystery
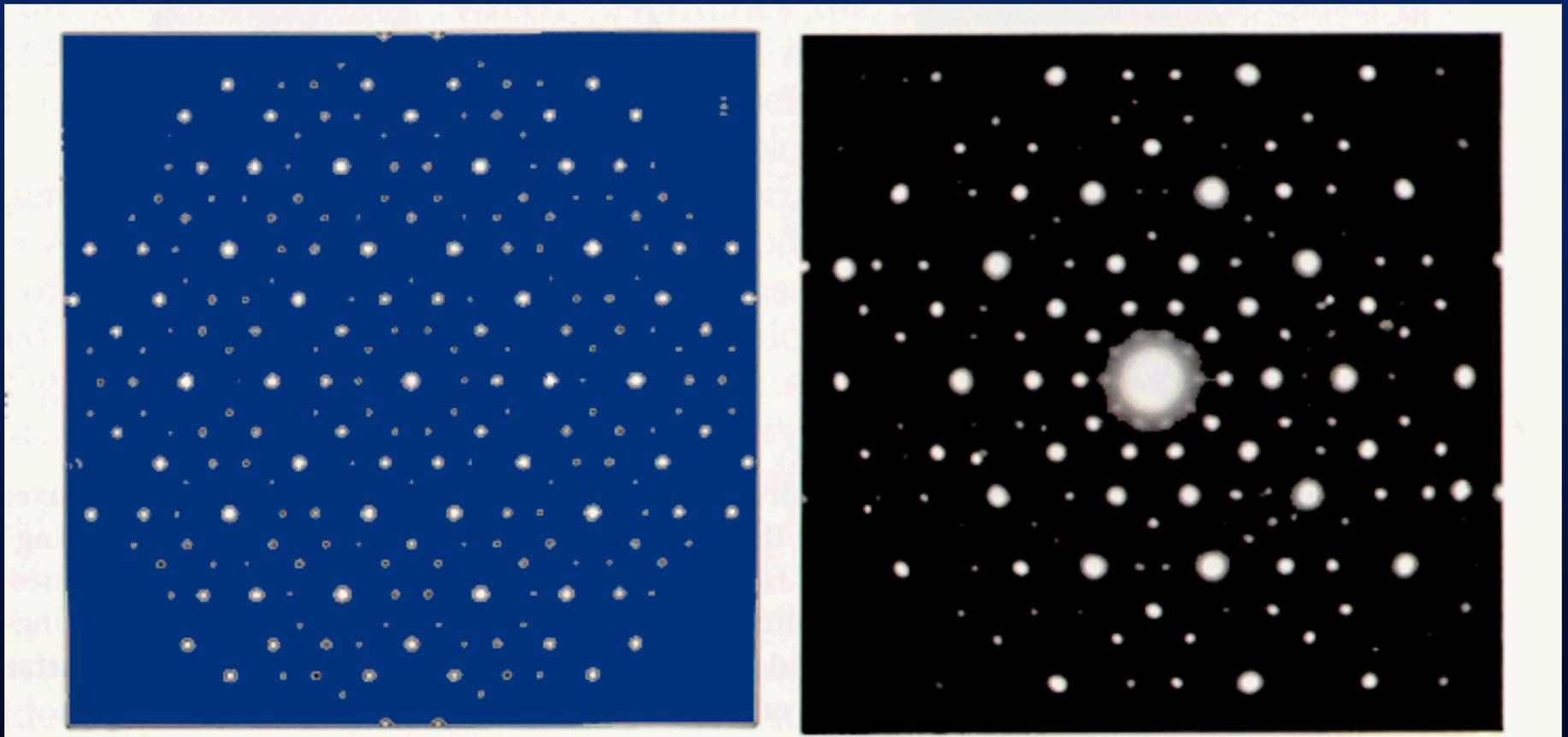
As it turns out, the pattern matches beautiful the theoretical pattern (on left) computed for the icosahedral quasicrystal patterns show in the previous slides. This was a sign that quasicrystals may be realized in the laboratory
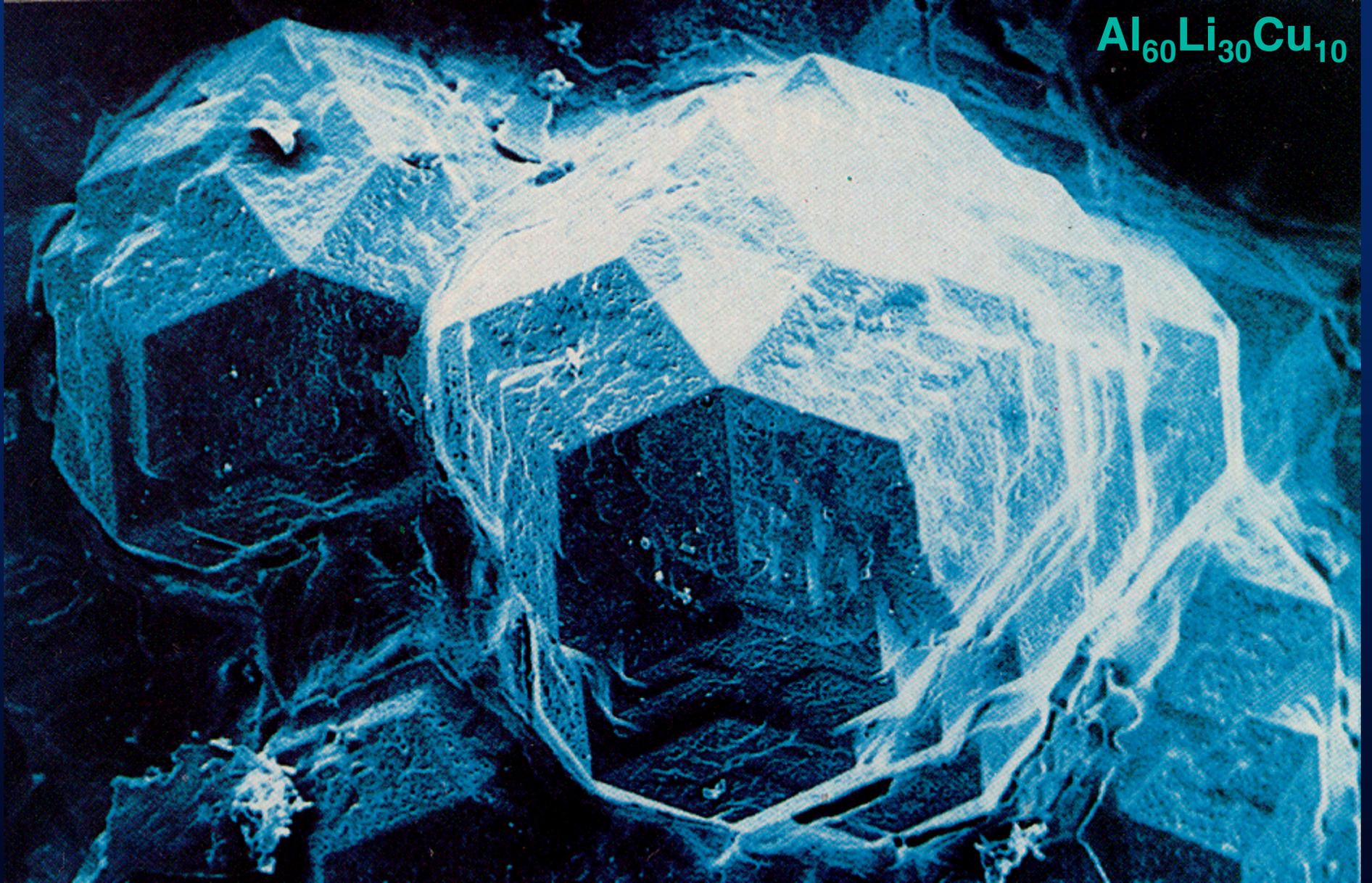
Since 1984, the field has blossomed, with many beautiful examples of quasicrystal alloys being discovered. A few example are shown in the next slides:
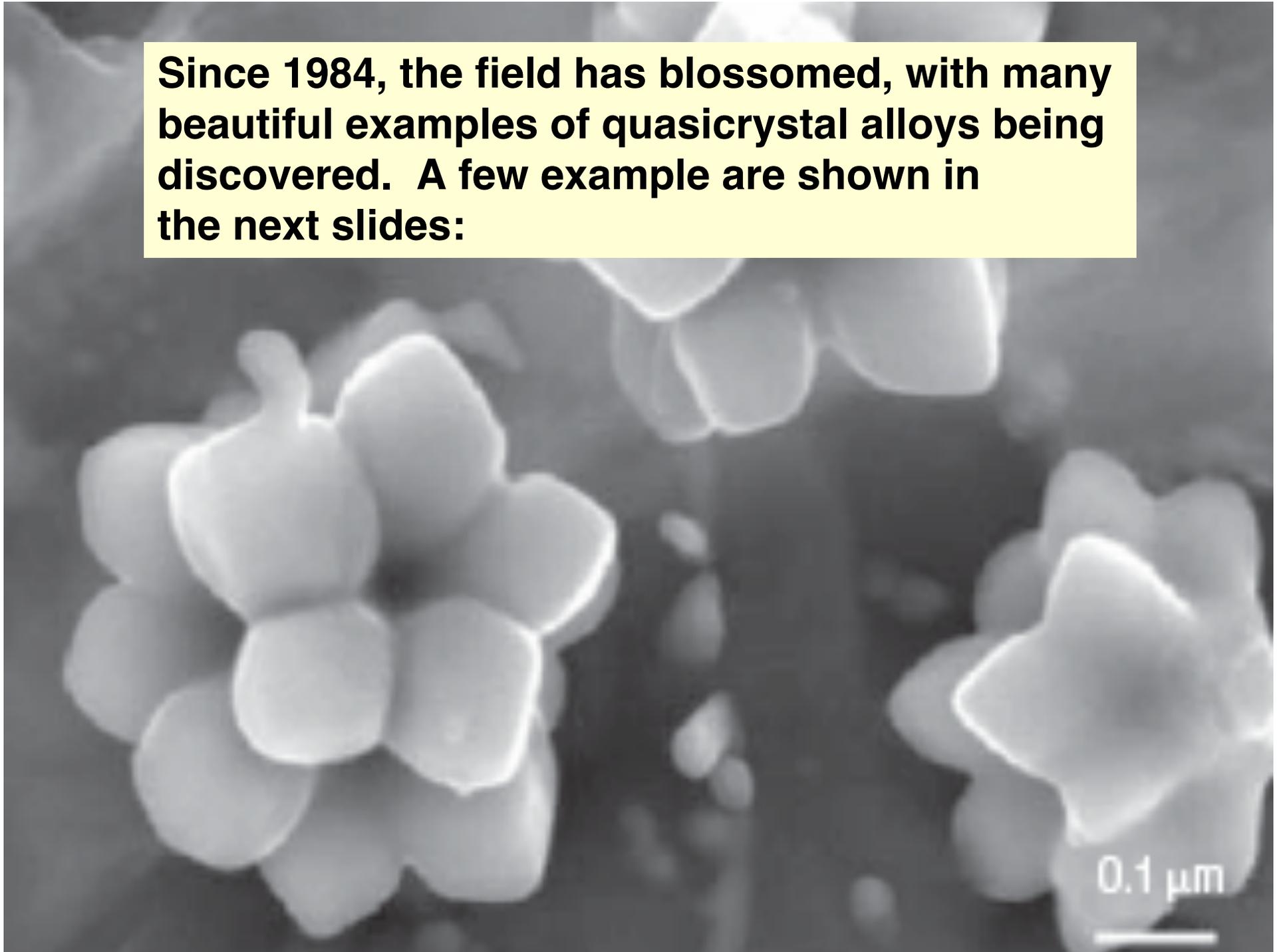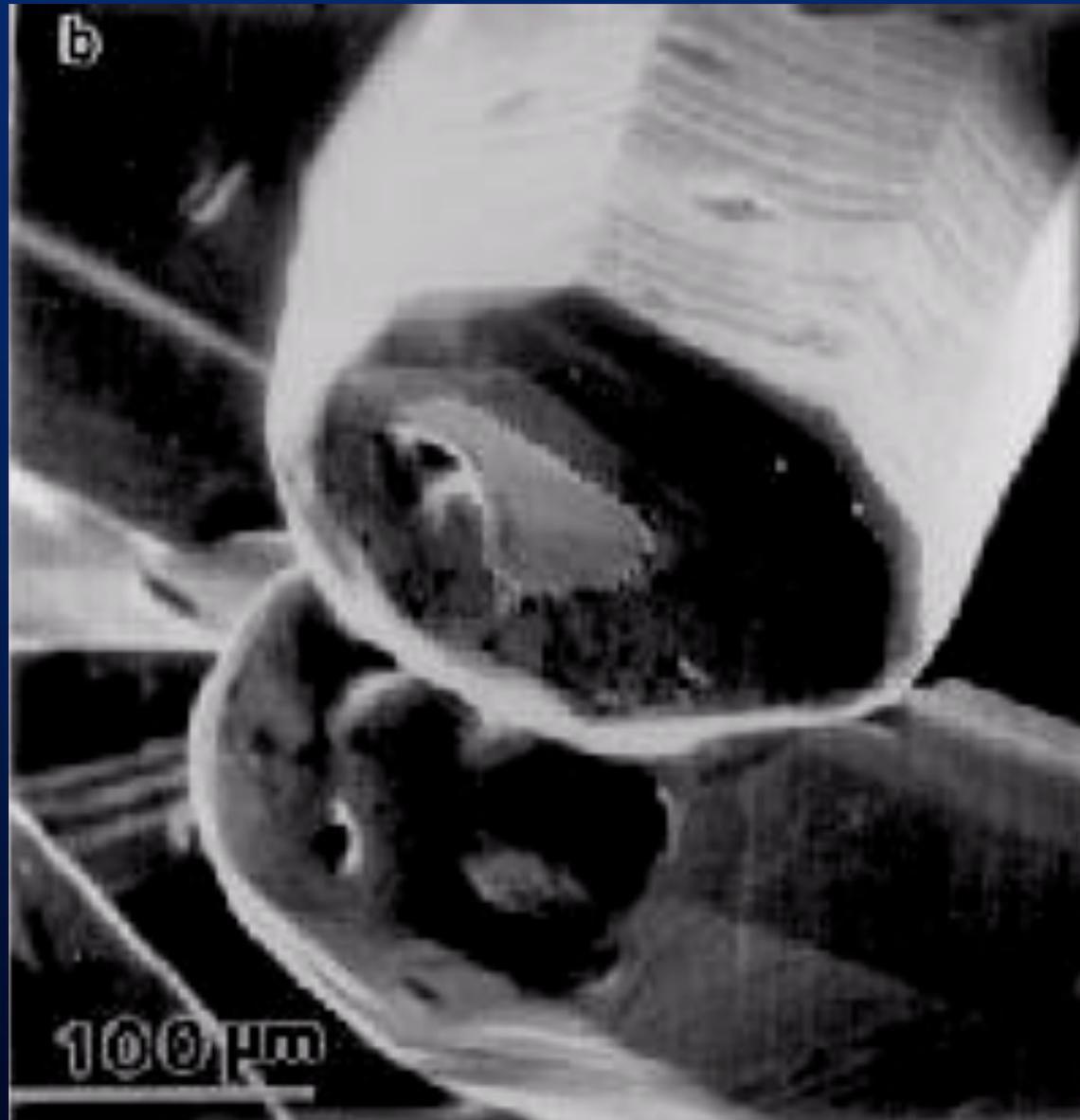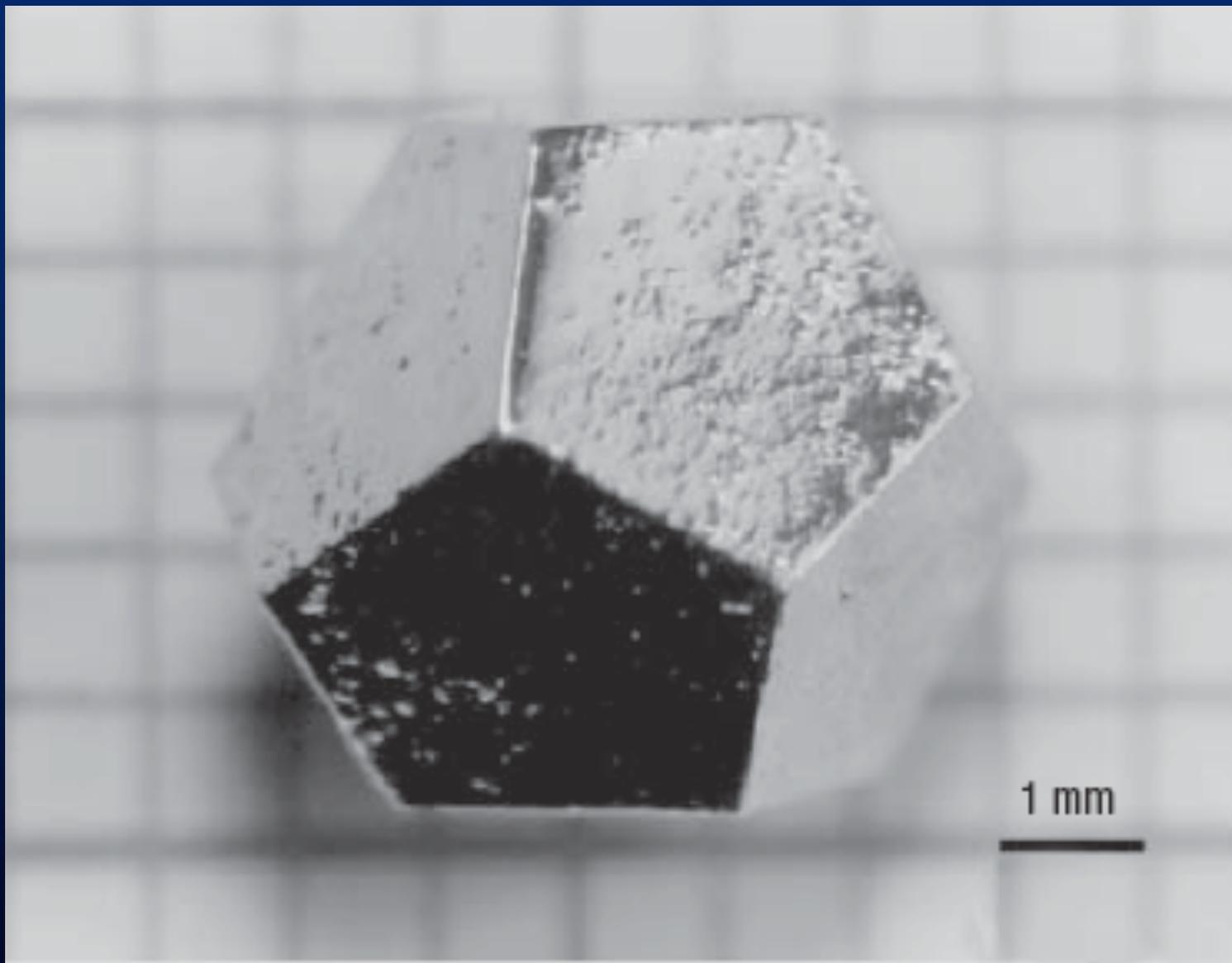
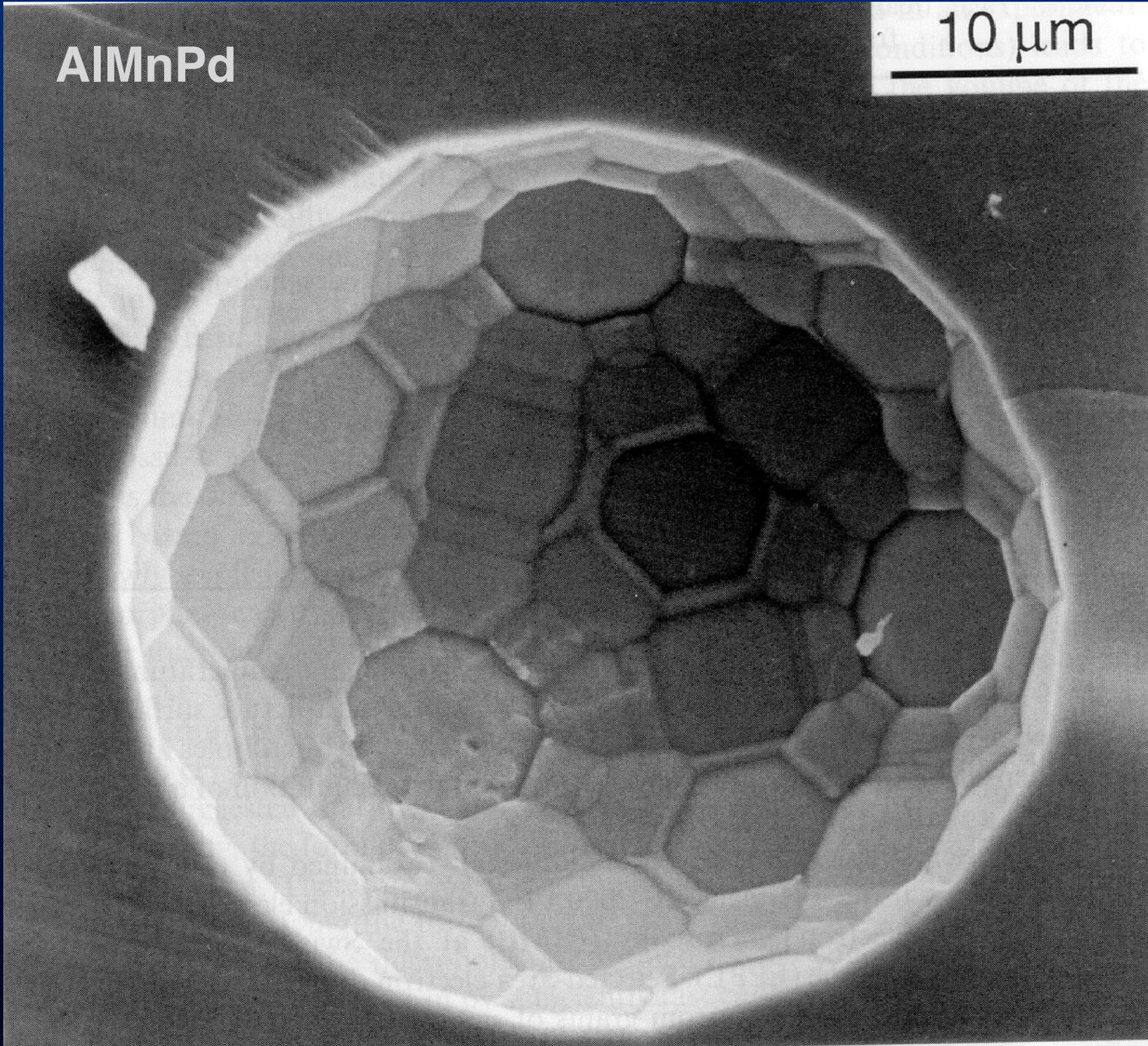$Al_{70} Ni_{15} Co_{15}$

$Al_{60}Li_{30}Cu_{10}$

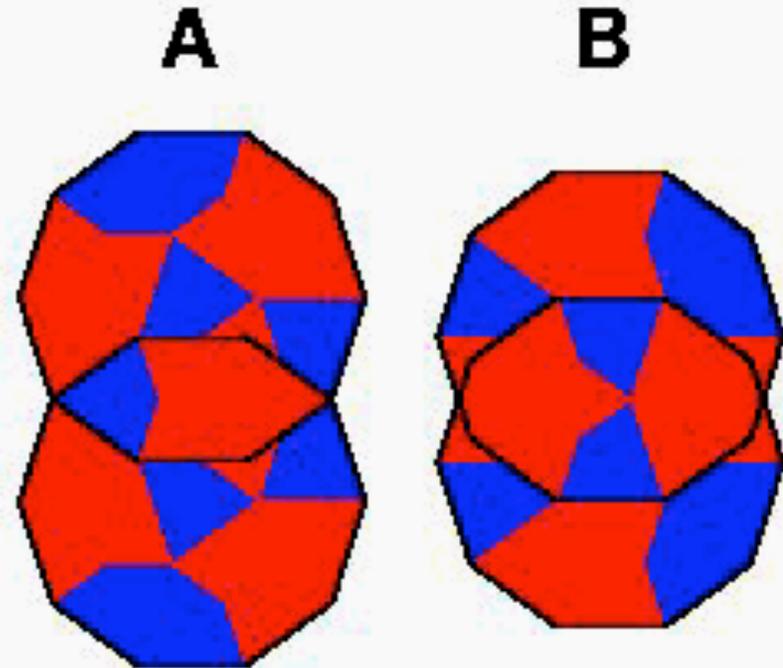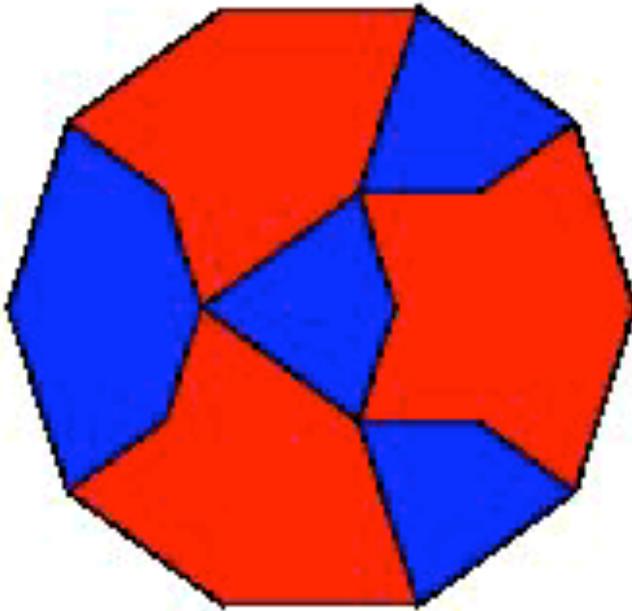$Zn_{56.8} Mg_{34.6} Ho_{8.7}$

AlMnPd

10 µm

Another view of quasicrystals is the Quasi-unit Cell Picture
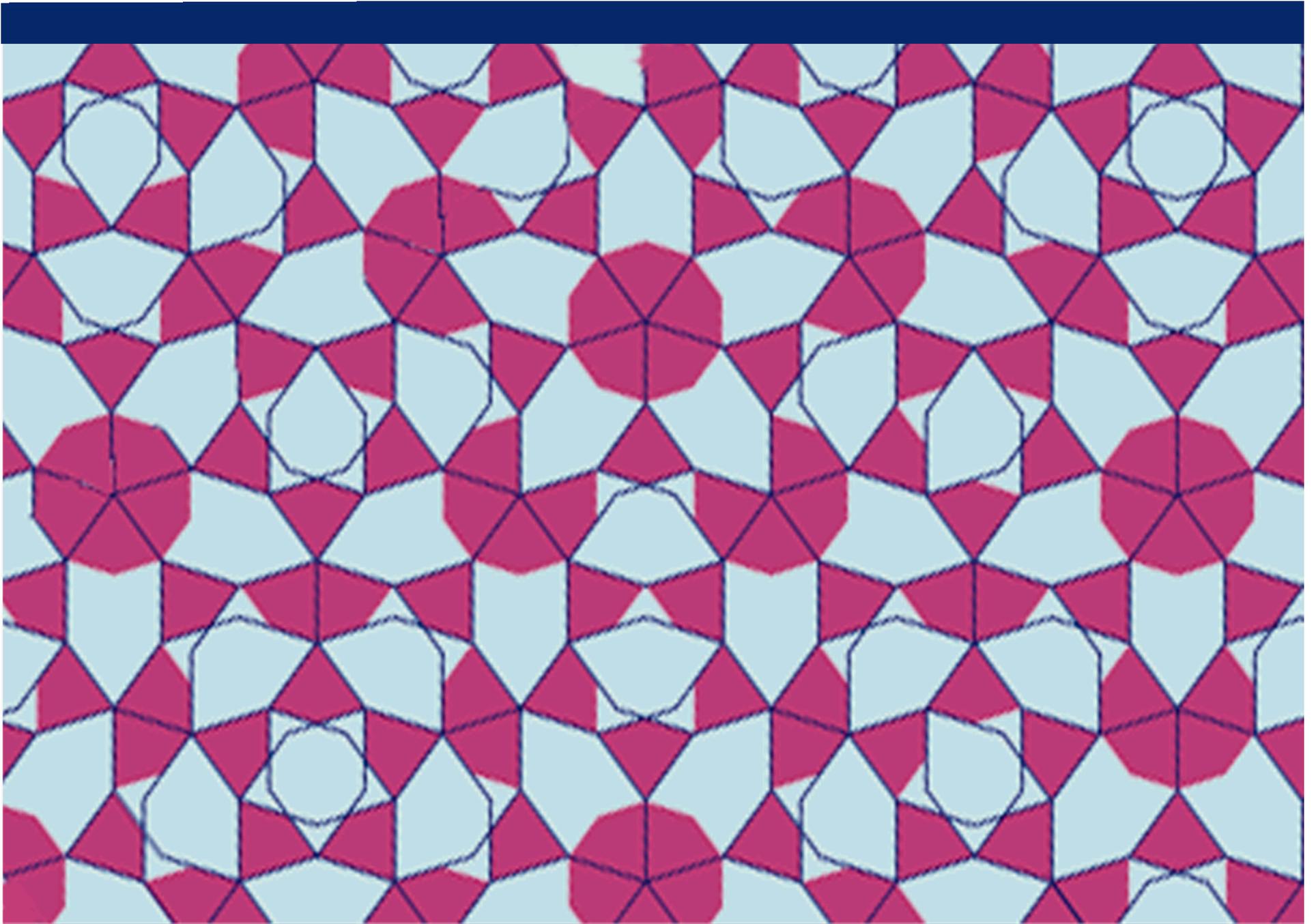
Gummelt Tile
(named after its discoverer Petra Gummelt)

A quasicrystal can also be obtained by repeating this single unit, but allowint it to overlap its neighbors. This can be mapped into a Penrose tiling.
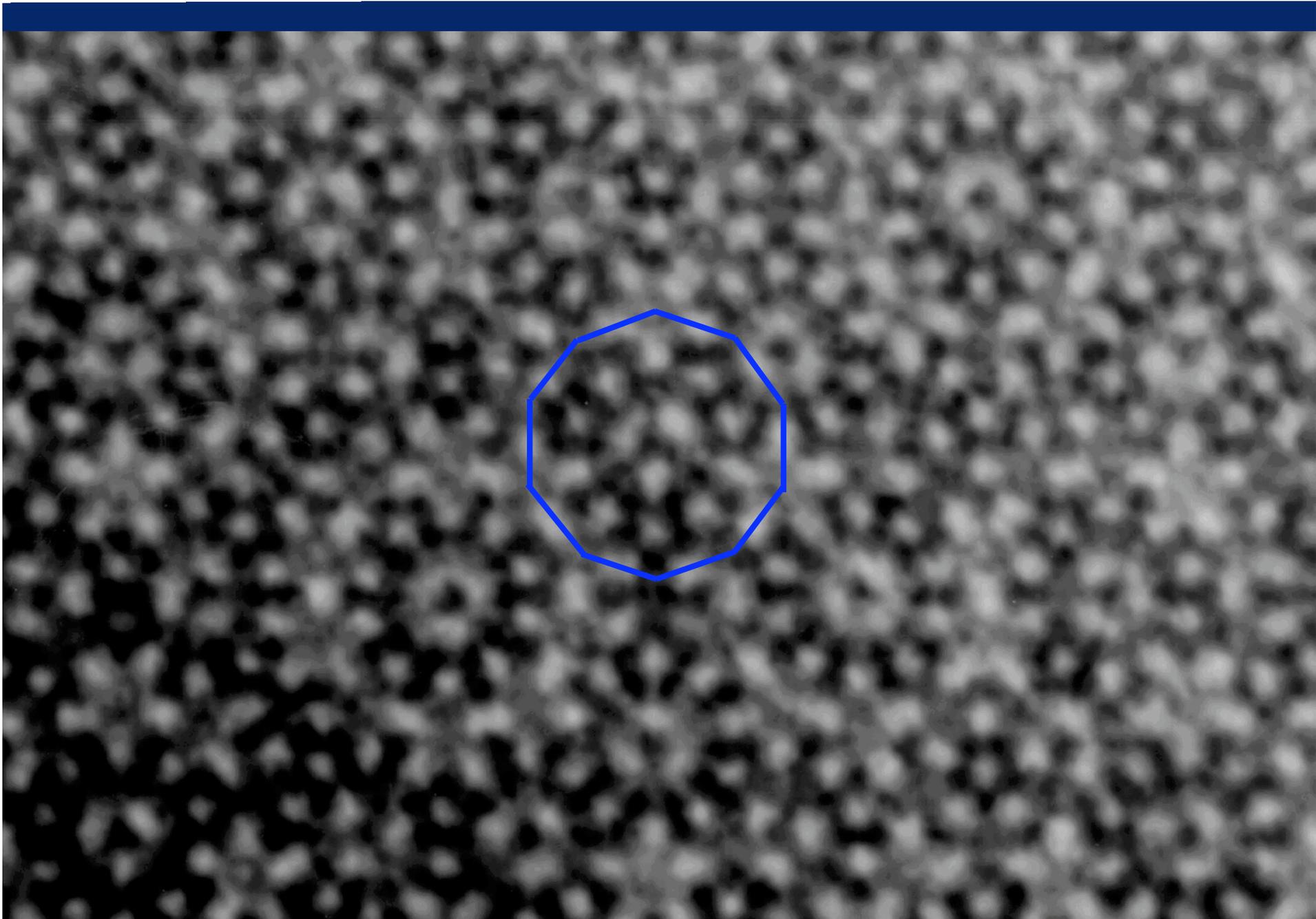P.J. Steinhardt, H.-C. Jeong (1996)
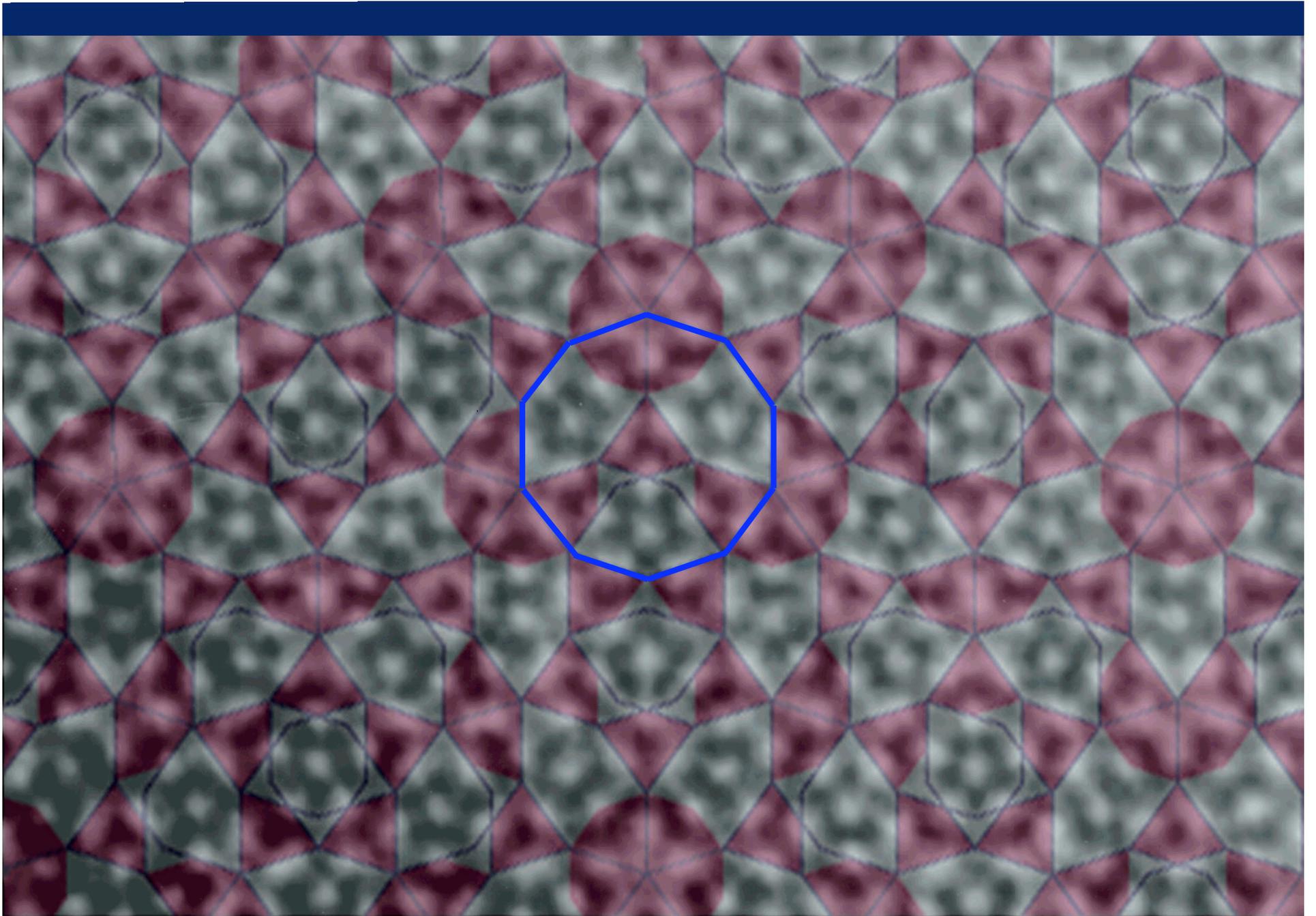
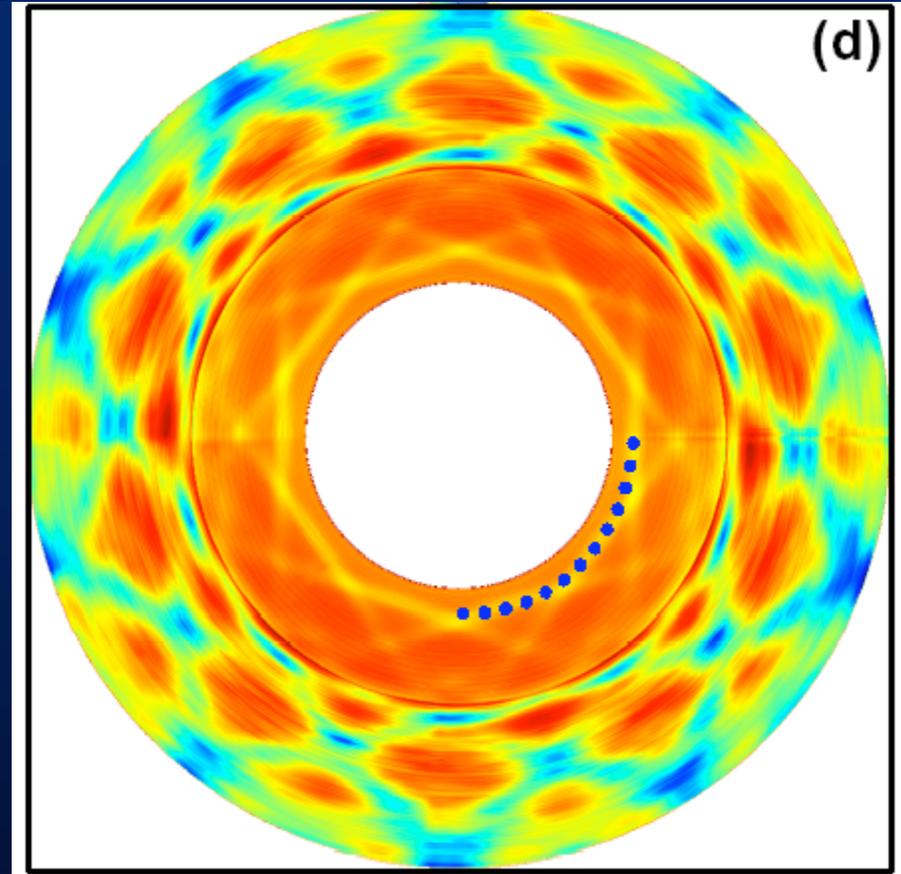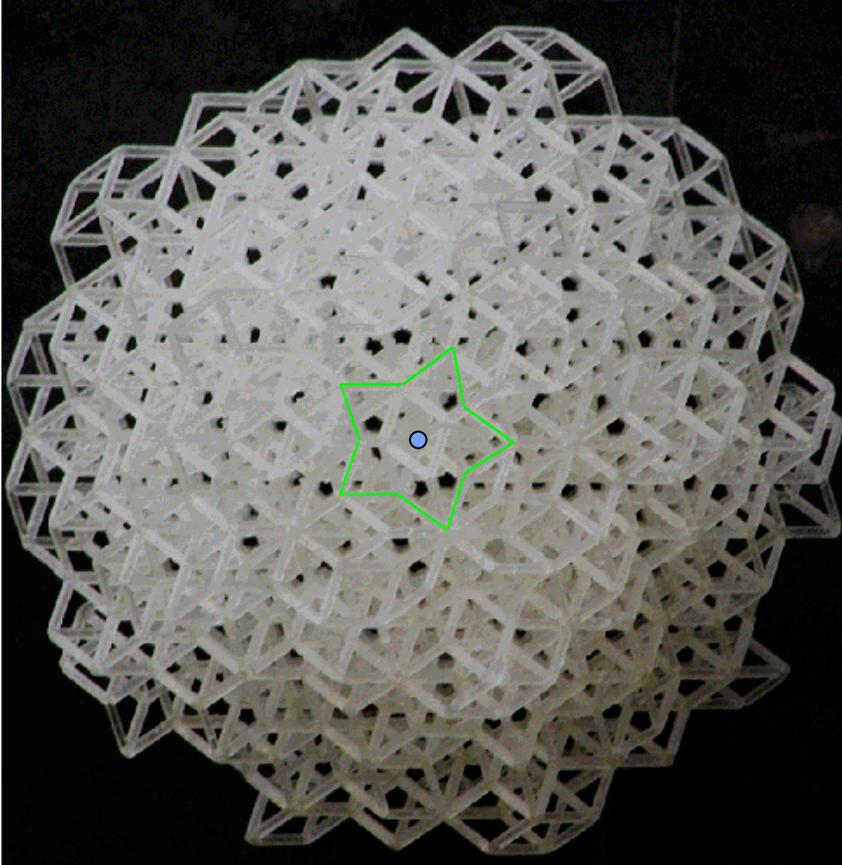Here is the overlapping Gummelt tile pattern

$Al_{72}Ni_{20}Co_8$

a decagonal arrangement in the real structure

a demonstration that the real atoms and the ideal pattern match

Weining Man, M. Megans, P. Chaikin, & PJS, Nature (2005) brought about another use of 3d icosahedral quasicrystals for photonics.

(d)

- **the construction of the world's largest 3d QC**

- **first measurement of photonic bandgap in 3d QC**

- **first visualization of 3d effective Brillouin zone**

- **demonstration of nearly spherical zone**
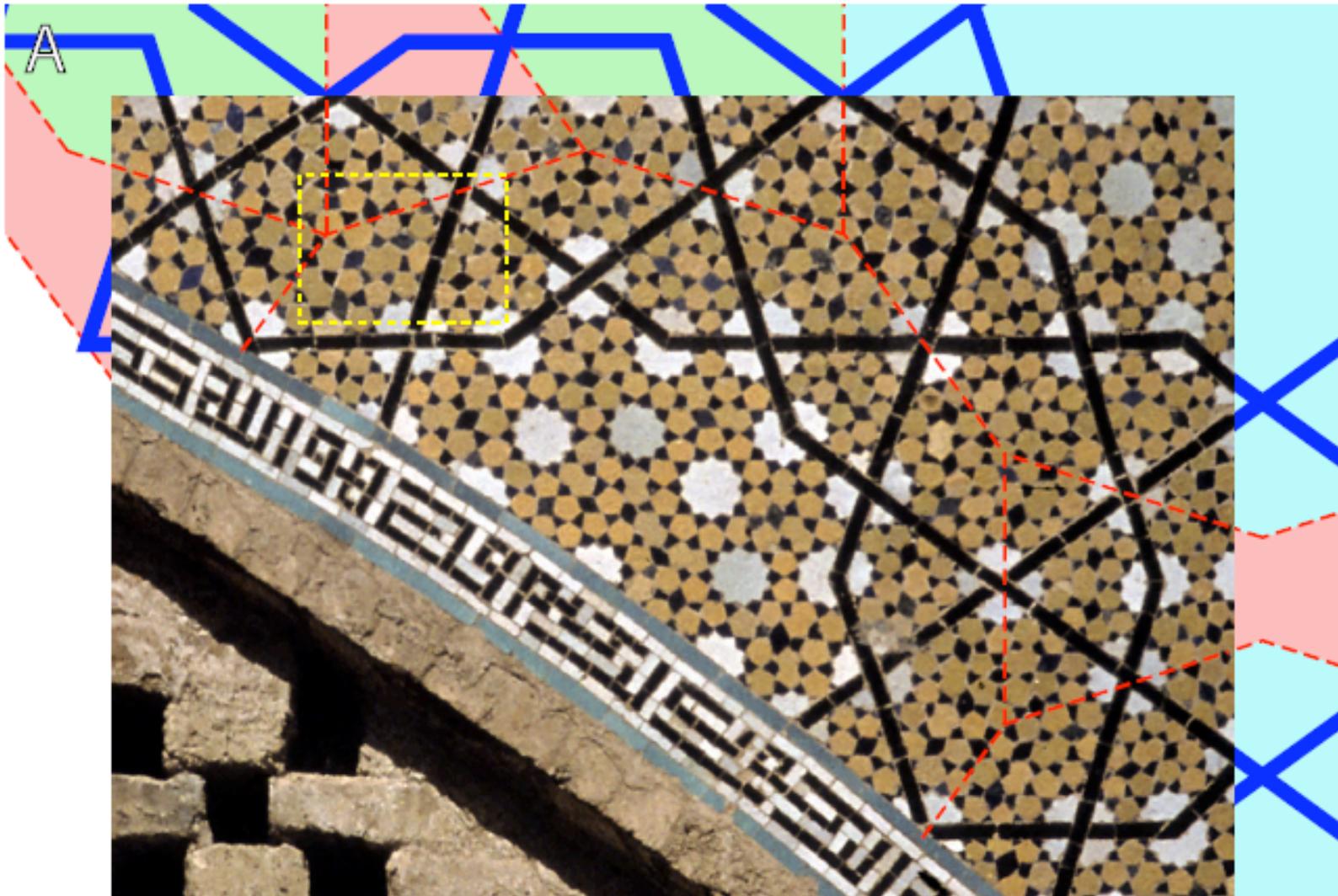
In Lu & Steinhardt (2007), this tiling on the Darb-i-Imam shrine in Isfahan is shown which is nearly perfectly quasicrystalline. Although it can be mapped into a Penrose tiling with only a few point-like defects, it appears more likely that the designers used a subdivision rule that, if continued, would lead to a different five-fold quasicrystalline pattern.