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Beauty in Particle Physics

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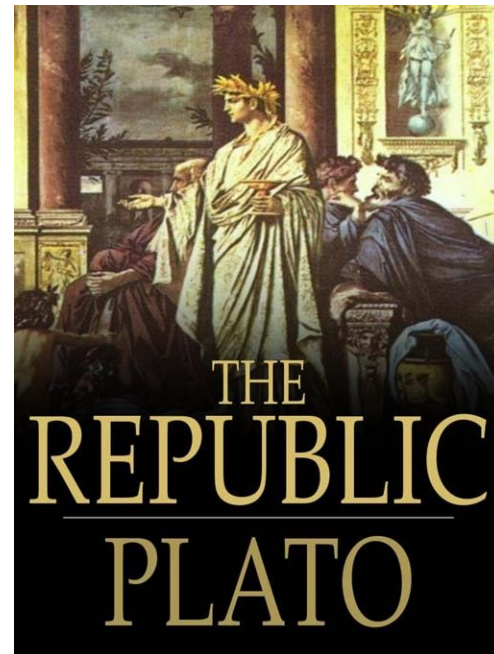
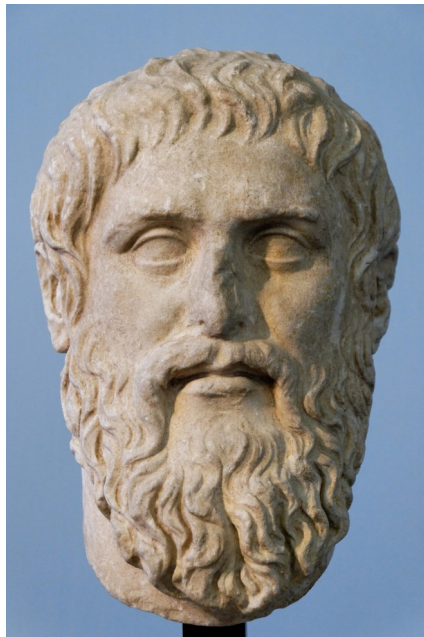
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Plato:

*Goal of education is to teach us love
what is beautiful*

(Republic, 375 B.C.)



Ode on a Grecian Urn



John Keats:

"Beauty is truth, truth beauty," – that is all
Ye know on earth, and all ye need to know.



Jesus Zamora Bonilla divides scientists and science philosophers into

1. Platonists (ultimate explanation of the Universe must possess beauty)

2. Sceptics (scientific research has nothing intrinsic to do with beauty)

Particle physicists and mathematicians

Scientists from other fields

Proponents of beauty

Henri Poincare: “The Scientist does not study nature because it is useful to do so. He studies it because he takes pleasure in it; and he takes pleasure in it because it is beautiful”

Richard Feynman: “You can recognize truth by its beauty and simplicity. When you get it right, it is obvious that it is right - because usually what happens is that more comes out than goes in”

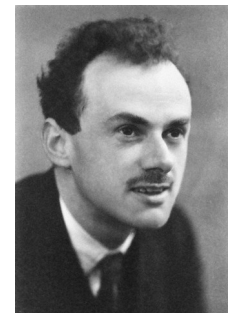
Frank Wilczek: “My work has been guided by trying to make the laws more beautiful”

Beauty as important as truth

Hermann Weyl: “In my work, I have always tried to unite the true with the beautiful; but when I had to choose one or the other, I usually chose the beautiful”

Paul Dirac: “it is more important to have beauty in one’s equations than to have them fit experiment”

Beauty more important than truth?



Proponents of beauty

Gian Giudice: “When you stumble on a beautiful theory you have the same emotional reaction that you feel in front of a piece of art.”

Steven Weinberg: “The horse breeder looks at a horse and says ‘That’s a beautiful horse.’ While he may be expressing an aesthetic emotion, I think he knows that that’s the kind of horse that wins races.”

Frank Wilczek: “having tasted beauty at the heart of the world, we hunger for more. In this quest, I think, there is no more promising guide than beauty itself.”

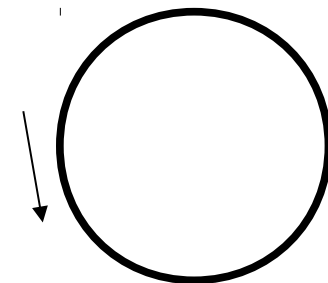


Beauty criteria

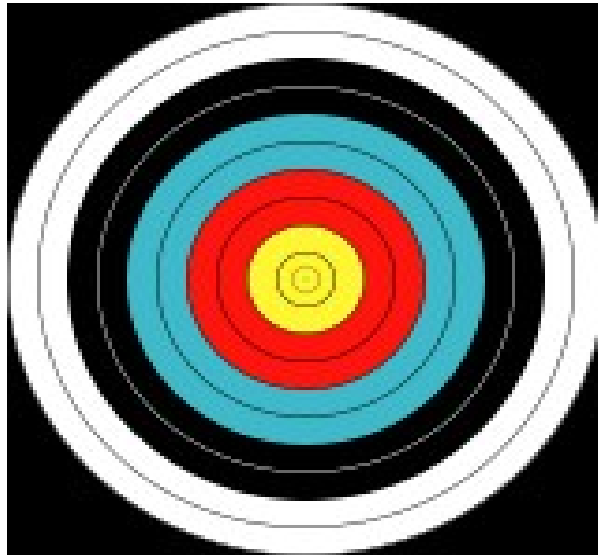
Frank Wilczek:

1. *Productivity*, getting out more than you put in: The more phenomena one can explain with less equations, the more beautiful the theory is.
2. *Symmetry*. According to Wilczek it's change without change. "You can make changes in physical objects or changes in the laws that could change them but don't".

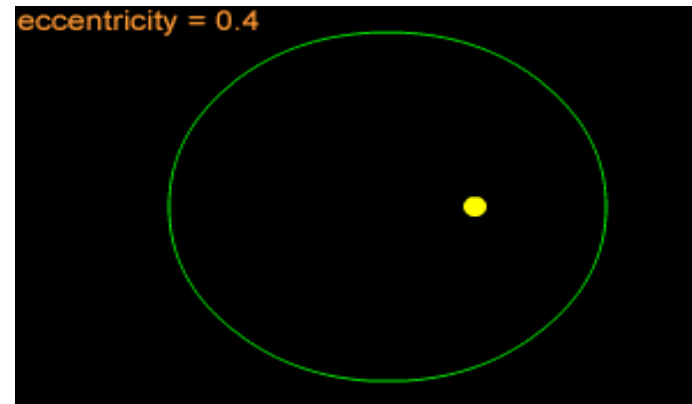
Circular symmetry



Circular symmetry and Newton's theory



Greeks: planetary orbits are circular



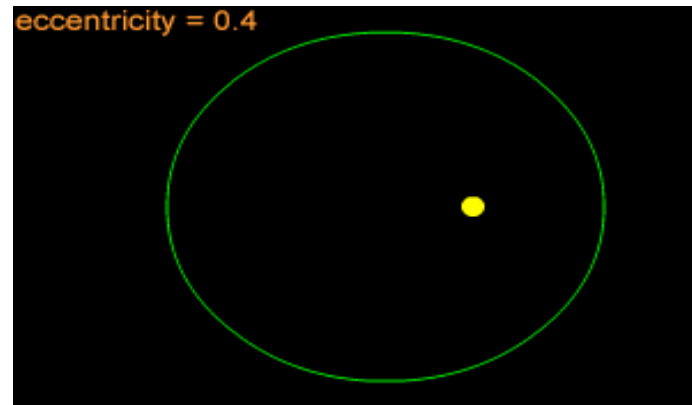
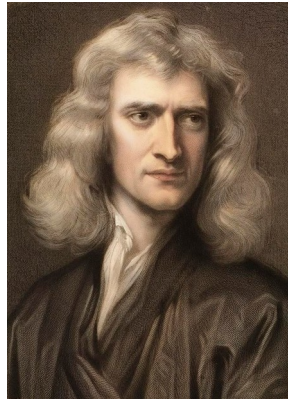
Kepler: planetary orbits are not circular!

Newton's gravitational law

$$F = G \frac{m_1 m_2}{r^2}$$

Important lesson: symmetry does not apply to the orbits (the solutions of the gravitational law), but to the law itself.

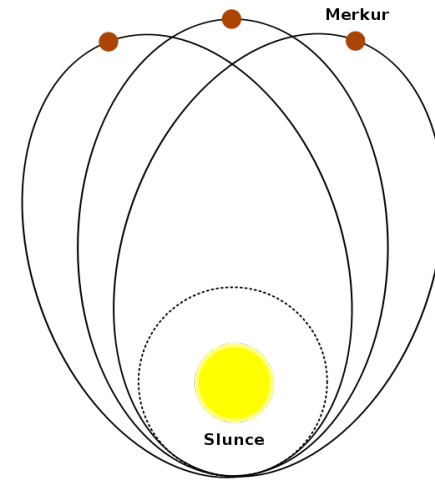
There can be many solutions to the law, some beautiful, some less so, but the law behind is one and it is beautiful.



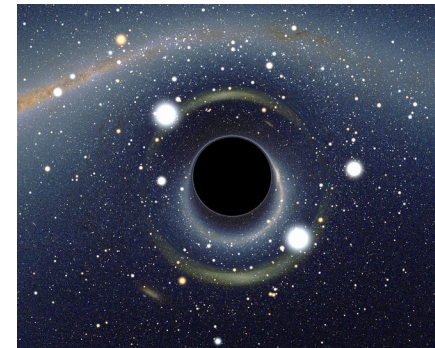
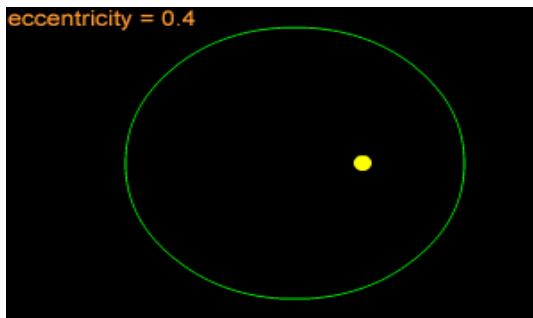
$$F = G \frac{m_1 m_2}{r^2}$$

Landau & Lifshitz 1975: "...the general theory of relativity ... represents probably the most beautiful of all existing physical theories."

$$F = G \frac{m_1 m_2}{r^2}$$



Anomalous precession of Mercury's perihelion



Black holes

General relativity

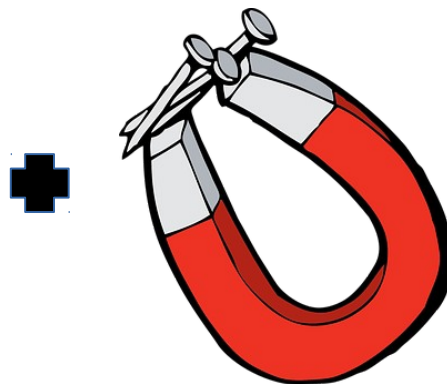
$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Maxwell's equations

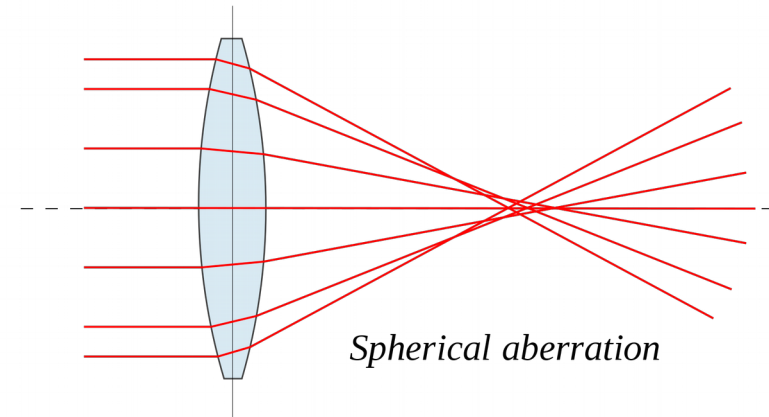
$$\begin{aligned}\nabla \cdot \vec{E} &= \frac{\rho}{\epsilon_0} \\ \nabla \cdot \vec{B} &= 0 \\ \nabla \times \vec{E} &= -\frac{\partial \vec{B}}{\partial t} \\ \nabla \times \vec{B} &= \mu_0 \vec{J} + \frac{1}{c^2} \frac{\partial \vec{E}}{\partial t}\end{aligned}$$



electricity

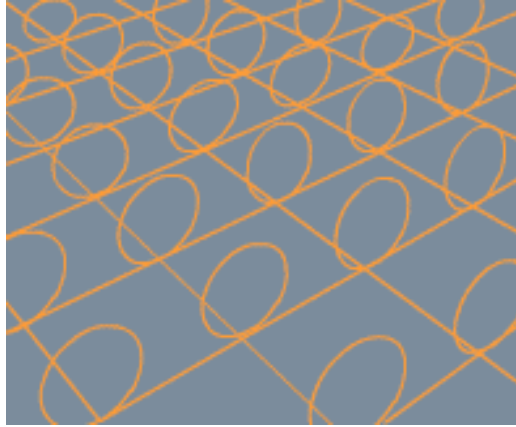


magnetism



optics

Gauge symmetry and Quantum Electrodynamics



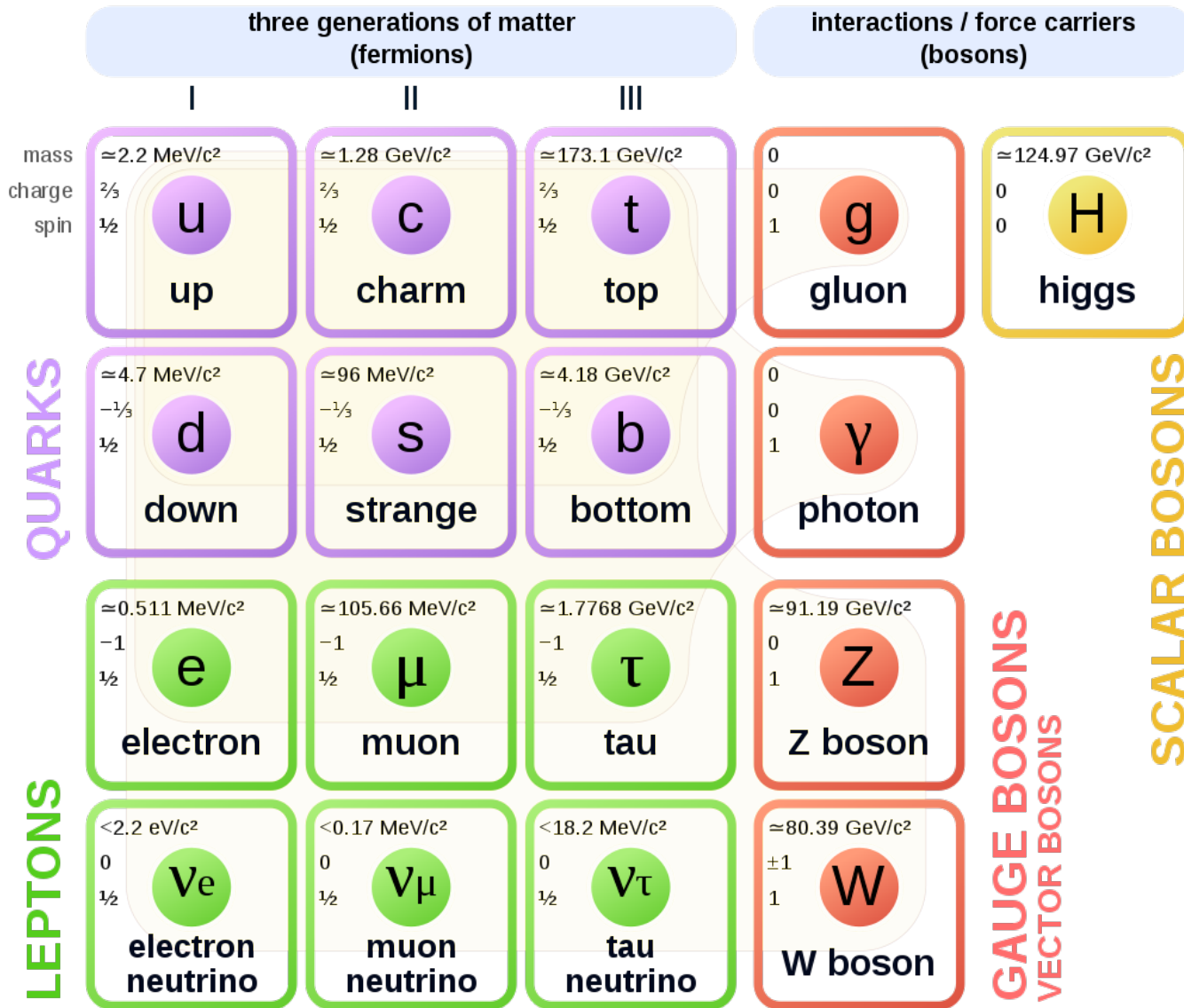
$$\mathcal{L} = \bar{\psi}(i\gamma^\mu D_\mu - m)\psi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$



$$\begin{aligned}\nabla \cdot \vec{E} &= \frac{\rho}{\epsilon_0} \\ \nabla \cdot \vec{B} &= 0 \\ \nabla \times \vec{E} &= -\frac{\partial \vec{B}}{\partial t} \\ \nabla \times \vec{B} &= \mu_0 \vec{J} + \frac{1}{c^2} \frac{\partial \vec{E}}{\partial t}\end{aligned}$$



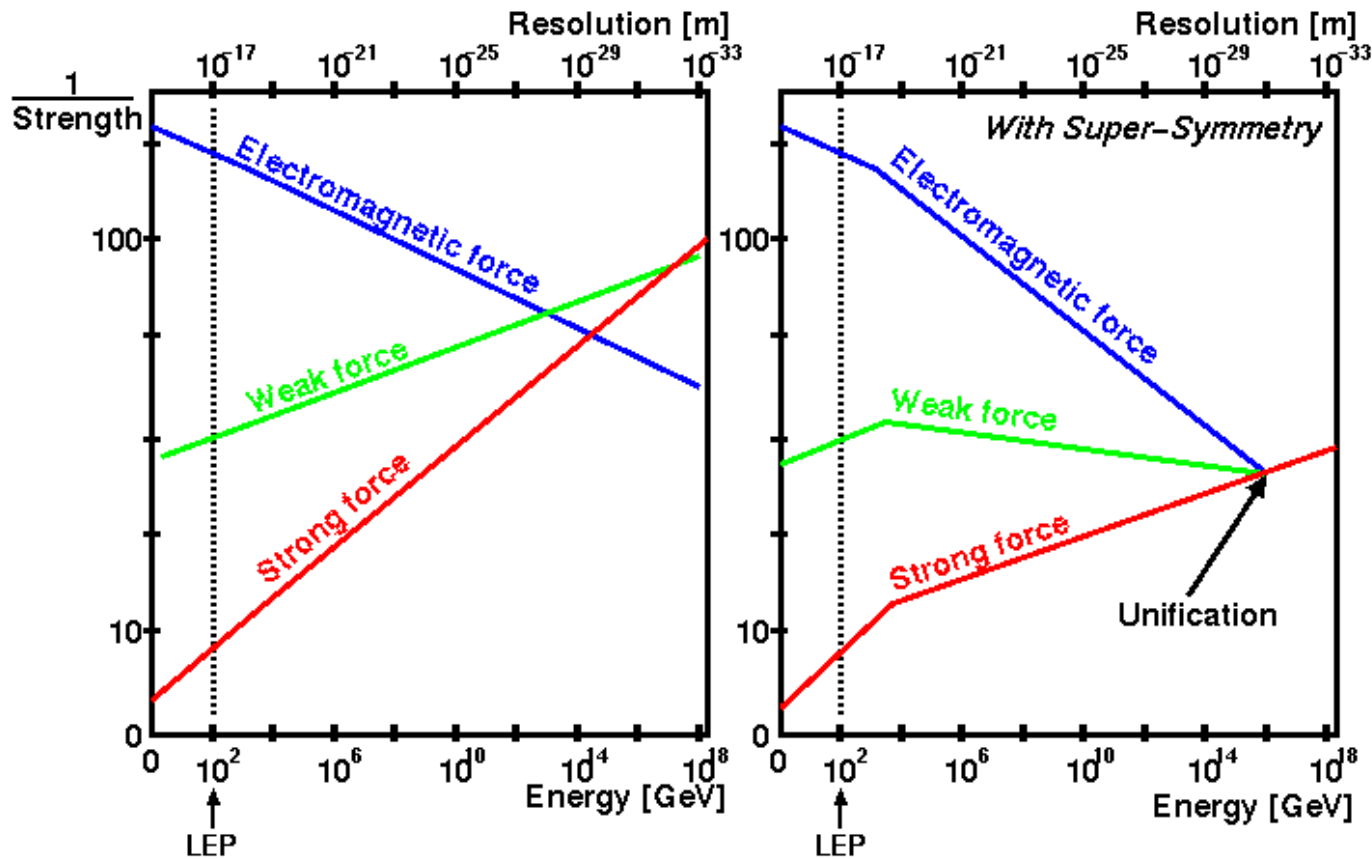
Standard Model of Elementary Particles



$$\begin{aligned}
 \mathcal{L} = & -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\
 & + i\bar{\psi} \not{D} \psi + h.c. \\
 & + \chi_i y_{ij} \chi_j \phi + h.c. \\
 & + |D_\mu \phi|^2 - V(\phi)
 \end{aligned}$$

19 free parameters

S. Weinberg: It's just a guess, but I think we'll get to final theory. And that will be really quite a remarkable turning point in the intellectual history of the human race



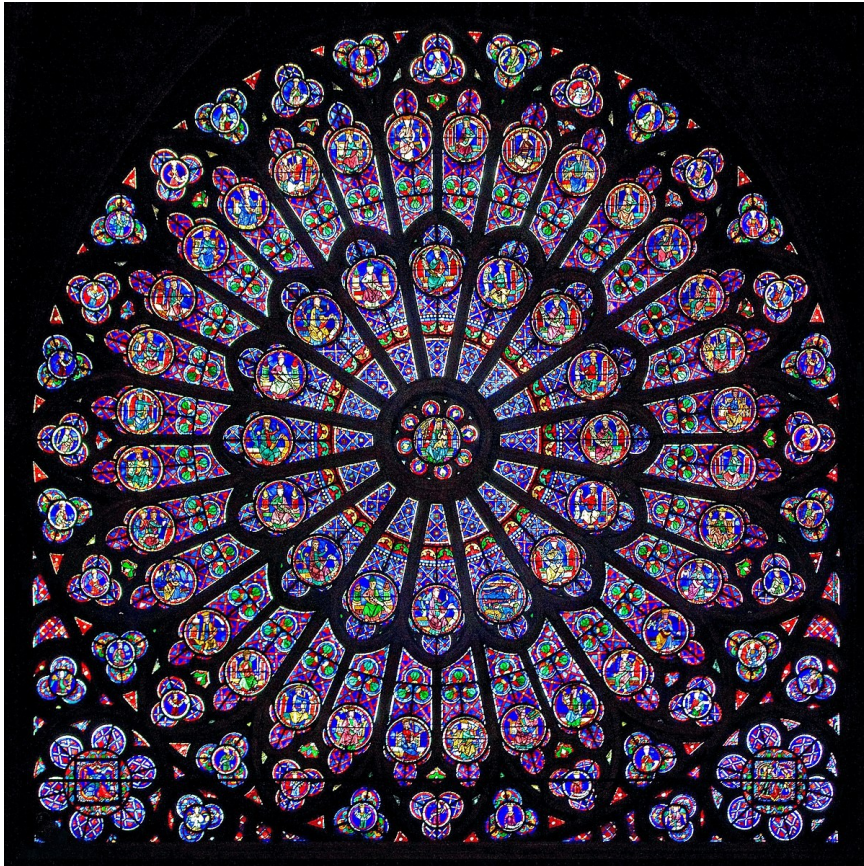
SUSY?

Superstrings?

E8?

???

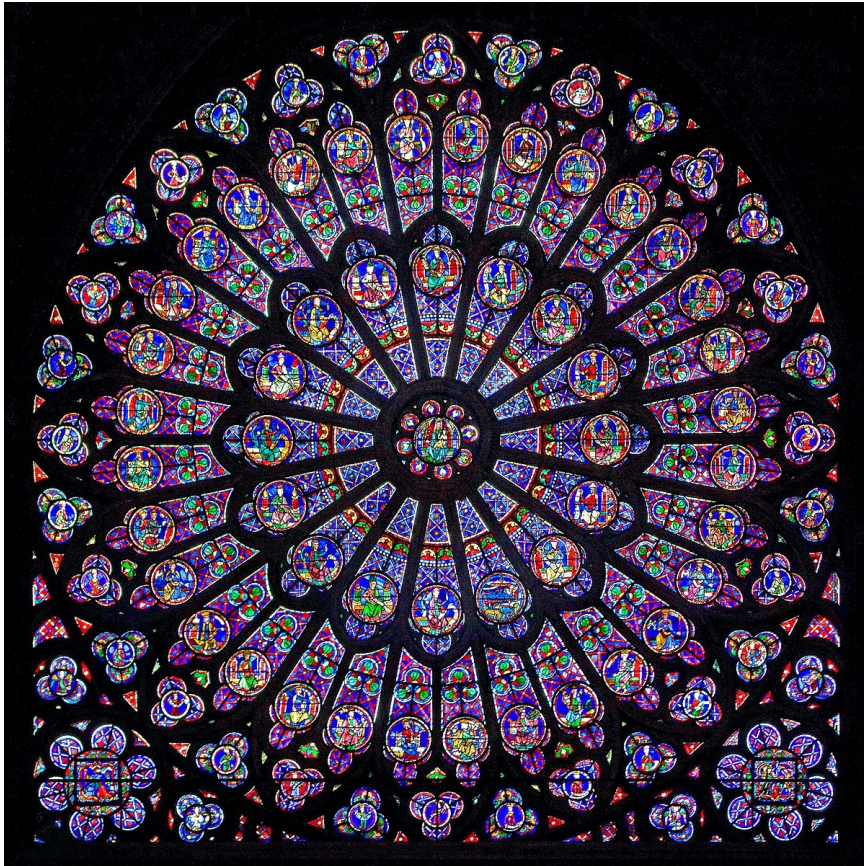
Artistic beauty



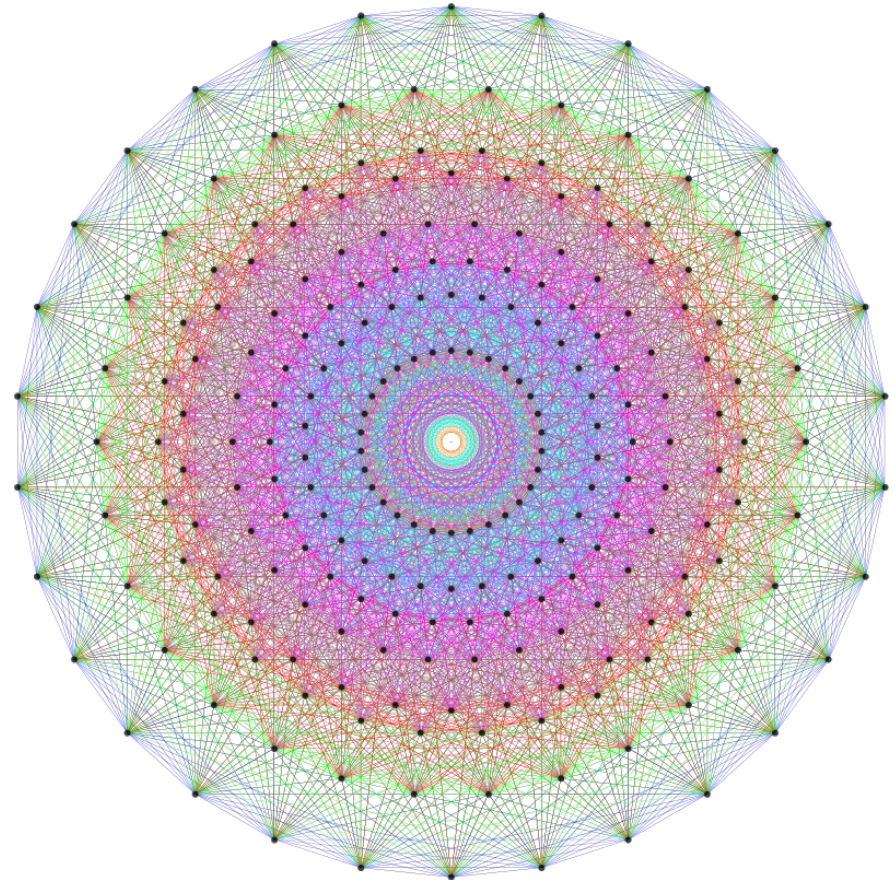
Gothic cathedral window



Jackson Pollock: Autumn Rhythm



Gothic cathedral window



E8 theory

Artistic beauty

Joachim Schummer: by redefining beauty as symmetry one deviates from the dominant tradition in artistic theory.

“There’s a reason why our galleries are not filled with paintings of perfect spheres”.

Ernst Gombrich said that too much symmetry ensures that “once we have grasped the principle of order ... it holds no more surprise”.

Artistic beauty, Gombrich believed, relies on a tension between symmetry and asymmetry.

Philip Ball adds “the field of physics has always been heir to Platonism – the mystical conviction of an orderly cosmos. ... for Plato it was precisely art’s lack of symmetry (and thus intelligibility) that denied it access to real beauty. Art was just too messy to be beautiful.”

