



A Short History of Space

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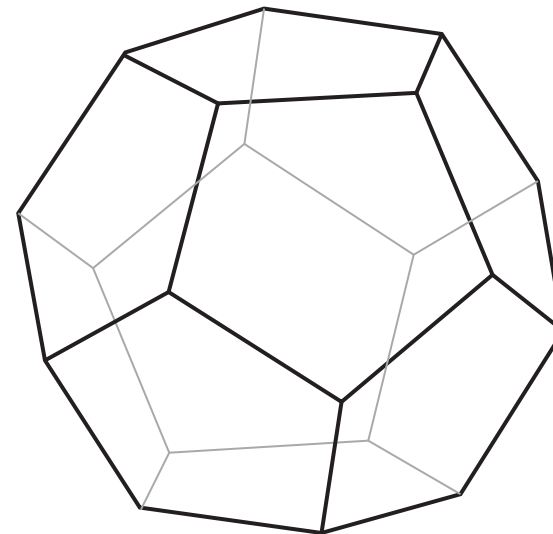
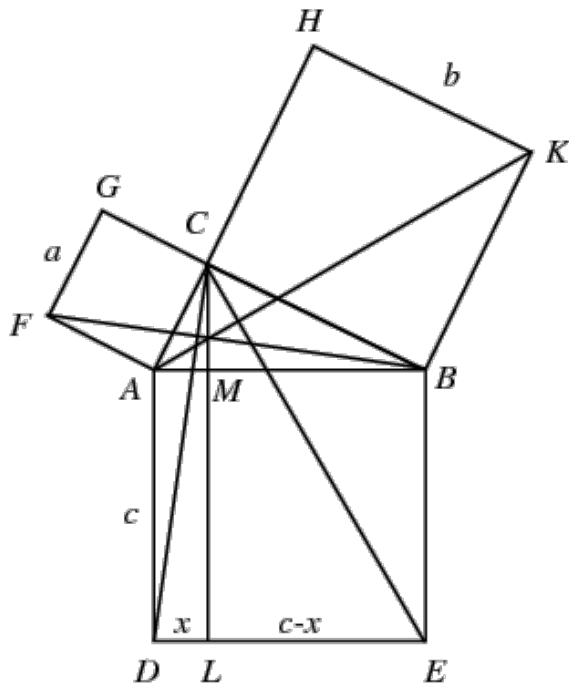
Friends of IHES Gala, 18 November 2014, New York City

Space in Greek Antiquity

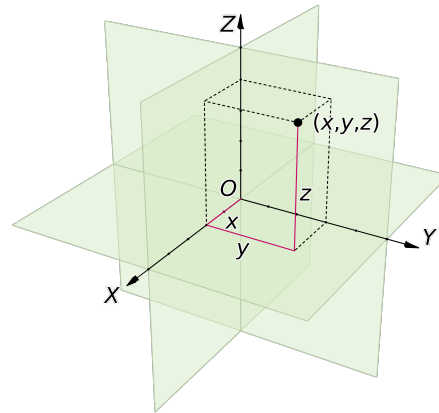
« topos » (place) or « kenon » (the void, cf « Only atoms and the void »)

? At best gaps between material objects rather than our « box space », i.e. the container of all material objects ?

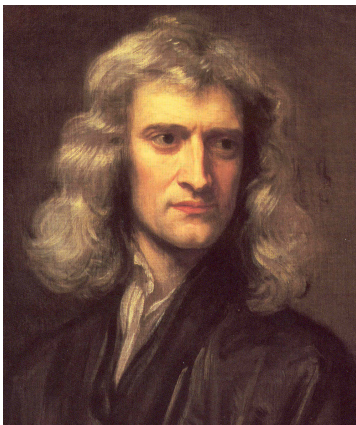
Euclidean geometry : figures rather than space



17th century : Absolute Space



« Although time, space, place and motion are very familiar to everyone, it must be noted that these quantities are popularly conceived solely with reference to the objects of sense perception. And this is the source of certain preconceptions; to eliminate them it is useful to distinguish these quantities into absolute and relative, true and apparent, mathematical and common. [...] Absolute, true and mathematical space remains similar and immovable without relation to anything external»



However, ...

Cabalistic lore + neoplatonism + Henri More → Newton's
« **sensorium Dei** »

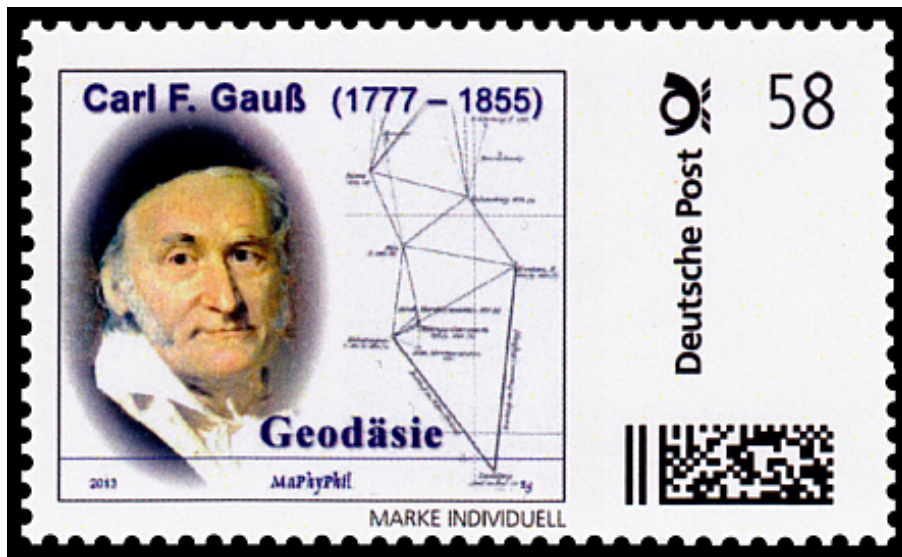
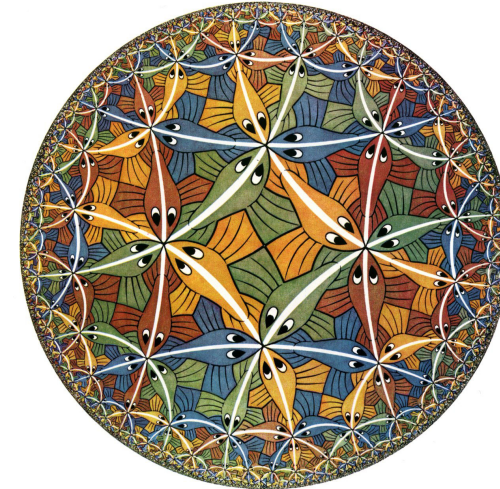
Leibniz : Space is not something that exists, but merely « the order of coexisting things »

Kant : Space is not a thing but a form of intuition, i.e. a condition of the representation of things.

Diderot's Encyclopédie : « Espace : Nous ne prendrons point de parti sur la question de l'espace ; [...] cette question obscure est inutile à la Géométrie & à la Physique. »

19th century : Non-euclidean geometries

~ 1830 Bolyai, Lobachevski



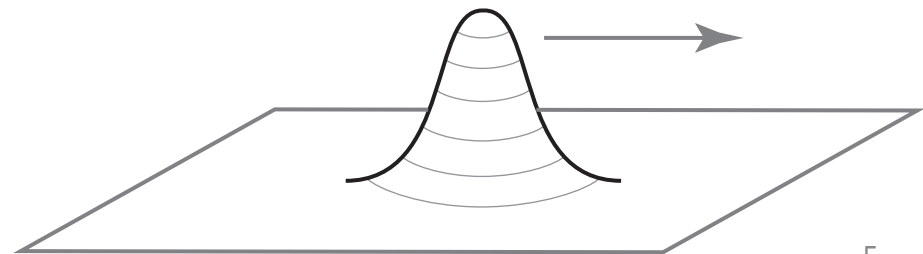
Gauss 1827

Riemann 1854 [1868]

W.K Clifford 1876 :

« On the Space-Theory of Matter »

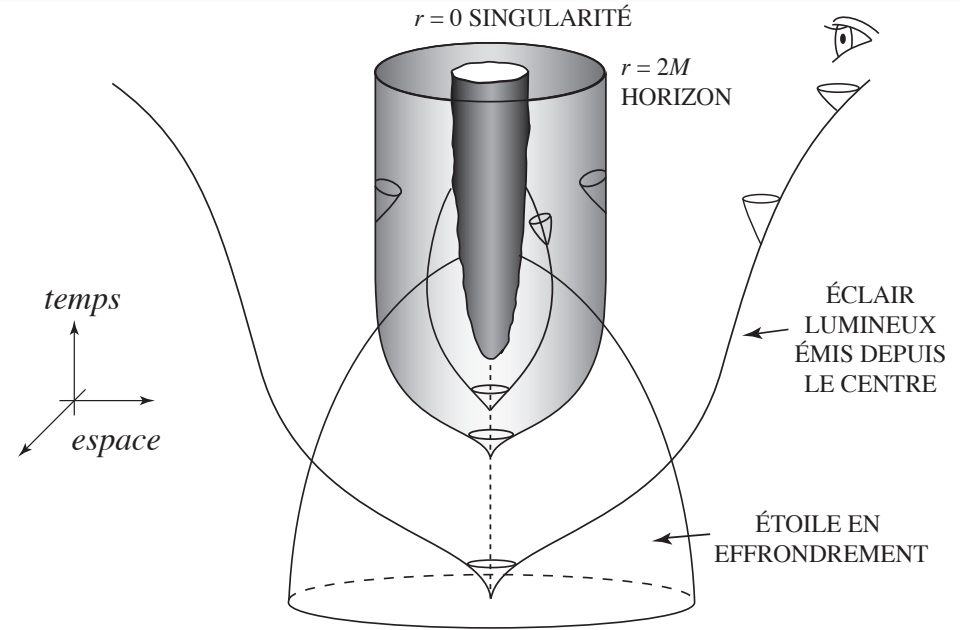
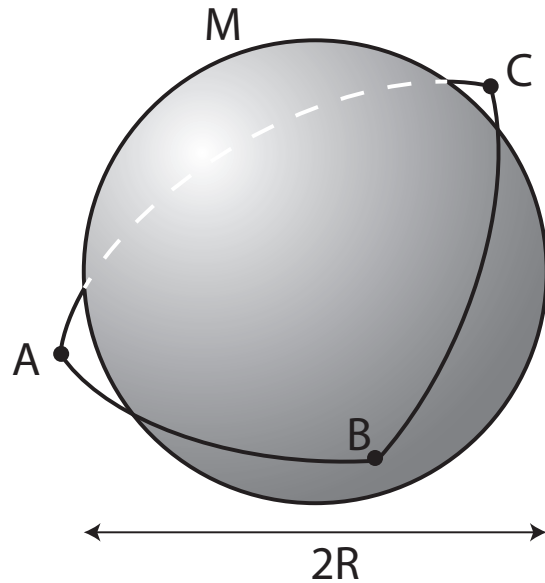
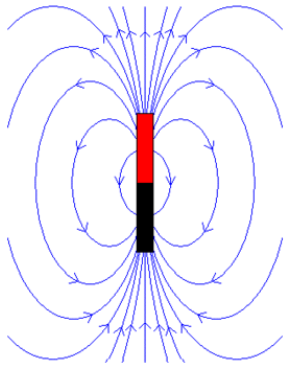
Triangle
Hohenhagen-Inselberg-Brocken



Einstein : space = field

Einstein : « There is no « empty » space, that is there is no space without a field »

Einstein's elastic space-field : $g(x) = \text{geometry} = \text{gravity}$



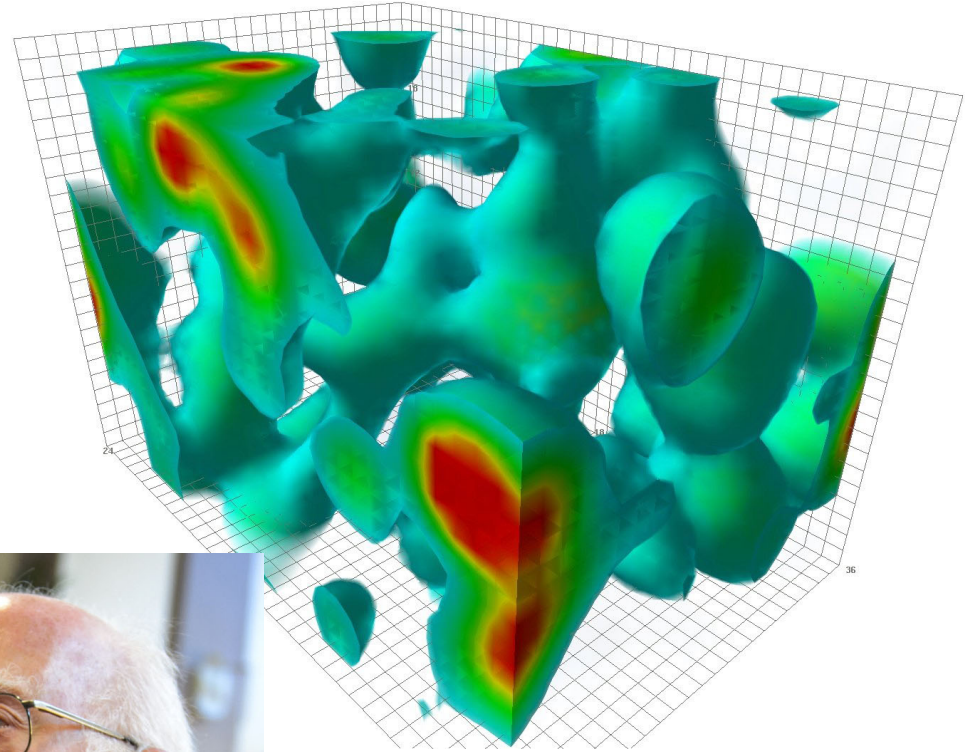
Oppenheimer-Snyder 1939

Black hole interior : big crunch, **rupture** beyond the elastic and plastic limits of space

$$\hat{A} + \hat{B} + \hat{C} \simeq \pi \left(1 + \frac{GM}{c^2 R} \right)$$

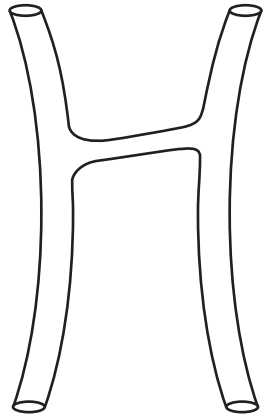
Space and the Quantum

Quantum Chromodynamics
Vacuum fluctuations



Brout-Englert-Higgs
field condensate
 $\langle H \rangle = 246 \text{ GeV}$

Space in String / M theory



Deep unification

string = matter = force = field \ni gravity = geometry

The Einsteinian elasticity of space comes from elastic strings

Cornucopia of elastic objects and their possible configurations
? Emergence of space (e.g. at a big bang) from a condensate of strings (or branes) ?

$$\mathbf{g}^{\text{Einstein}} = \langle \mathbf{g}^{\text{quantum}} \rangle \neq 0$$

?

CONTAINER = CONTENT

?

To conclude : Einstein's last words on Space (1953) :

« It required a severe struggle to arrive at the concept of independent and absolute space, indispensable for the development of theory. It has required no less strenuous exertions subsequently to overcome this concept – a process which is probably by no means as yet completed. »

