A Journey through Architecture, Black Holes, and NanoArchitectonics

Guy Le Lay

Aix-Marseille University, CNRS-PIIM, France

NW2SD, Marseille, France, July 16-19, 2019

International Klein Blue (IKB) Patented in 1960

Unique creation in the history of architecture, emblematic icon of Brussels**,** **the Atomium** was constructed for the first post-war universal world exhibition (EXPO 58) The nine spheres represent a bcc iron crystallographic cell magnified 165 billion times;

Conception:
Ing. **André Waterkeyn**
Architects:
André and Jean Polak

Pavilion of the United States for the 1967 World Fair, Expo 67

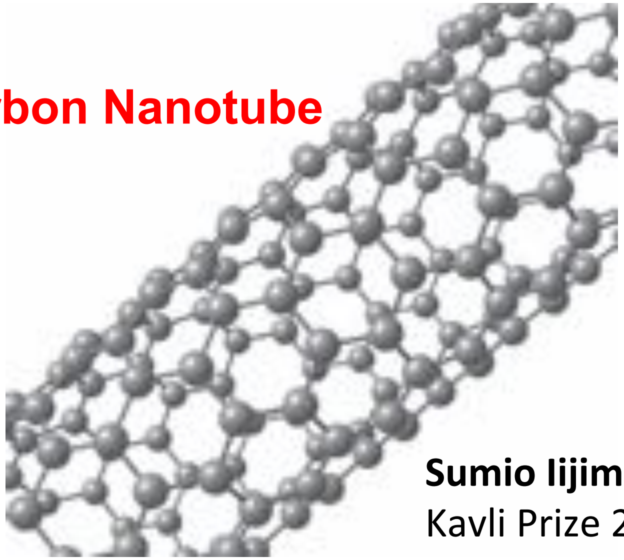
Low dimensional carbon allotropes

0D-Fullerene C_{60}

The « buckyball »

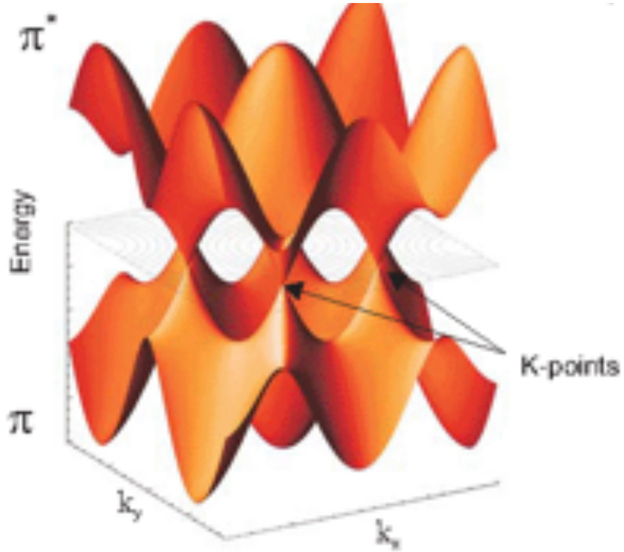
Robert Curl, Harry Kroto and **Richard Smalley**
Nobel Prize in Chemistry 1996

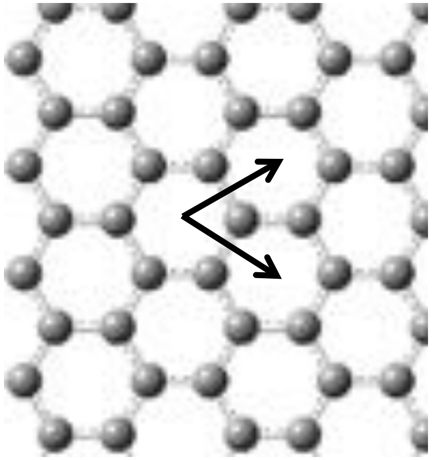
1D-Carbon Nanotube

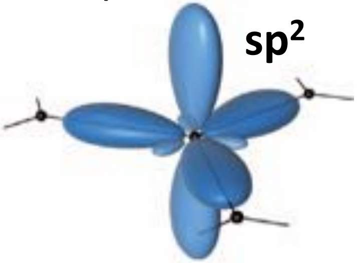


Sumio Iijima
Kavli Prize 2008

2D-Graphene







Andre Geim and Konstantin Novoselov 2010 Nobel Prize in Physics
"for groundbreaking experiments regarding the **2D material graphene**"

Monolayer graphene: 2.3% light absorbance !

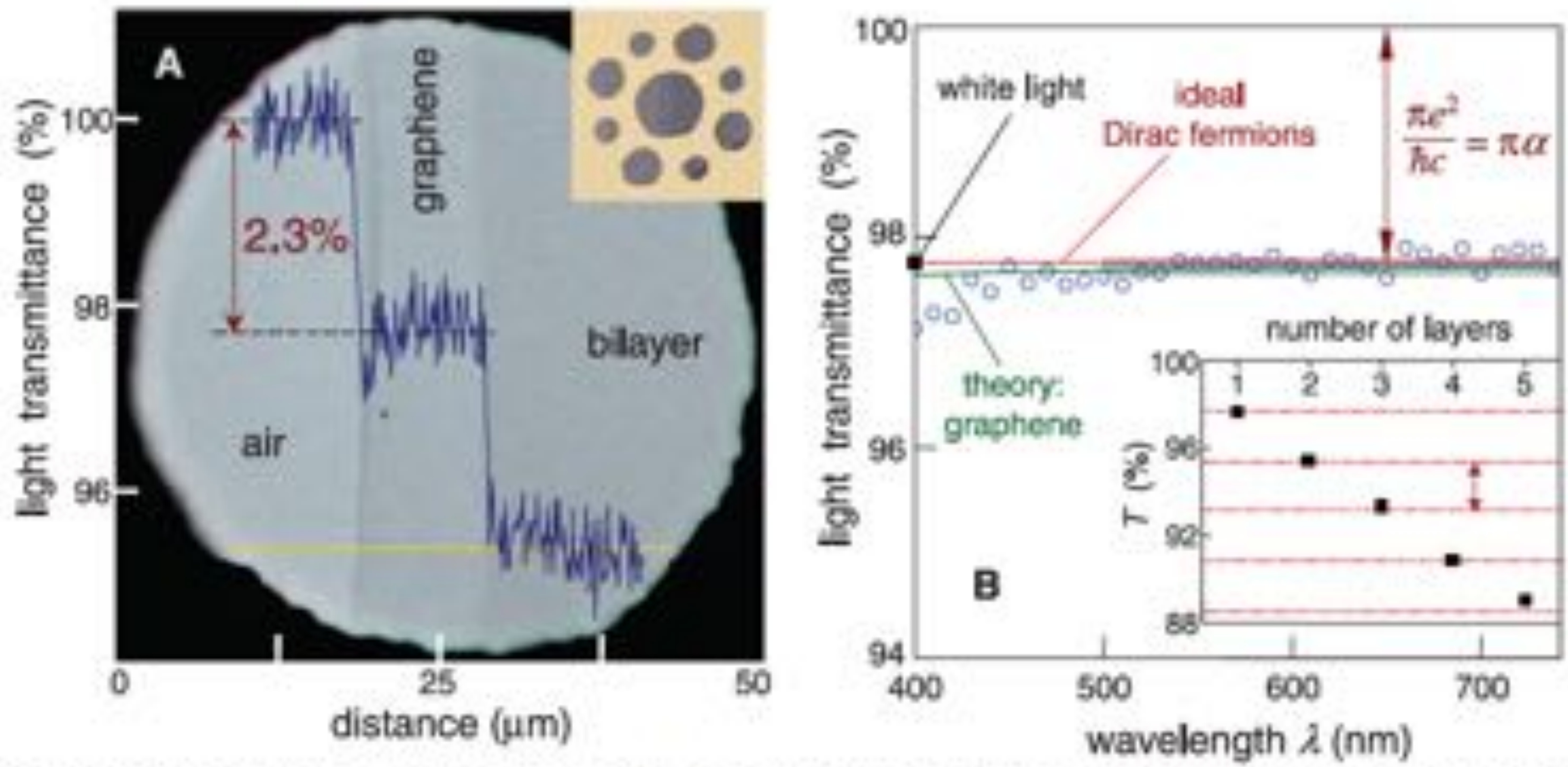
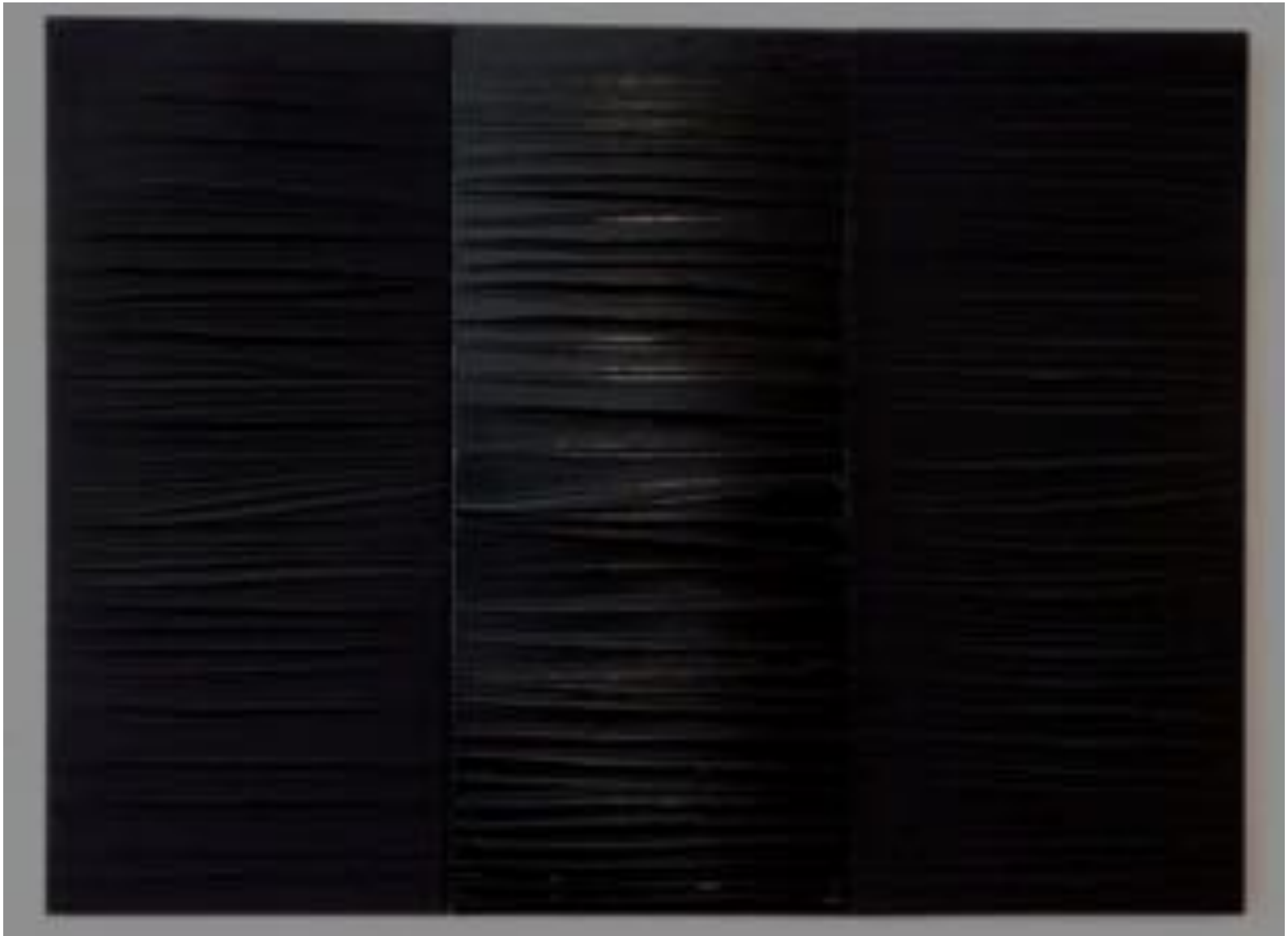


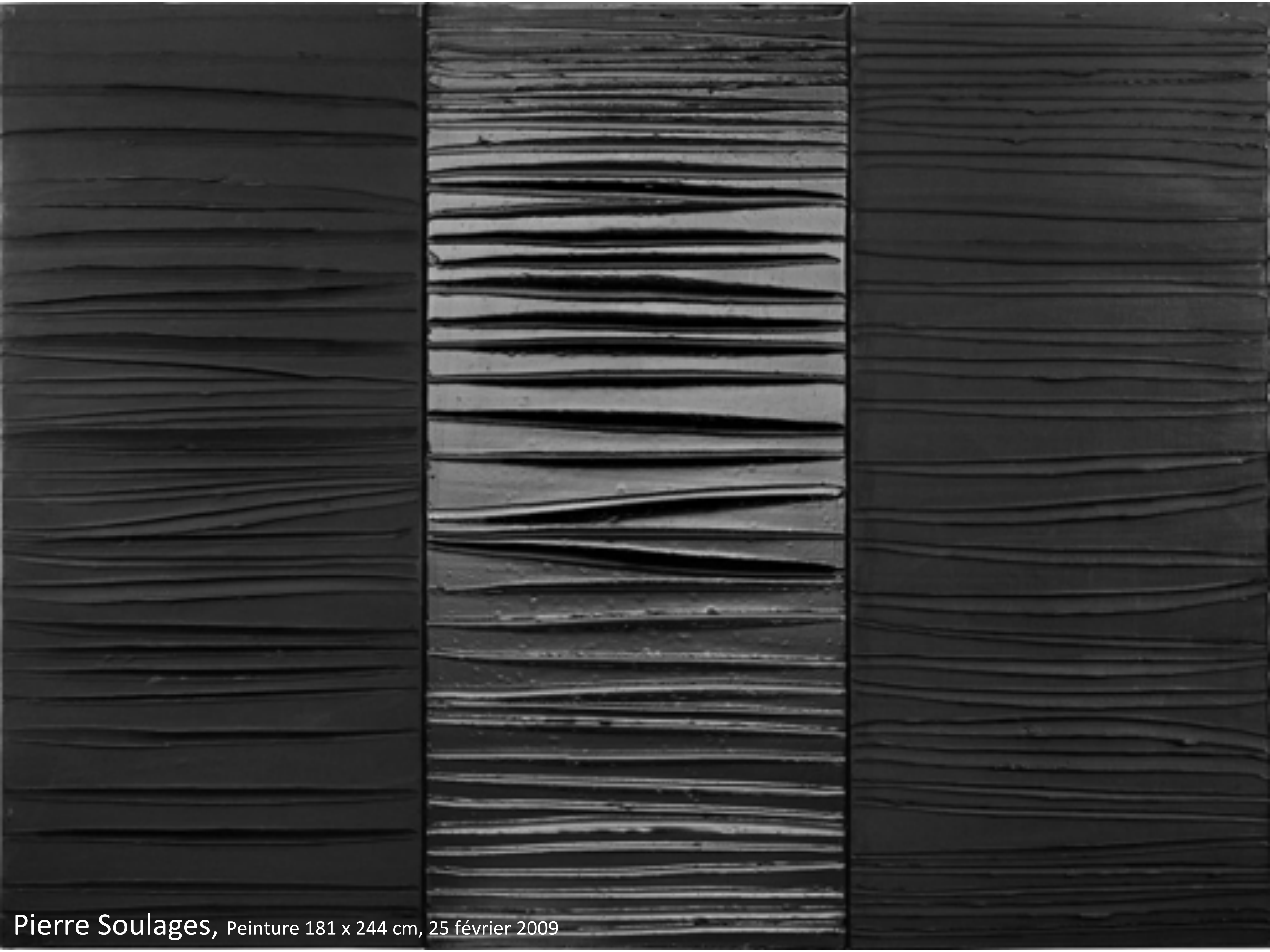
Fig. 1. Looking through one-atom-thick crystals. **(A)** Photograph of a 50-µm aperture partially covered by graphene and its bilayer. The line scan profile shows the intensity of transmitted white light along the yellow line. (Inset) Our sample design: A 20-µm-thick metal support structure has several apertures of 20, 30, and 50 µm in diameter with graphene crystallites placed over them. **(B)** Transmittance spectrum of single-layer graphene (open circles). Slightly lower transmittance for $\lambda < 500$ nm is probably due to hydrocarbon contamination (5). The red line is the transmittance $T = (1 + 0.5\pi\alpha)^{-2}$ expected for two-dimensional Dirac fermions, whereas the green curve takes into account a nonlinearity and triangular warping of graphene's electronic spectrum. The gray area indicates the standard error for our measurements (5). (Inset) Transmittance of white light as a function of the number of graphene layers (squares). The dashed lines correspond to an intensity reduction by $\pi\alpha$ with each added layer.

Nair *et al.*, Science 320, 1308 (2008)

Striations on the thick black paint reflect light, creating the « noir-lumière » ou « outrenoir » (« black-light » or « beyondblack »)



Pierre Soulages Un **Outrenoir** Musée de Rodez, France

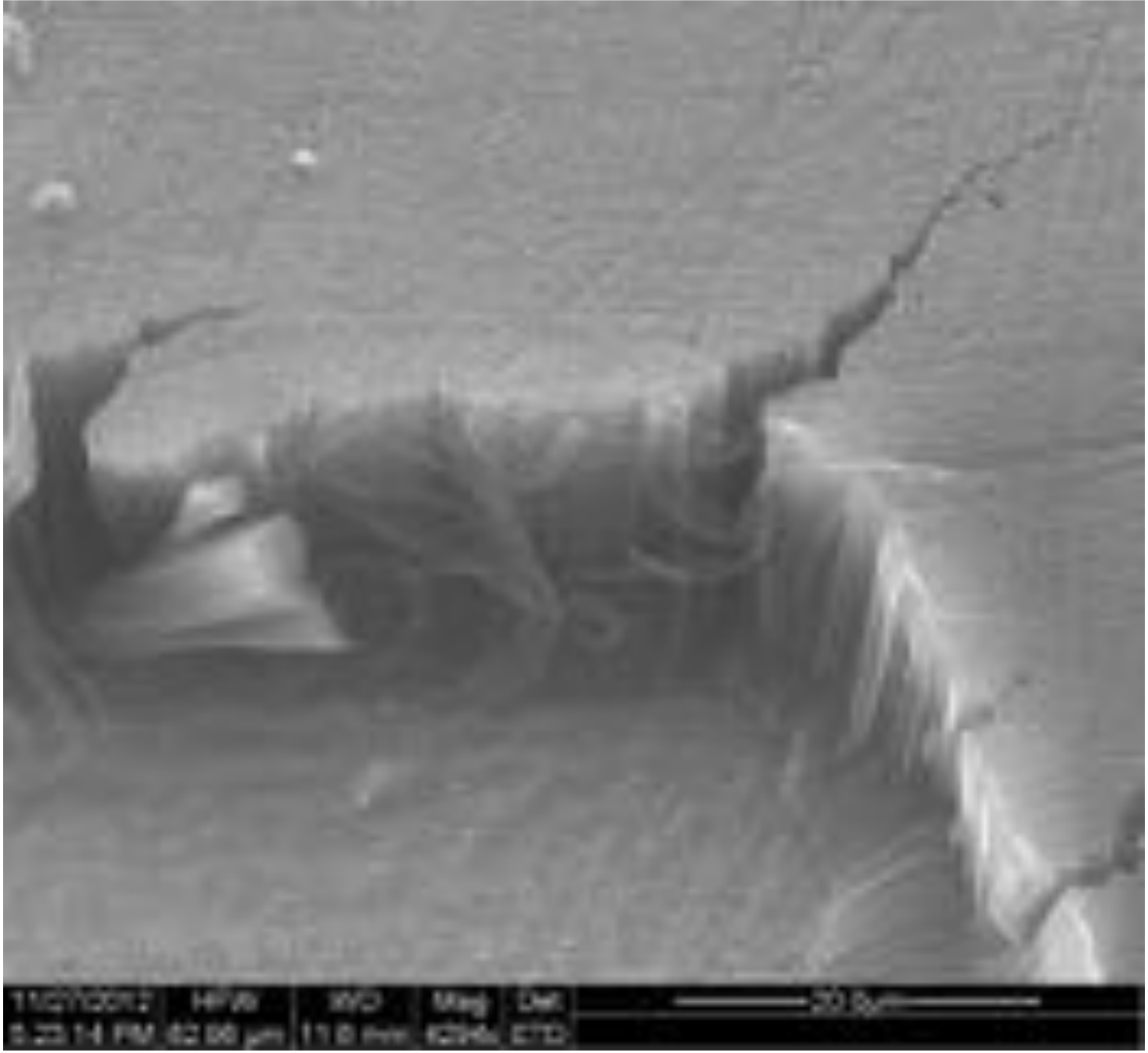


Pierre Soulages, Peinture 181 x 244 cm, 25 février 2009

"Vantablack", a strange and alien material, so black that it **absorbs 99.965 % of visual light**. This "Super Black" is so painfully dark that human eyes struggle to discern its dimension and shape – a phenomenon that gives an impression as though one was looking into a black hole. The never-before-seen dizzying pool of darkness emits practically as much as it absorbs, and thence, is a nearly perfect **Black Body**

Photo : Surrey Nano Systems

Patent bought by artist **Anish Kapoor**



Vertically **A**ligned **N**ano**T**ube **A**rrays create VANTABLACK.
The layer is about 20-30 micrometers high, constituted of nanotubes of about 20 nm in diameter perpendicular to the surface, and their volume density is just about 1% of that of the film

Artist **Anish Kapoor** next to "Descent Into Limbo », a dark pit, roughly 8 feet deep and 10 feet across, painted in Vantablack, the “darkest man-made substance”—a black so black it's not even a color, it's actually a series of nanotubes -that is Kapoor’s medium of choice- it reflects so little light as to give the impression of a bottomless portal into the earth.

A Man Fell Into Anish Kapoor's Black Hole of Art in Portugal

Katherine Cusumano

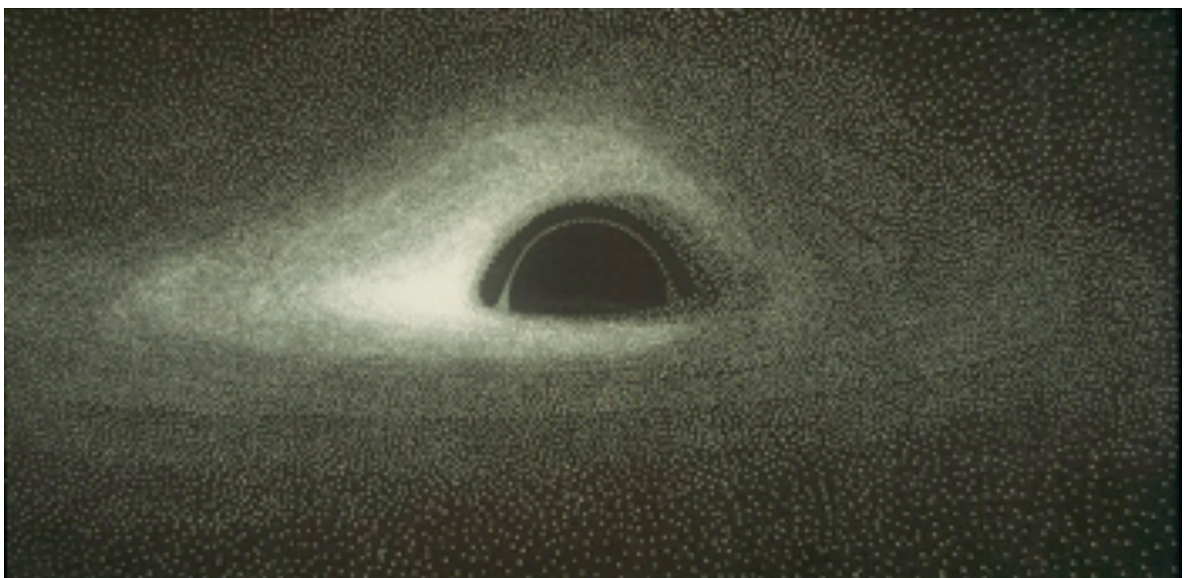
August 20, 2018

Opening of "Anish Kapoor: Work, Thoughts, Experiments" at the Serralves Foundation in Porto, Portugal, July 2018.

https://www.wmagazine.com/story/man-falls-into-anish-kapoor-black-hole-portugal-museum

MIGUEL RIOPA/Getty Images

1rst image of the supermassive black hole (about 6.5 billion times the mass of our Sun) at the center of the Messier 87 galaxy, about 55 million light years from Earth, by the Event Horizon Telescope collaboration Astrophysical Journal Letters, April 2019 https://www.theverge.com/2019/4/10/18303661/first-picture-black-hole-sagittarius-event-horizon-telescope

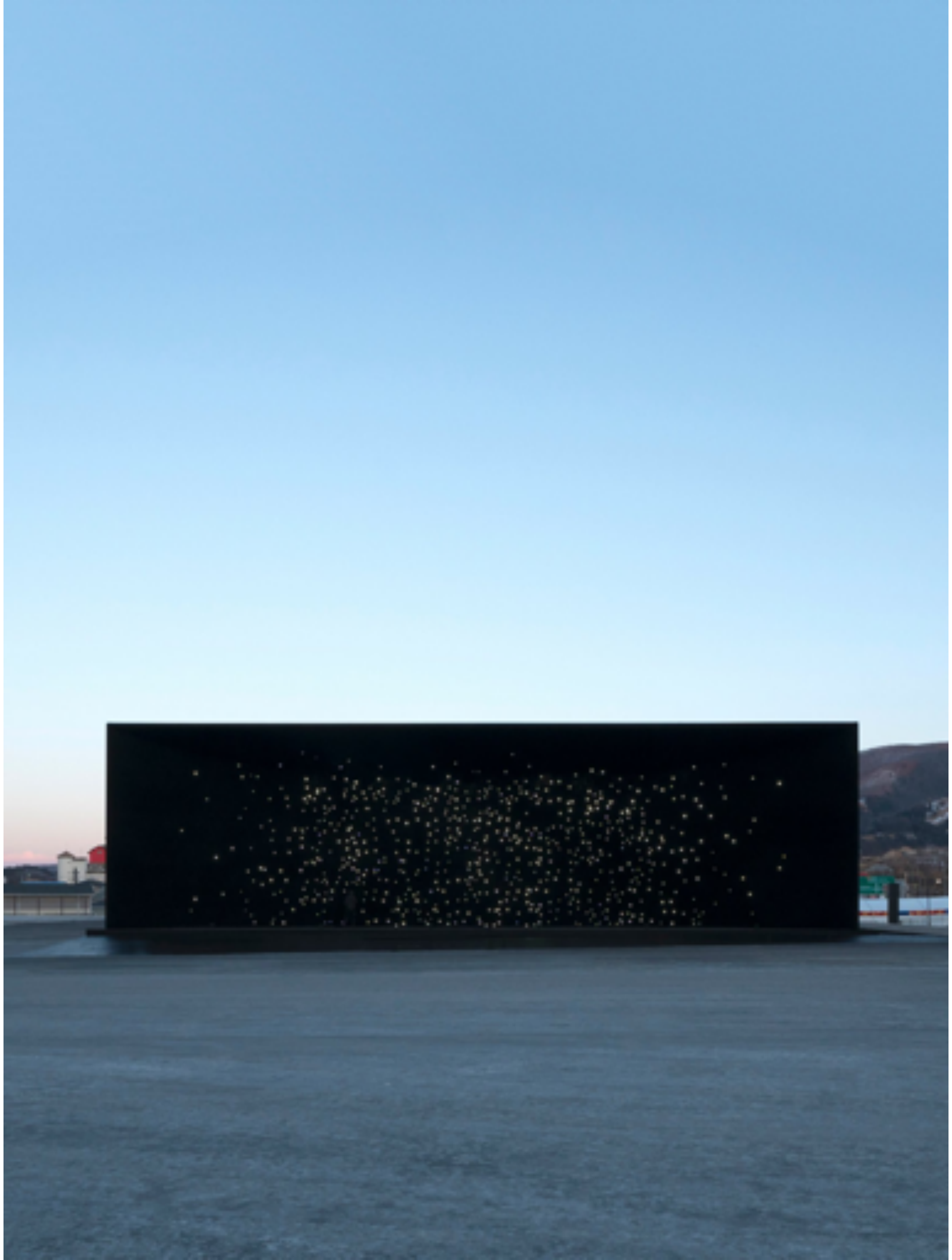


Jean-Pierre Luminet, "Image of a Spherical Black Hole with Thin Accretion Disk," Astronomy and Astrophysics 75 (1979): 228–35

Frederik’De Wilde’s “NanoBlck Sqr #1”

Asif Khan's super-dark Vantablack Hyundai pavilion for
Pyeongchang Winter Olympics 2018 in South Korea

https://www.dezeen.com/2018/02/07/asif-khan-coats-pavilion-super-dark-vantablack-vbx2-pyeongchang-winter-olympics-2018-worlds-darkest-material/



The **Beijing National Aquatics Center**, known as the **Water Cube,** was designed and built for the 2008 Summer Olympics by an international consortium from Australia, England and China.

The Kelvin problem

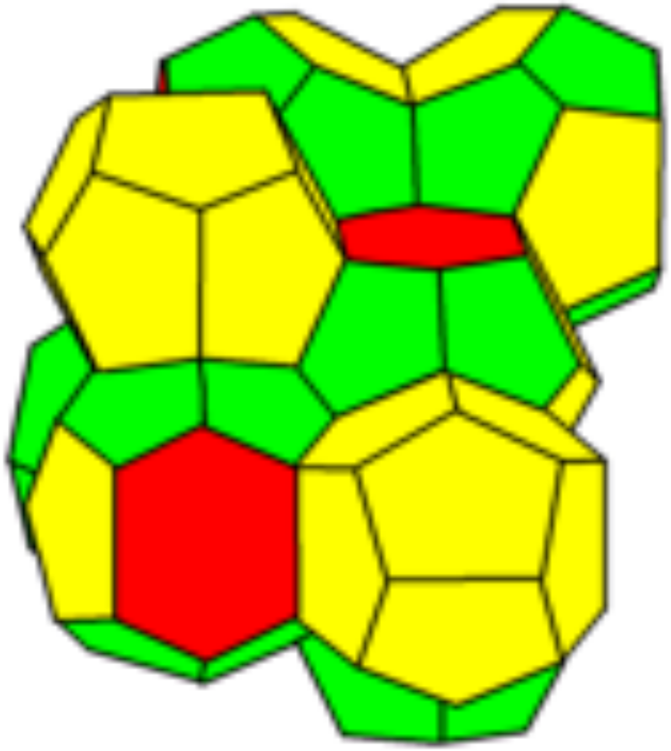
Polyhedral 'foam' by **truncated octahedra**

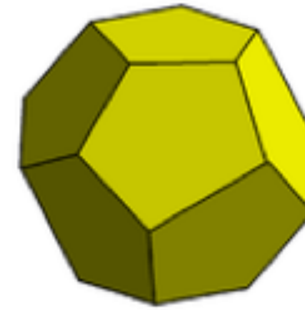
In 1887, Lord Kelvin asked how space could be partitioned into cells of equal volume with the least area of surface between them, i.e., what was the most efficient bubble foam? This problem has since been referred to as the Kelvin problem.

He proposed a foam, based on the bitruncated cubic honeycomb, which is called the Kelvin structure. This is the convex uniform honeycomb formed by the truncated octahedron, which is a 14-faced space-filling polyhedron (a tetradecahedron), with 6 square faces and 8 hexagonal faces. To conform to Plateau's laws governing the structures of foams, the hexagonal faces of Kelvin's variant are slightly curved.

The Kelvin conjecture is that this structure solves the Kelvin problem: that the foam of the bitruncated cubic honeycomb is the most efficient foam. The Kelvin conjecture was widely believed, and no counter-example was known for more than 100 years, until it was disproved by the discovery of the Weaire–Phelan structure.

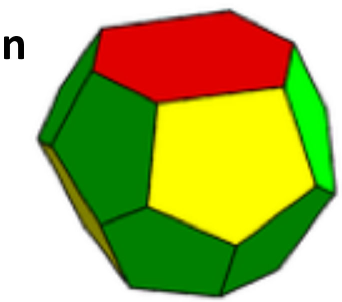
The Weaire–Phelan structure differs from Kelvin's in that it uses two kinds of cells, although they have equal volume. From a topological and symmetrical point of view, one is a **pyritohedron**, an irregular dodecahedron with pentagonal faces, possessing tetrahedral symmetry (Th).





The second is a form of truncated hexagonal trapezohedron, a species of **tetrakaidecahedron** with two hexagonal and twelve pentagonal faces, in this case only possessing two mirror planes and a rotoreflection symmetry.

Tetrakaidecahedron

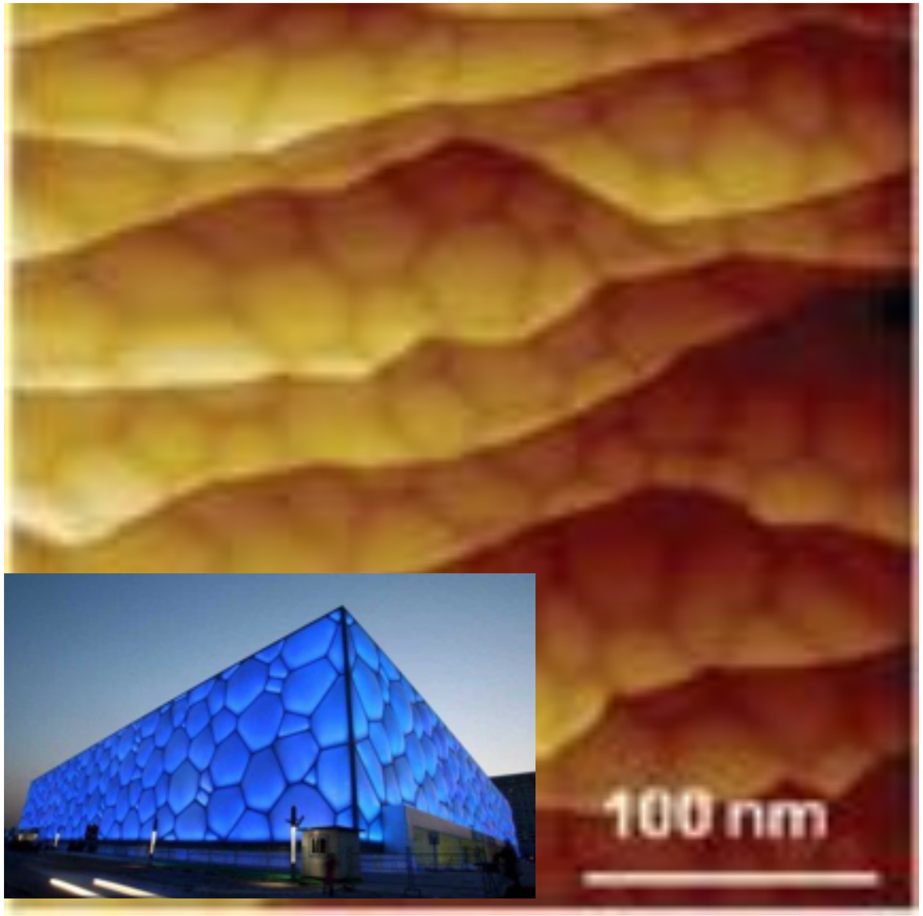


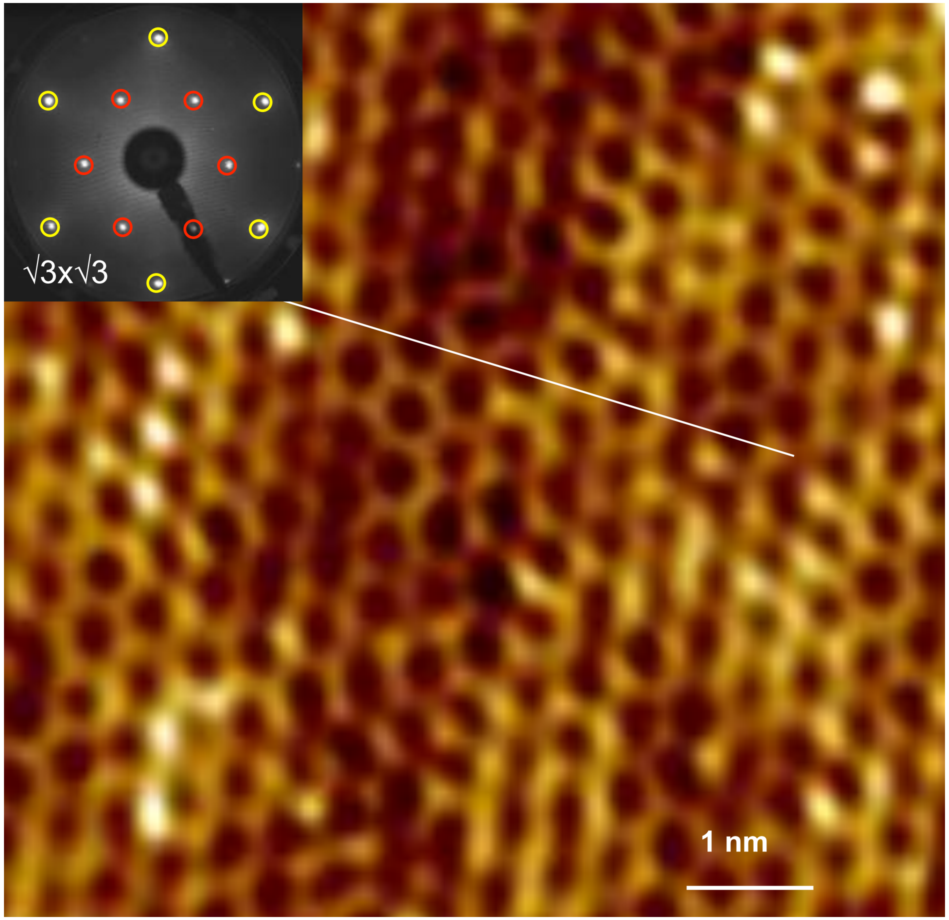
Like the hexagons in the Kelvin structure, the pentagons in both types of cells are slightly curved**. The surface area of the Weaire–Phelan structure is 0.3% less than that of the Kelvin structure.**

It has not been proved that the Weaire–Phelan structure is optimal.


50 nm

Plumbene: Silicene's Heaviest Cousin





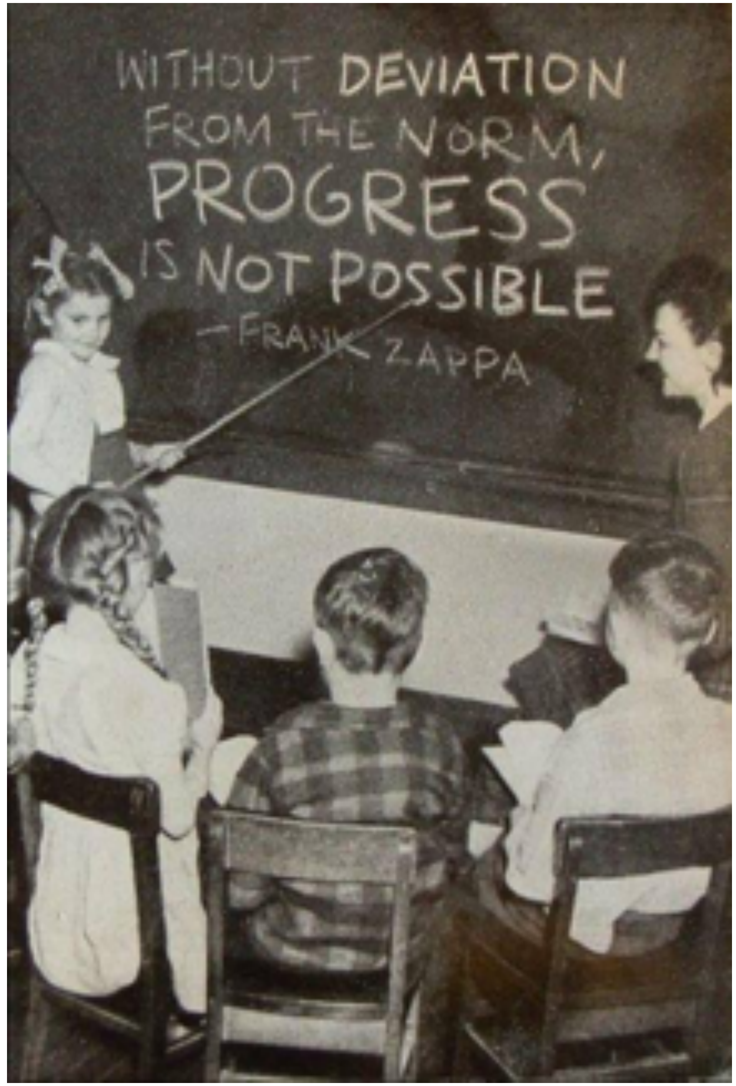
Graphene's Latest Cousin: Plumbene Epitaxial Growth on a "Nano WaterCube"

J. Yuhara,… G. Le Lay, Adv. Mat., 1901017 (2019) ; **Realization:** Pb/Pd(111)

2D topological superconductor?

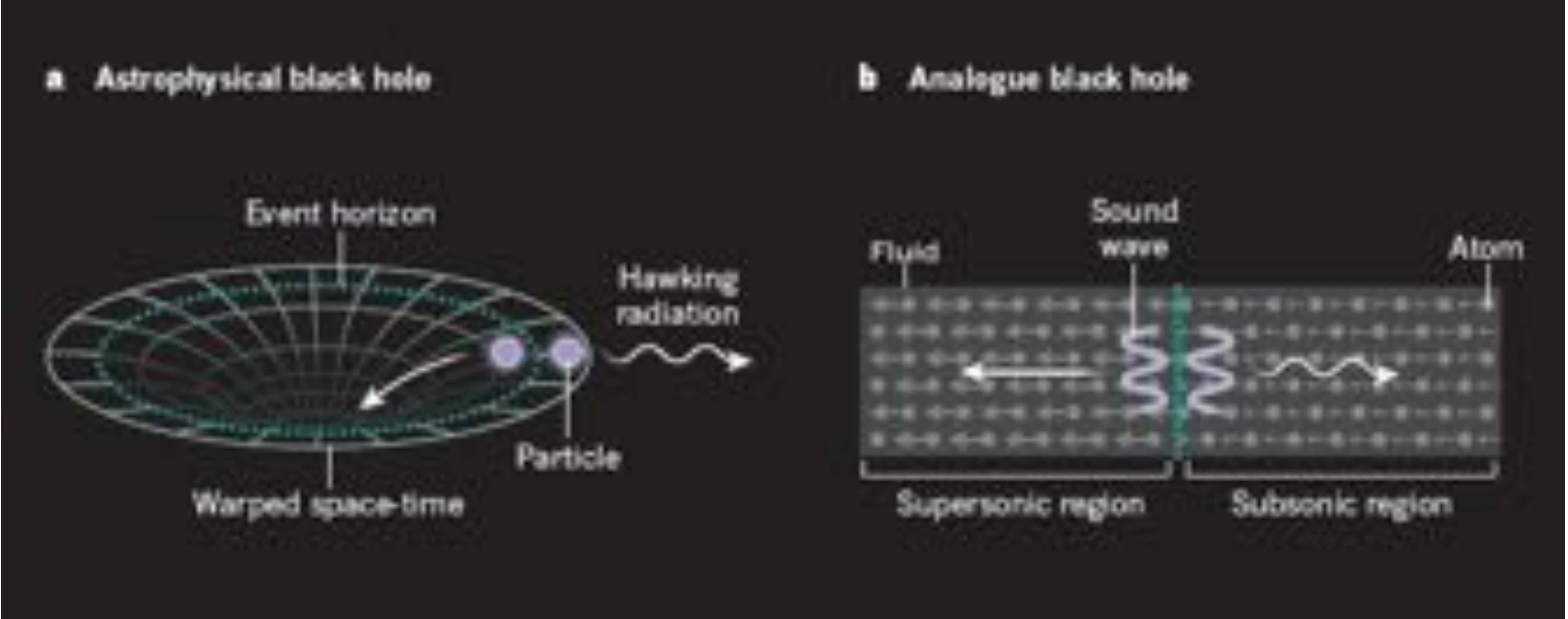
Zhang *et al.*, Chem. Phys. Lett. 712 (2018) 78

To conclude



"Nothing is more difficult than catching a black cat in a dark room, above all if it is not inside".

Confucius



Modelling black holes in the laboratory. a, An astrophysical black hole is characterized by an extremely warped region of space-time. In the 1970s, Stephen Hawking studied what happens when a pair of particles is produced from the vacuum of space near a black hole's event horizon, ie. the boundary beyond which nothing can escape. He found that one of the particles would be absorbed by the black hole, and the other would be emitted into space in the form of thermal radiation, which is now called Hawking radiation. b, de Nova *et al*. Nature 569, 688 (2019) report observations of an analogue black hole, which is based on a flowing fluid of ultracold atoms. One region of the fluid travels at a supersonic speed and a connected region travels at a subsonic speed; sizes of grey arrows indicate speed. The boundary between these regions provides an analogue black-hole event horizon. When a pair of sound waves is produced near this boundary, one of the waves is absorbed into the supersonic region, and the other is emitted away from the region in the form of Hawking radiation.

Stephen Hawking and William Unruh

Hawking radiation (1974)
Black holes emit near the event horizon a black body radiation at a temperature (the Hawking temperature) inversely proportional to its mass.
Alternatively, imagine a quantum field in its vacuum state, in the space-time surrounding a star. When the latter collapses to a black hole, the state of the quantum field changes and evolves into a thermal state at the Hawking temperature.

Unruh radiation (1976)
Close to a black hole, the radiation is predominantly Unruh; further away, it is predominantly Hawking. Unruh radiation is observed by a detector when it is placed in a state of uniform acceleration, whereas if the same detector is at rest or in a state of uniform motion, no radiation is observed. *The Unruh radiation in the case of uniform acceleration is like a black body with a temperature proportional to the acceleration*. The relevance to black holes is that, close to a black hole, the geometry of a spherical black hole can be transformed so that it looks like that of a uniformly accelerated object.
John Bell suggested that Unruh radiation might be observed in an electron storage ring.

After S. De Bièvre

THE HAWKING EFFECT (1974) Black holes emit a black body radiation at a temperature (the Hawking temperature) inversely proportional to its mass. Alternatively, imagine a quantum field in its vacuum state, in the space-time surrounding a star. When the latter collapses to a black hole, the state of the quantum field changes and evolves into a thermal state at the Hawking temperature.

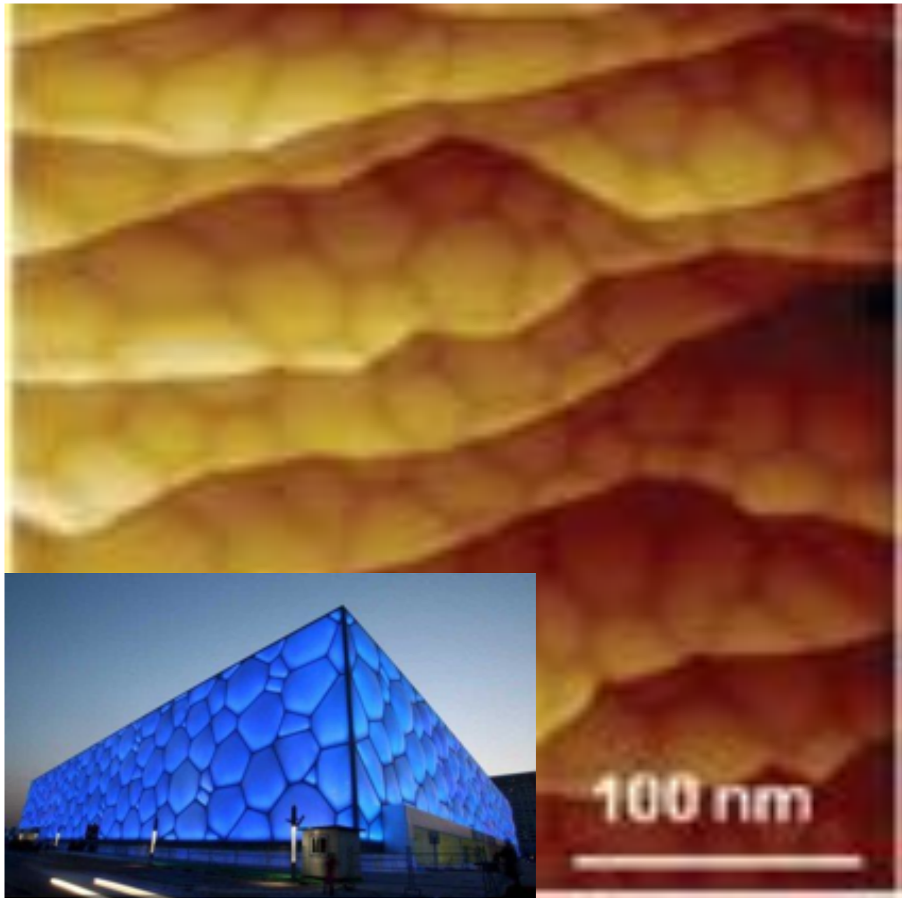
THE UNRUH EFFECT (Unruh 1976) The conceptually and technically difficult Hawking effect deals with quantum fields in strong gravitational fields. Unruh asked a related, simpler question: since according to the equivalence principle, gravitation and acceleration are two sides of the same coin, he wondered:

“How does a vacuum field look to an accelerated (rather than inertial) observer? Or, similarly, what happens if a detector is accelerated through a vacuum field?”

Answer: When a detector, coupled to a relativistic quantum field in its vacuum state, is uniformly accelerated through Minkowski spacetime, with proper acceleration a, it registers a thermal black body radiation at temperature

$$T = \frac{\hbar a}{2\pi c k_{\rm B}} \sim 10^{-19} a$$

In other words, it perceives a thermal bath of particles.


100 nm

Blacker than black: the material is so dark it appears as a black hole to the human eye.