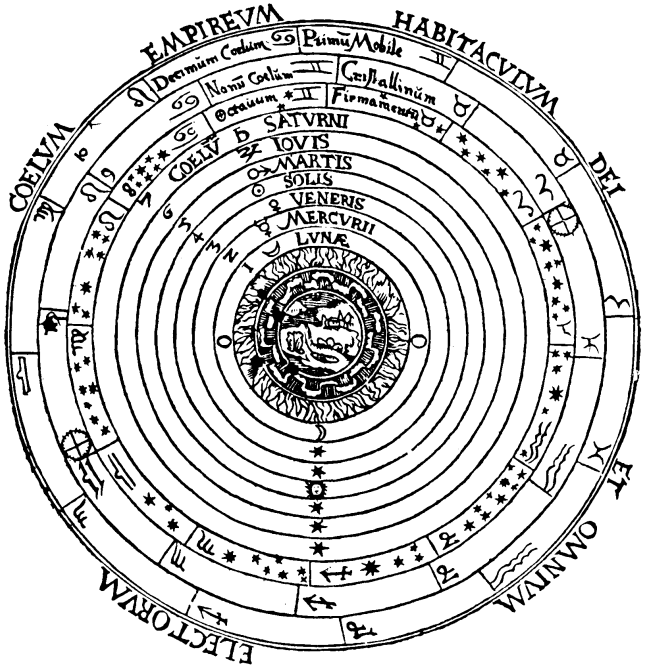
La forme de l'Univers : des trous noirs à l'espace chiffonné

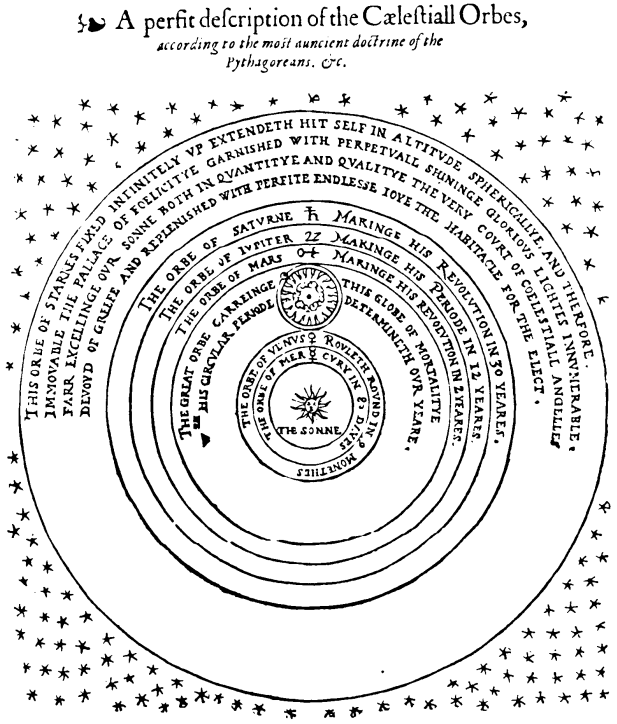
J.-P. Luminet

L.A.M. & CPT

CPPM 11 avril 2015

L'univers des Grecs

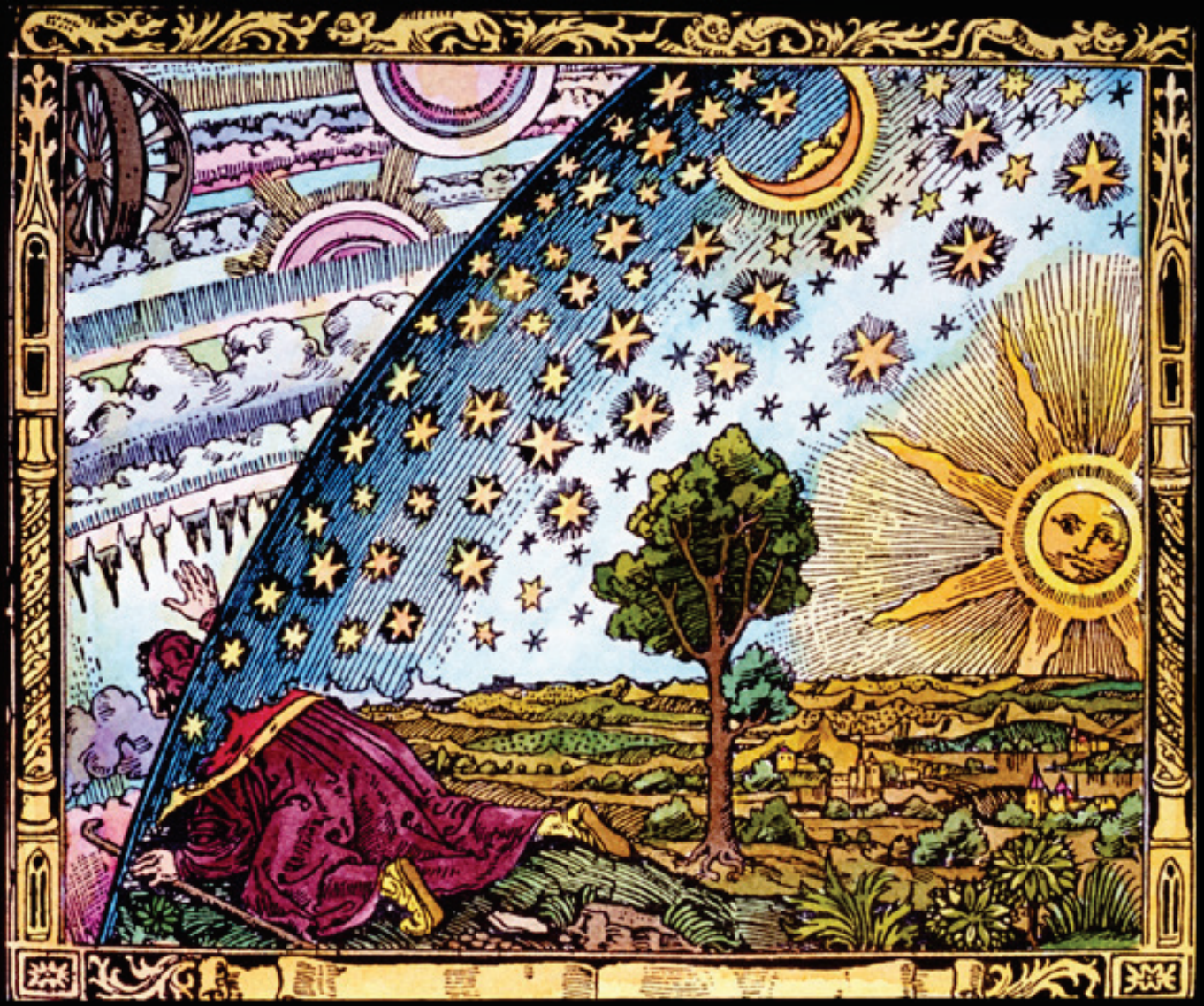




Aristote, Ptolémée (Copernic, Kepler) :
fini

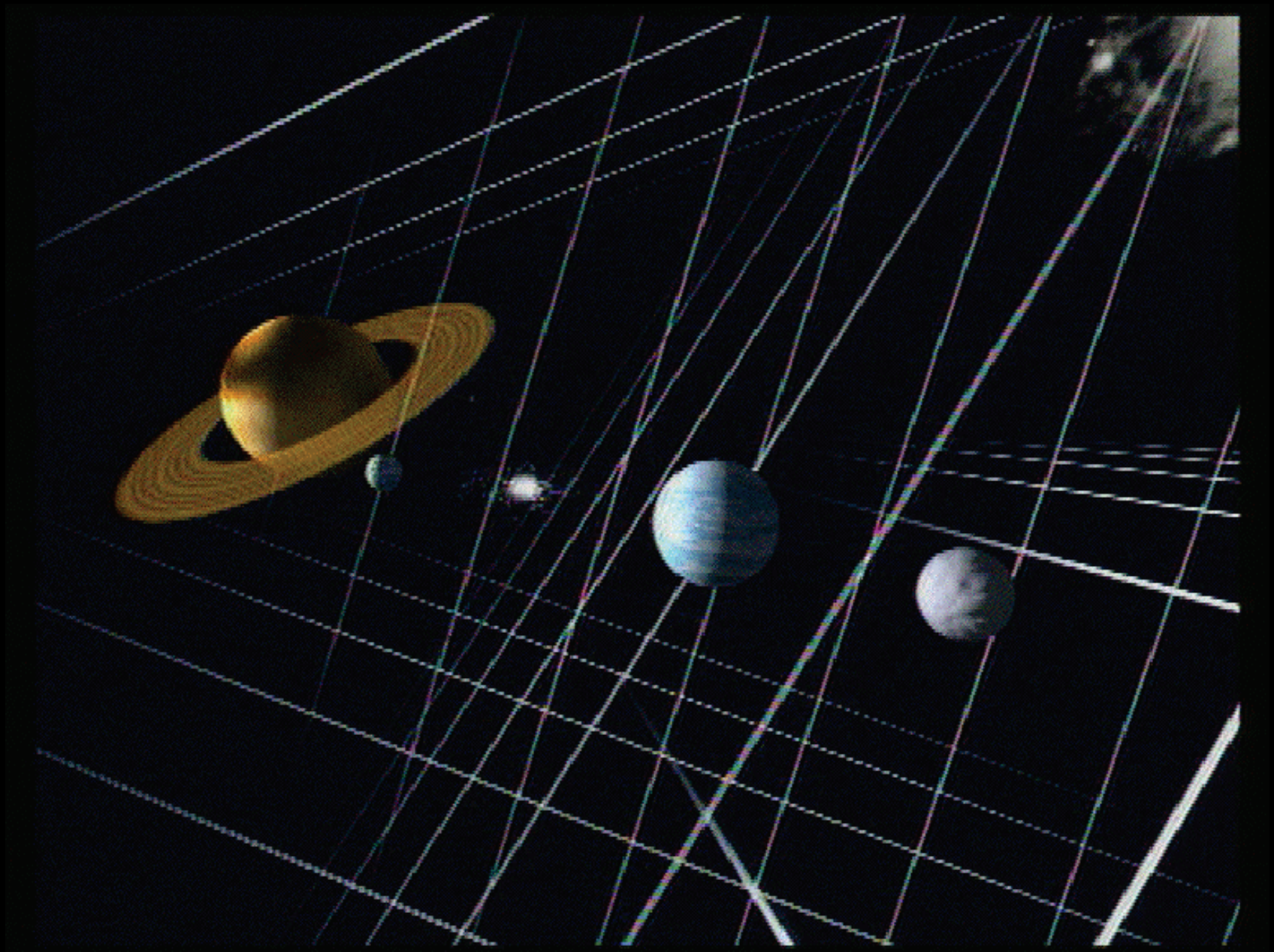
Atomistes (Cuse, Bruno, Descartes) :
infini

Paradoxe du bord

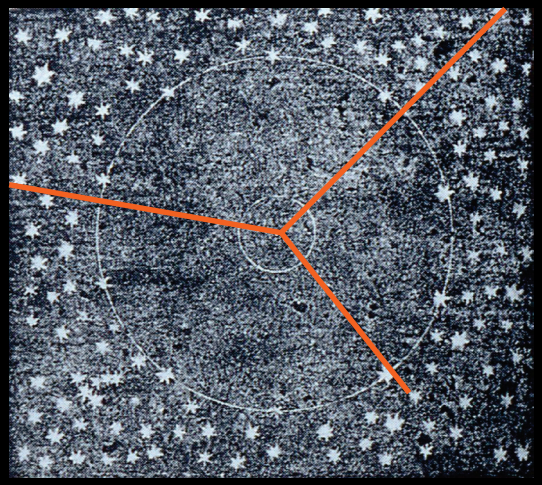


Archytas de Tarente (Ve s. av.JC), Lucrèce (Ier s. av.JC)

XVII^{e} siècle : Espace infini (Newton)



1) Paradoxe de la nuit noire !



Si l'espace était infini (nombre infini d'étoiles) et éternel, alors la nuit serait brillante !

2) Paradoxe de la duplication !

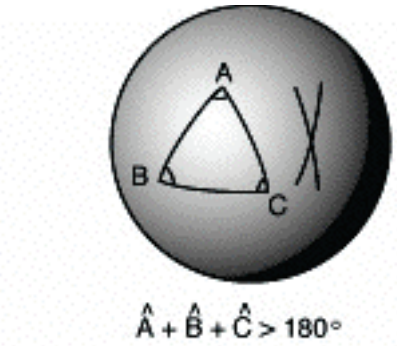
3) Paradoxe des quantités infinies !

Solution la plus
« simple » ?

Espace fini sans bord !

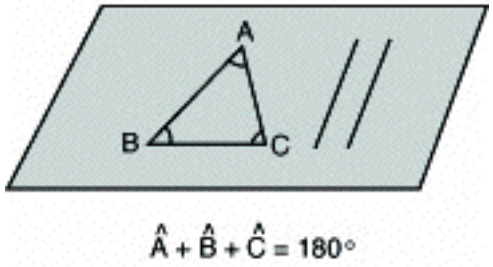
XIX^{e} s. : Géométries Non-euclidiennes

Riemann (1854)



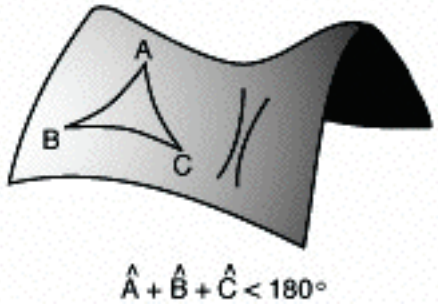
Courbure Positive

Gauss (1848)



Courbure Nulle

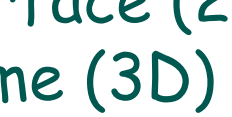
Lobatchevski (1829)



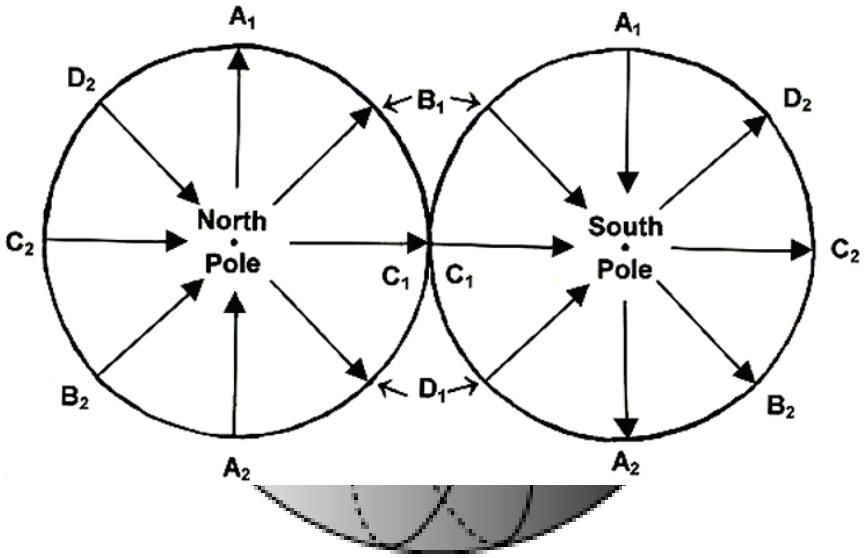
Courbure Négative

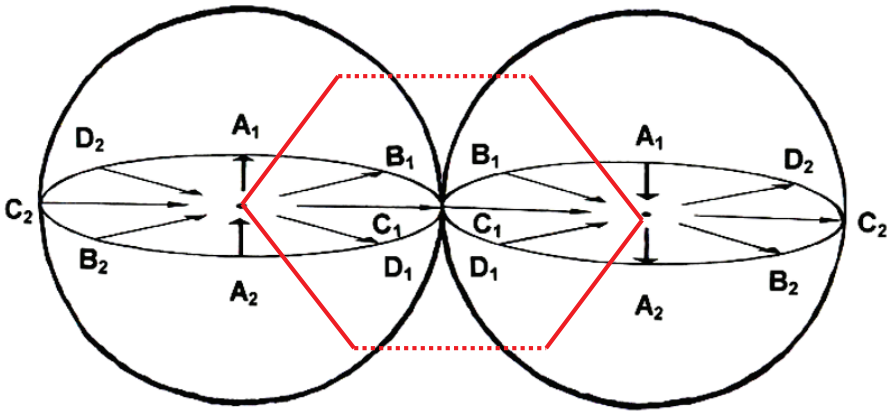
Hypersphère : espace fini sans bord

Sphère = Surface (2D) d'un volume (3D) sphérique, sans bord

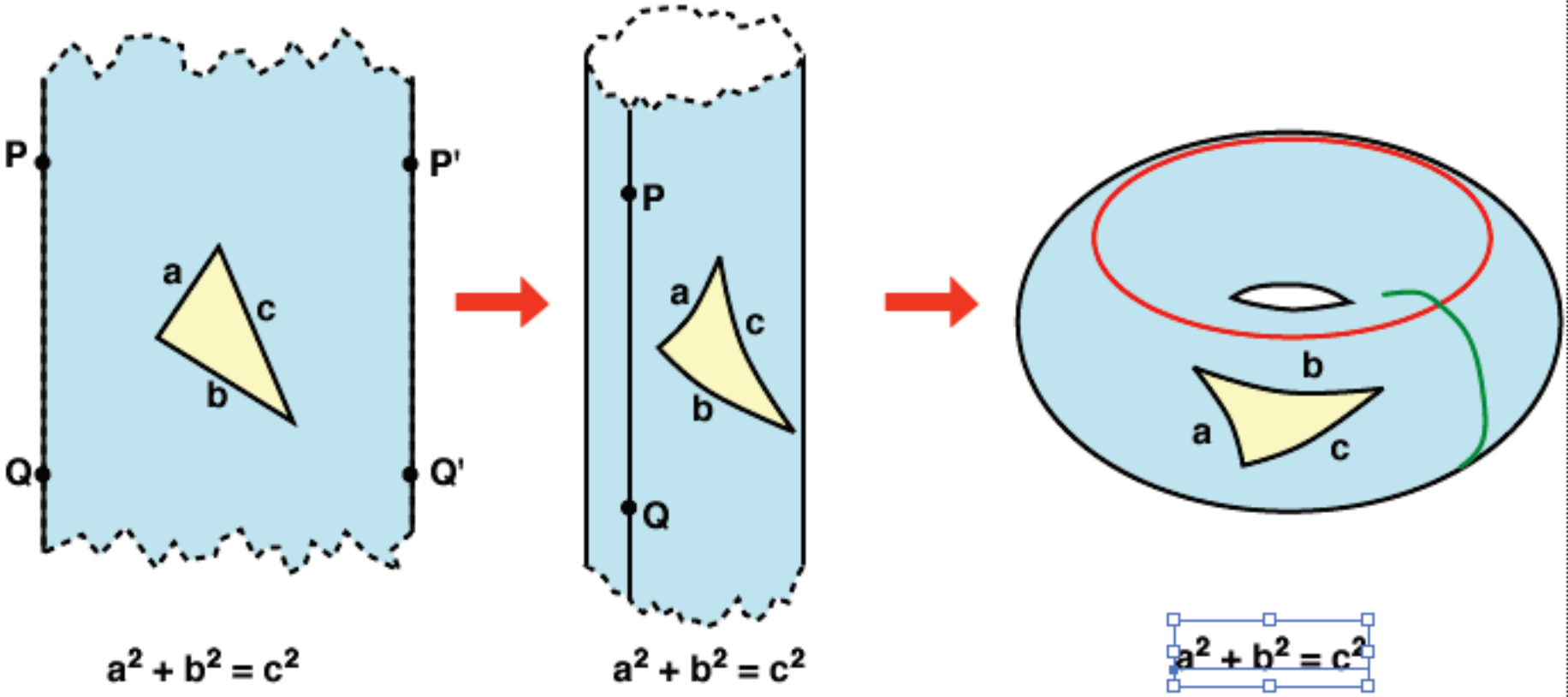


Hypersphère = Surface (3D) d'un hypervolume (4D), sans bord





XIX^{e} s. : Topologie

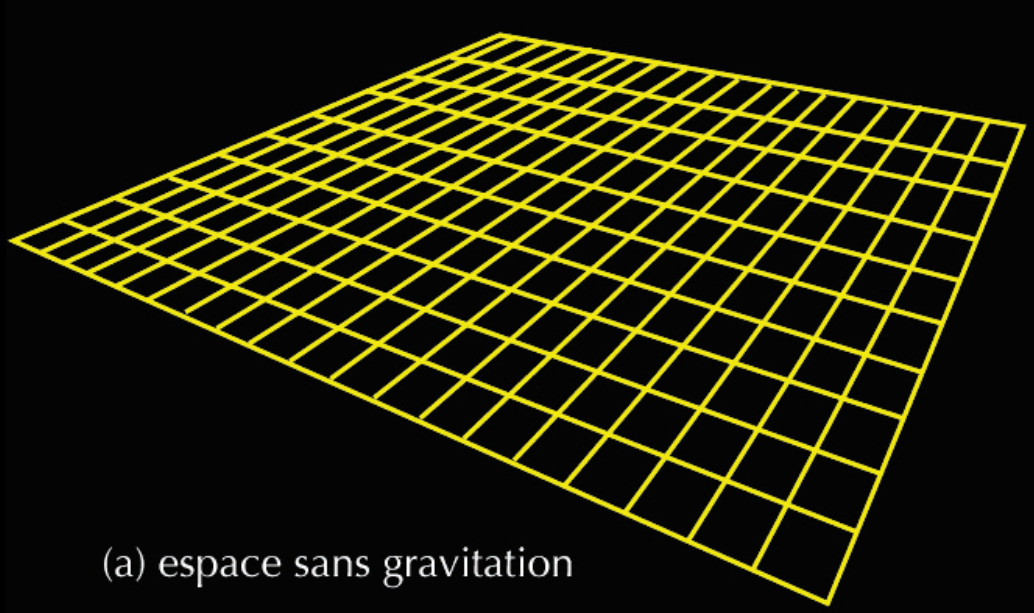


Plan

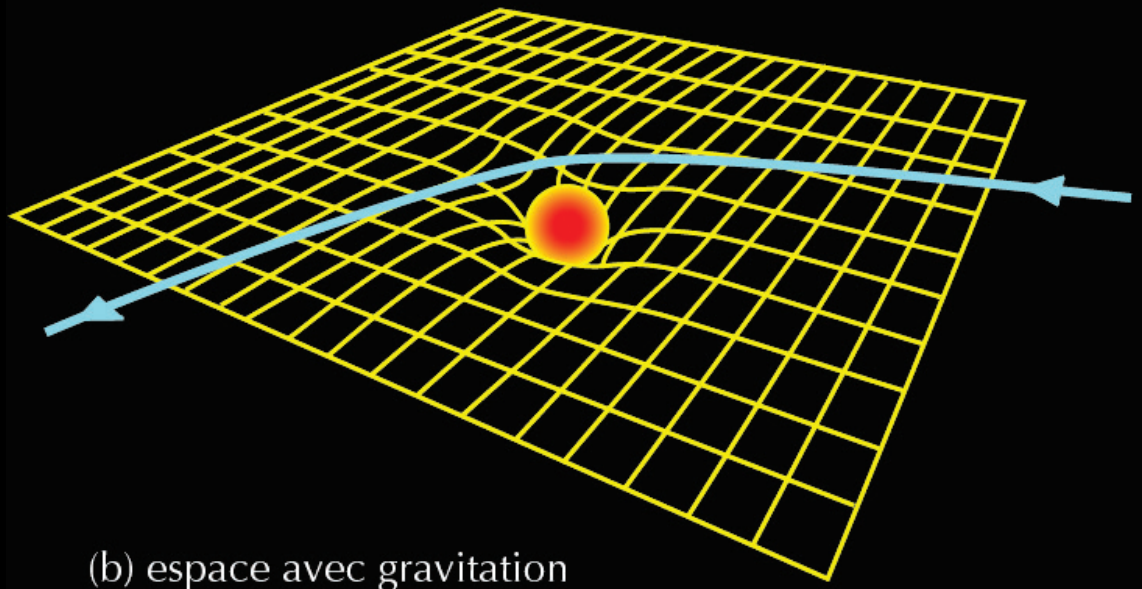
Cylindre

Tore plat

Relativité Générale:
Espace- temps courbe



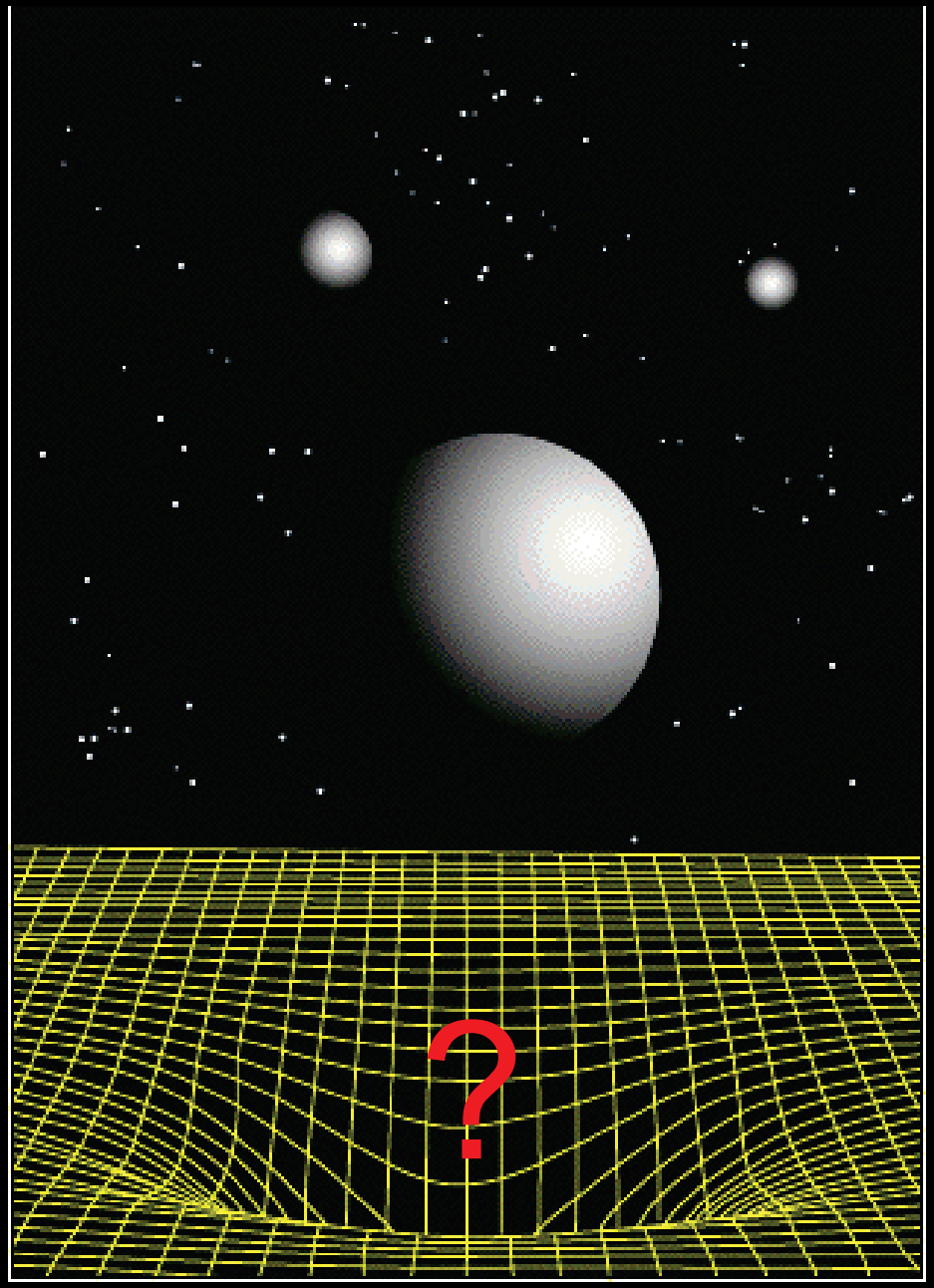
(a) espace sans gravitation



(b) espace avec gravitation

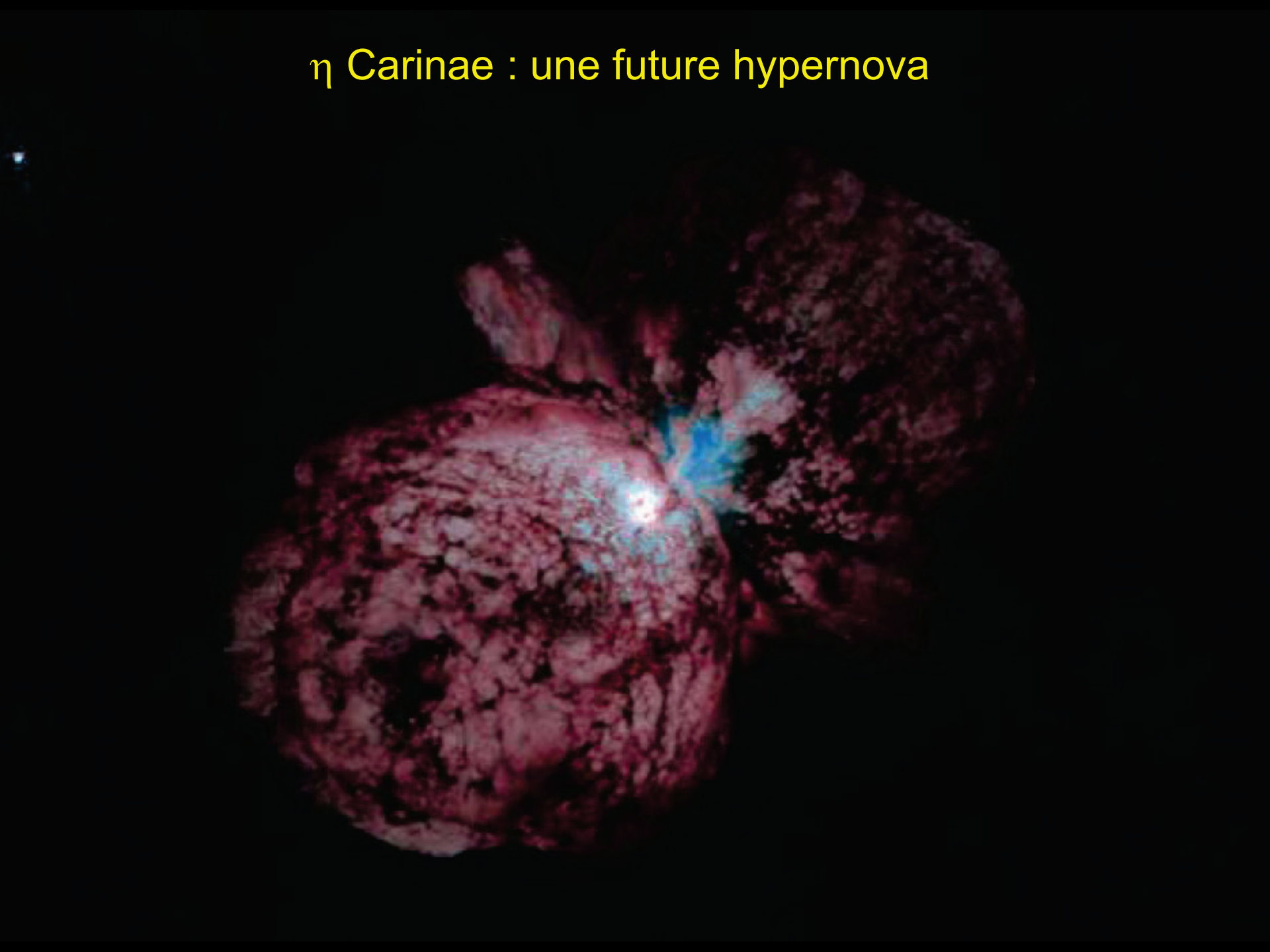
Equations d' Einstein

courbure = matière-énergie




Si $M_* > 40\ M_S$
TROU NOIR !

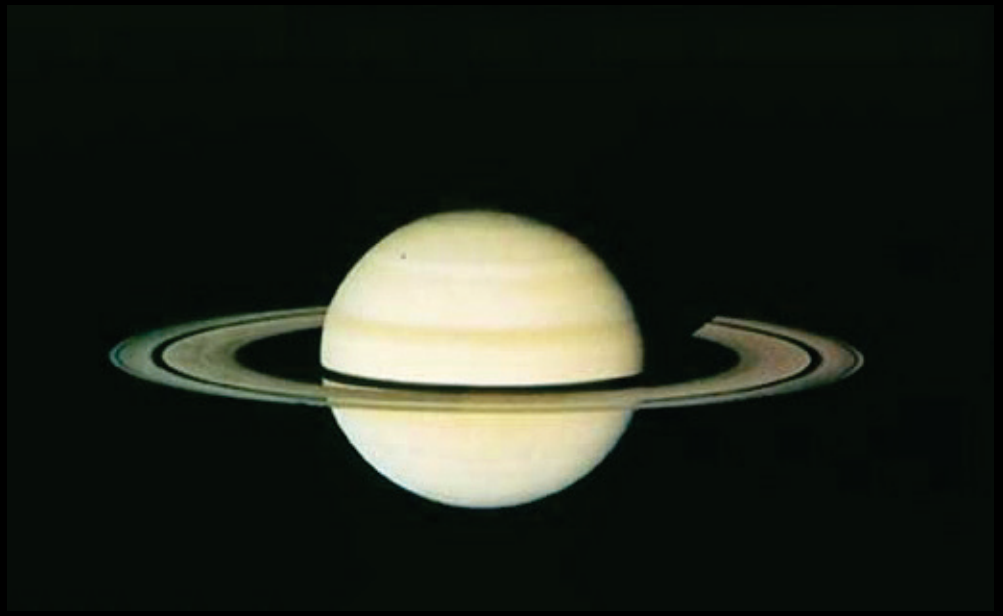
η Carinae : une future hypernova



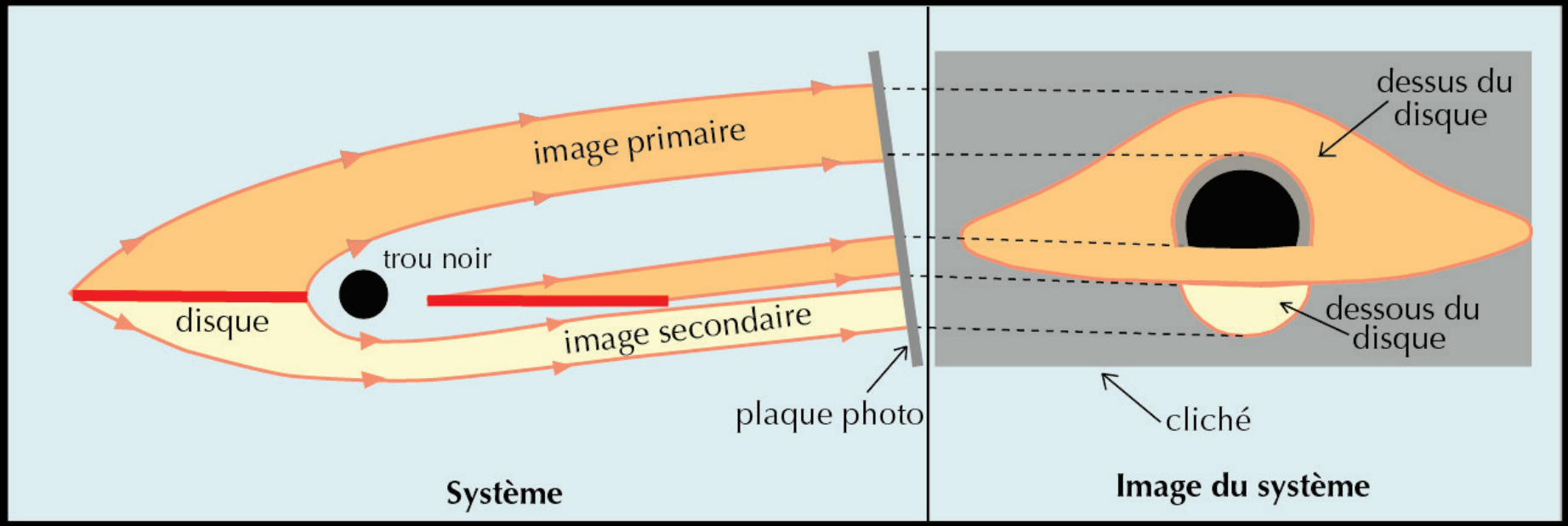
Le trou noir distord la forme de l'espace

- autour
- derrière
- à l'intérieur

Espace-temps Newtonien

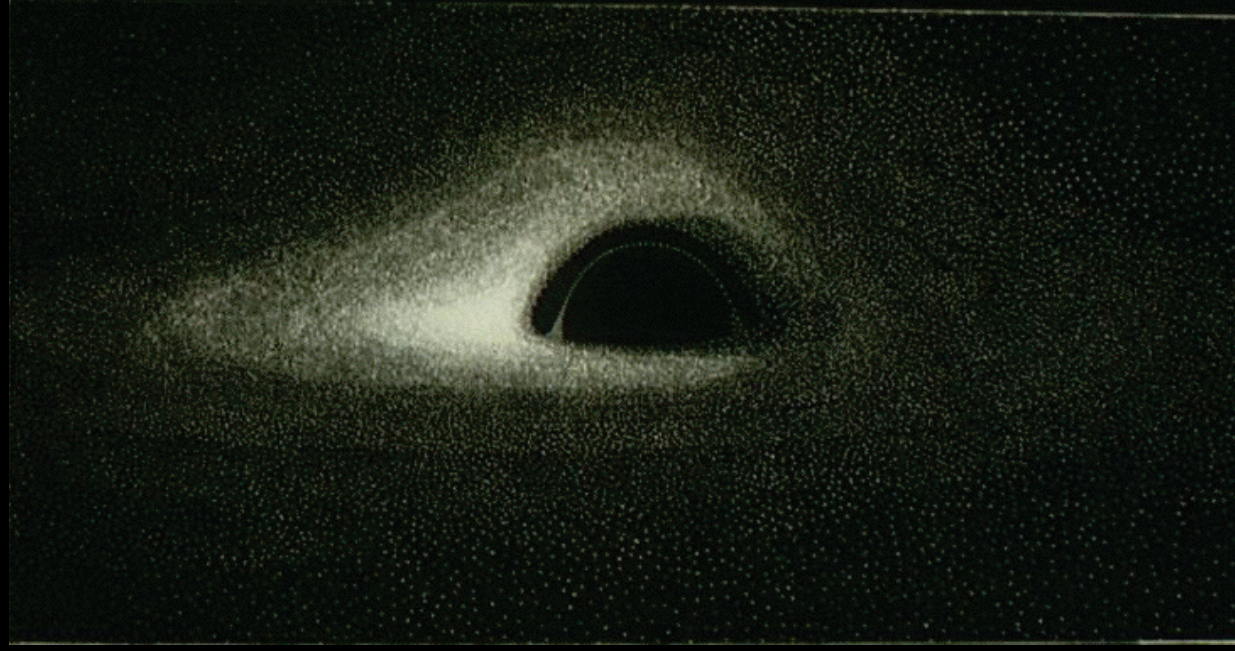


Espace-temps courbe



J.-P. Luminet

Astron. Astrophys. **75**, 228-235 (1979)



J.-A.Marck

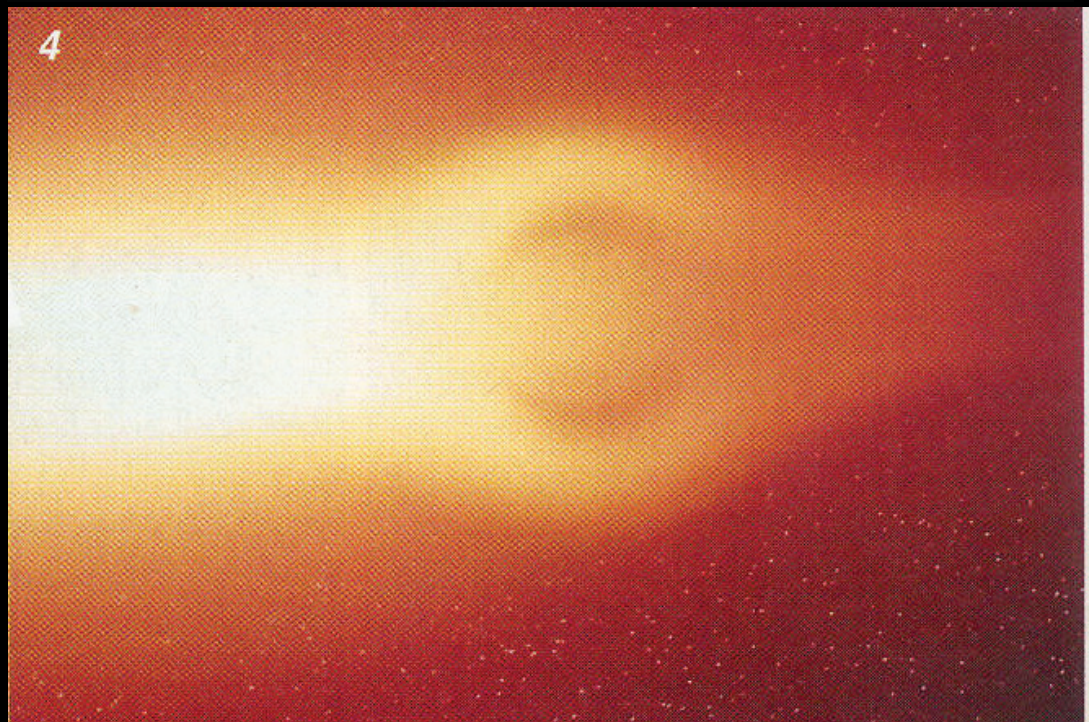
Class. Quant. Grav. **13**, 393-402 (1996)

Thorne et al.

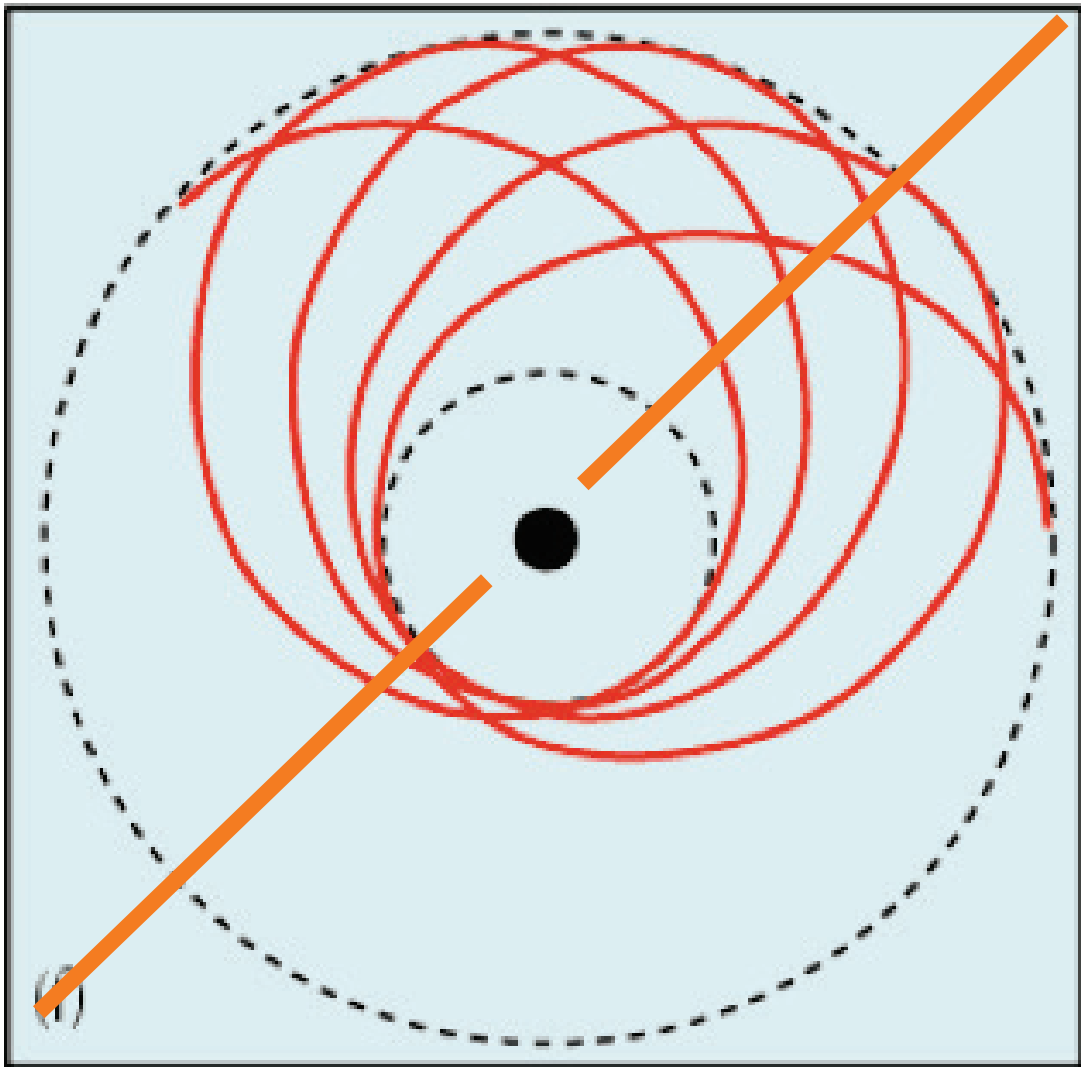
Interstellar (2014)

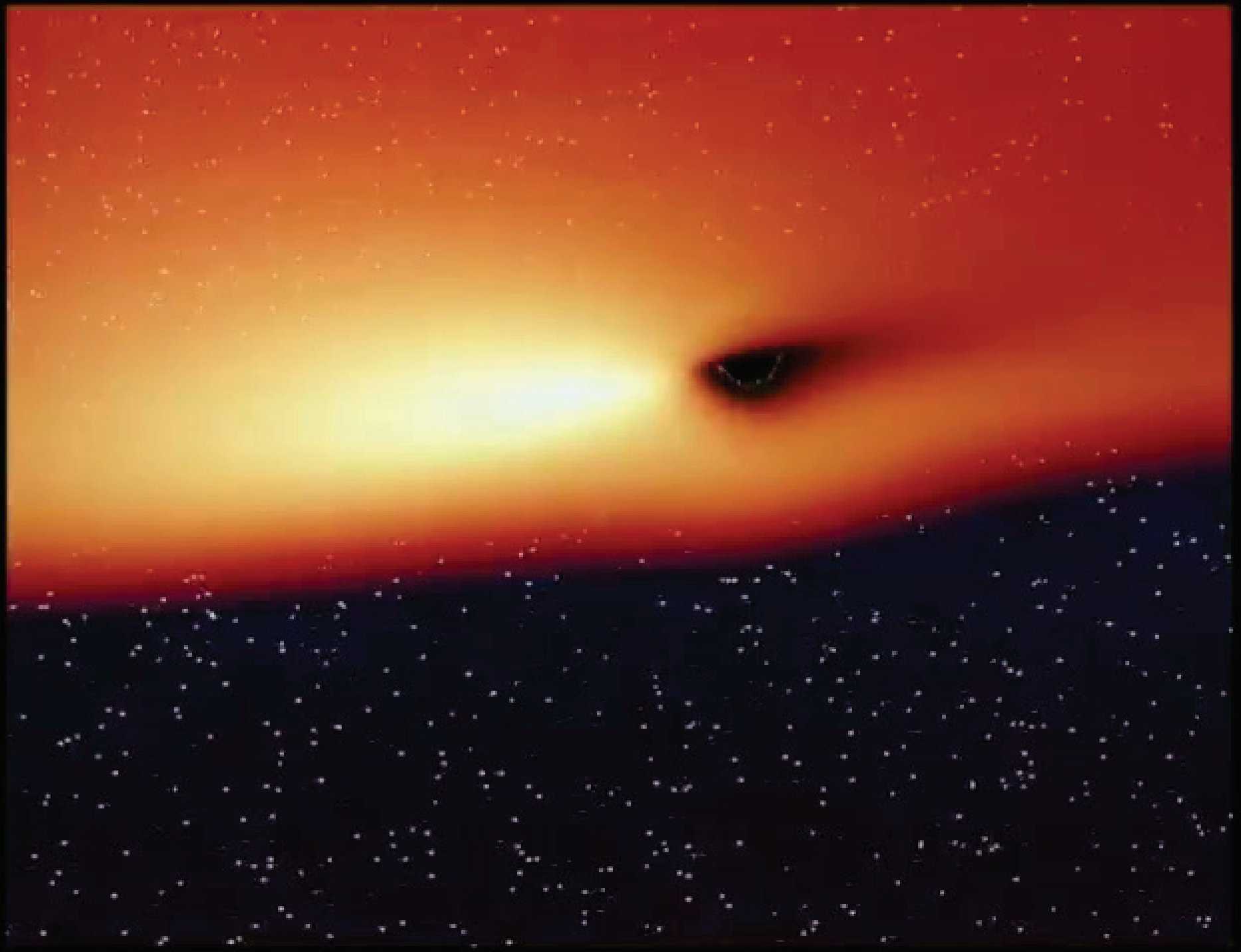
J.-P. Luminet & J.-A. Marck

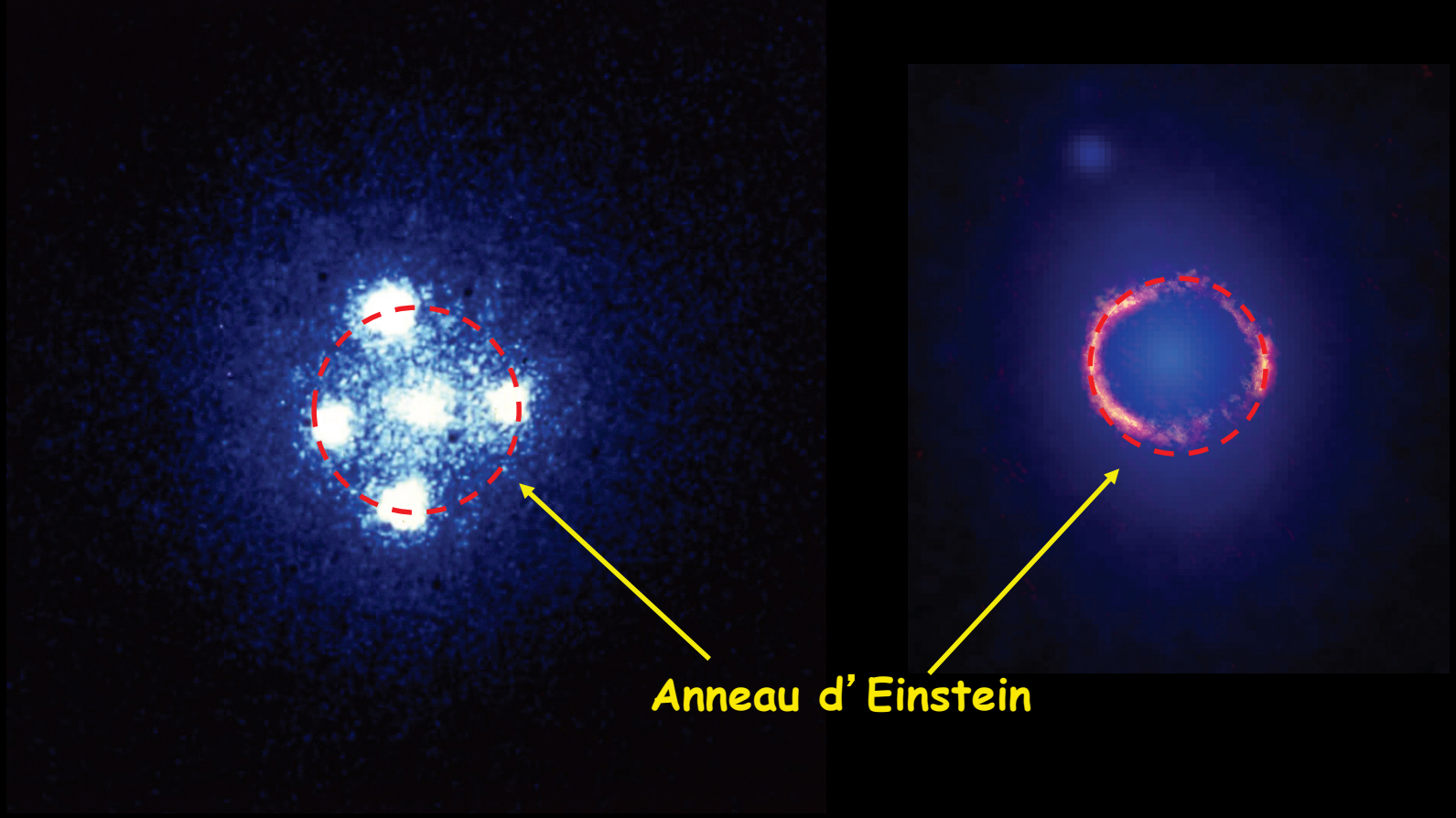
Pour la Science (1997)

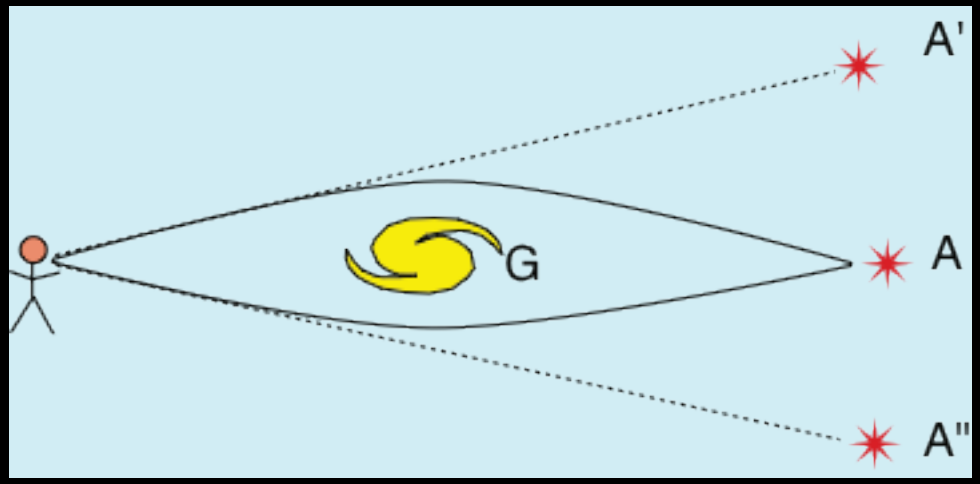


Voyage dans un trou noir
(J.A.Marck, 1993)



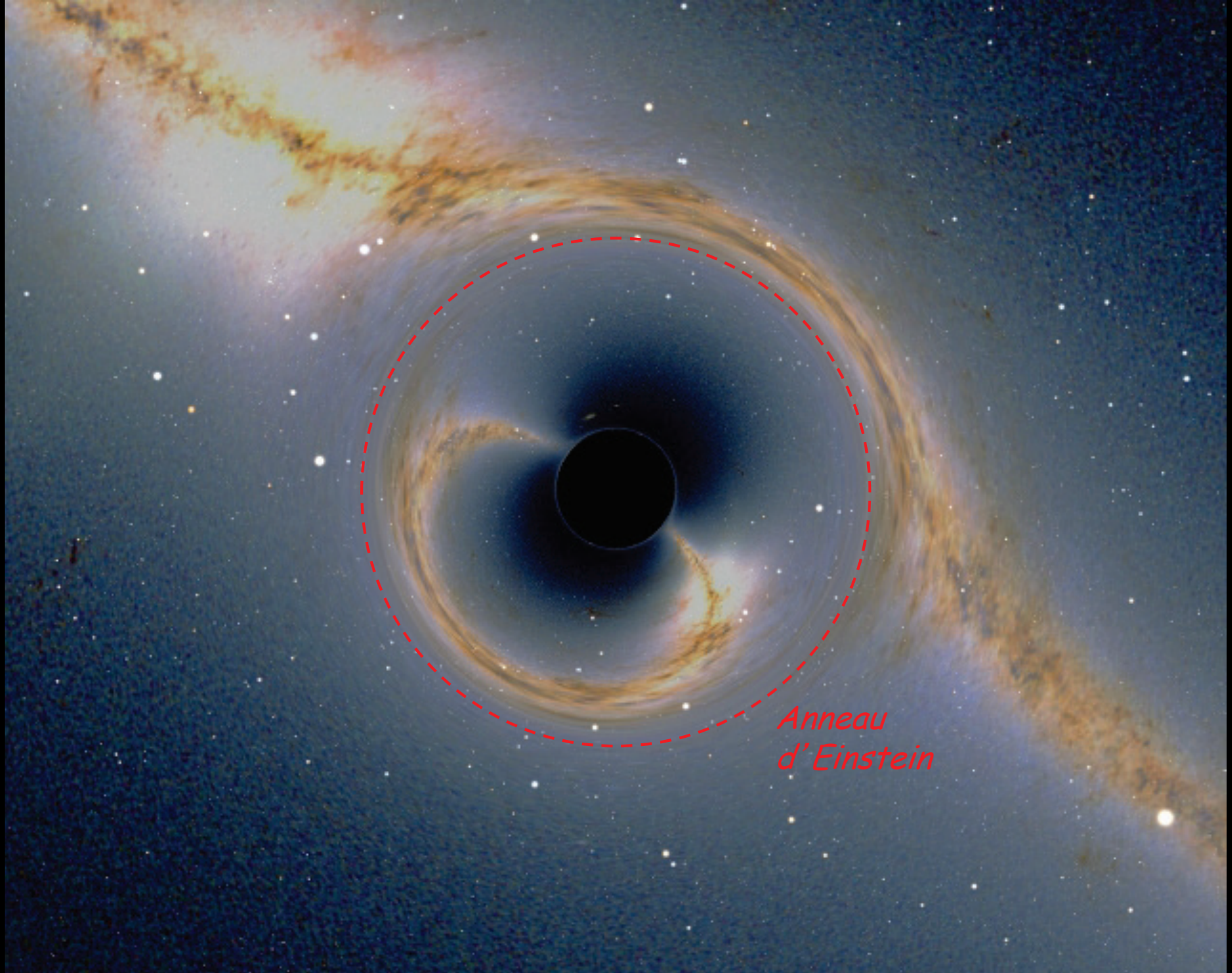




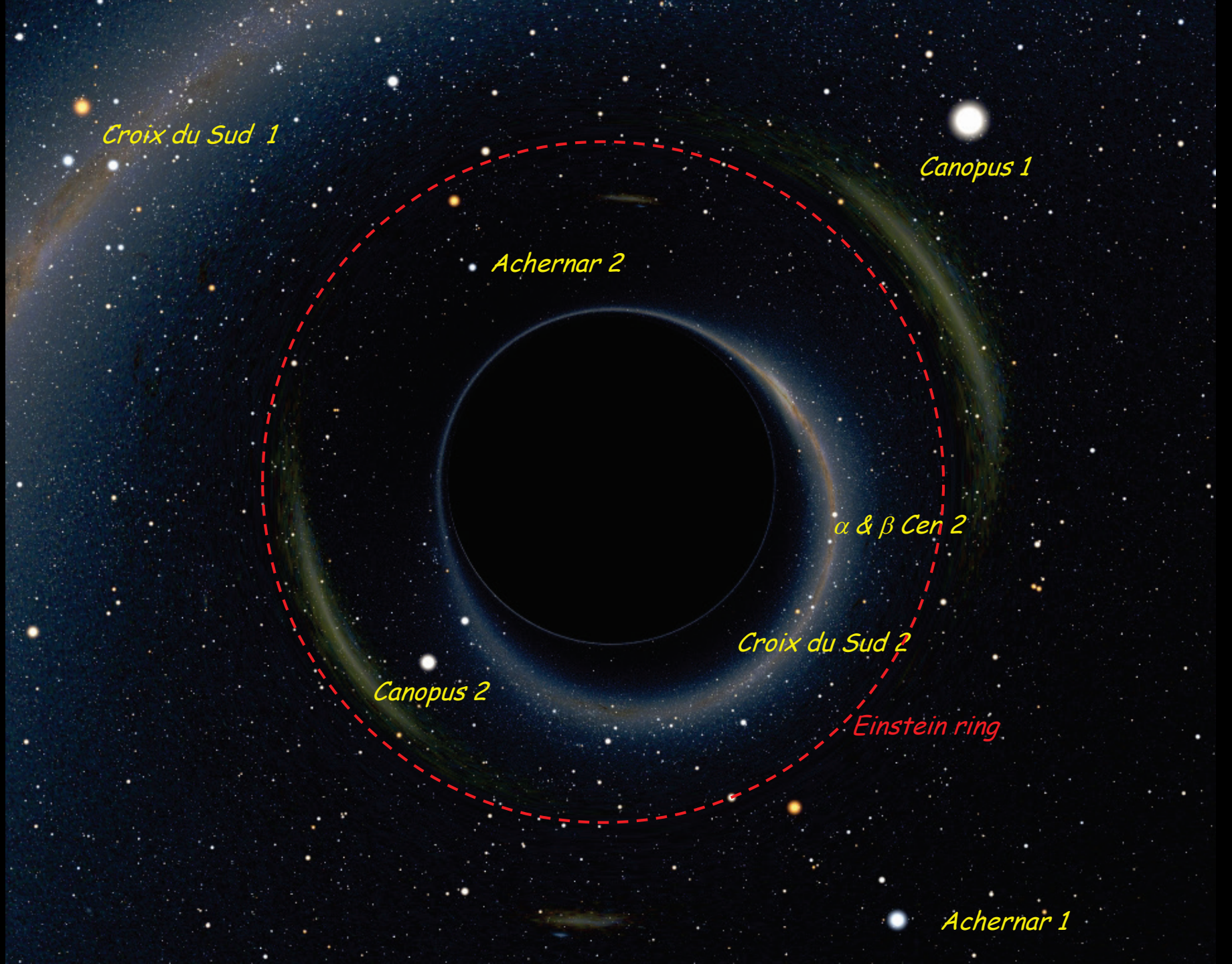


Mirage Gravitationnel

Trou noir devant la Voie lactée
(Riazuelo, 2006)


Anneau
d' Einstein

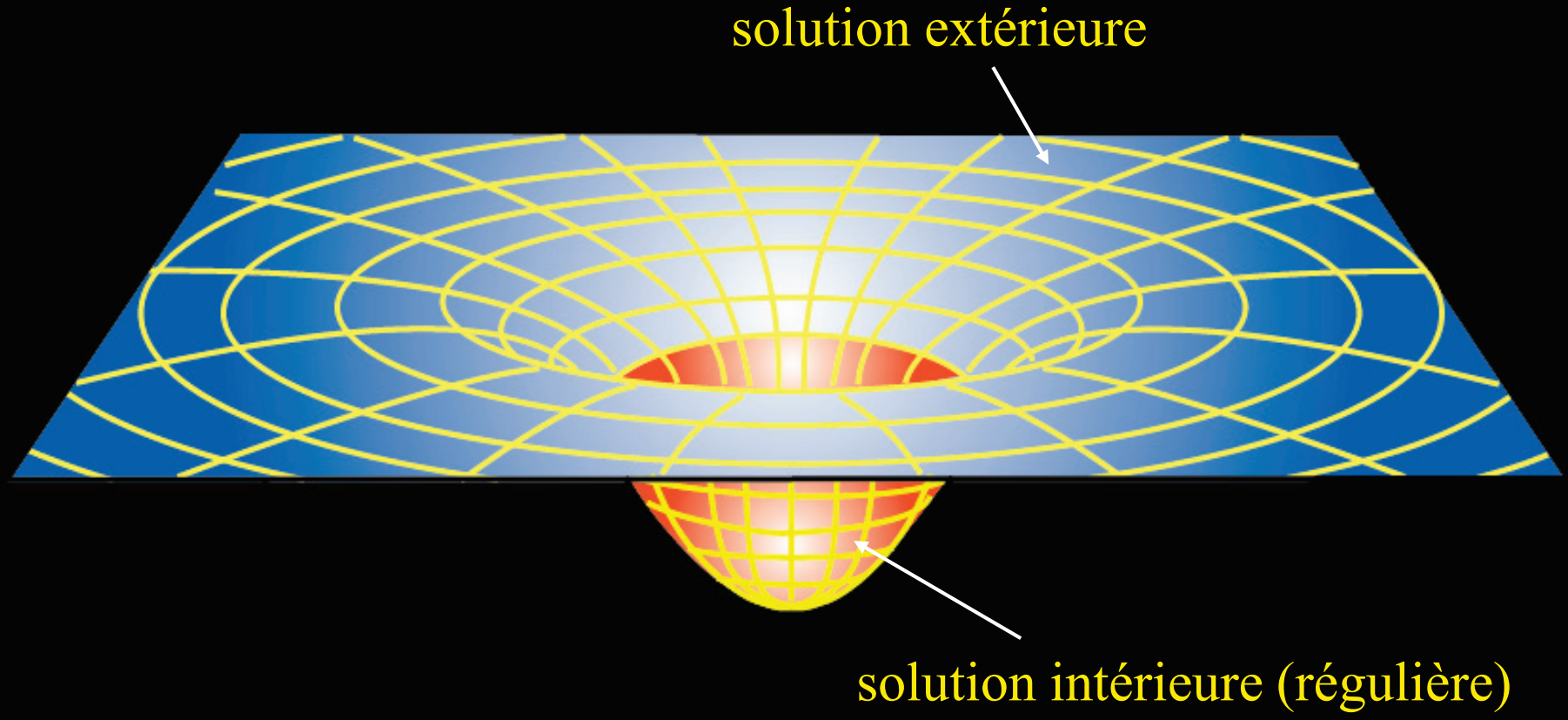
Trou noir devant les Nuages de Magellan


Croix du Sud 1
Canopus 1
Achernar 2
α & β Cen 2
Croix du Sud 2
Canopus 2
Einstein ring
Achernar 1

Trou noir devant les Nuages de Magellan

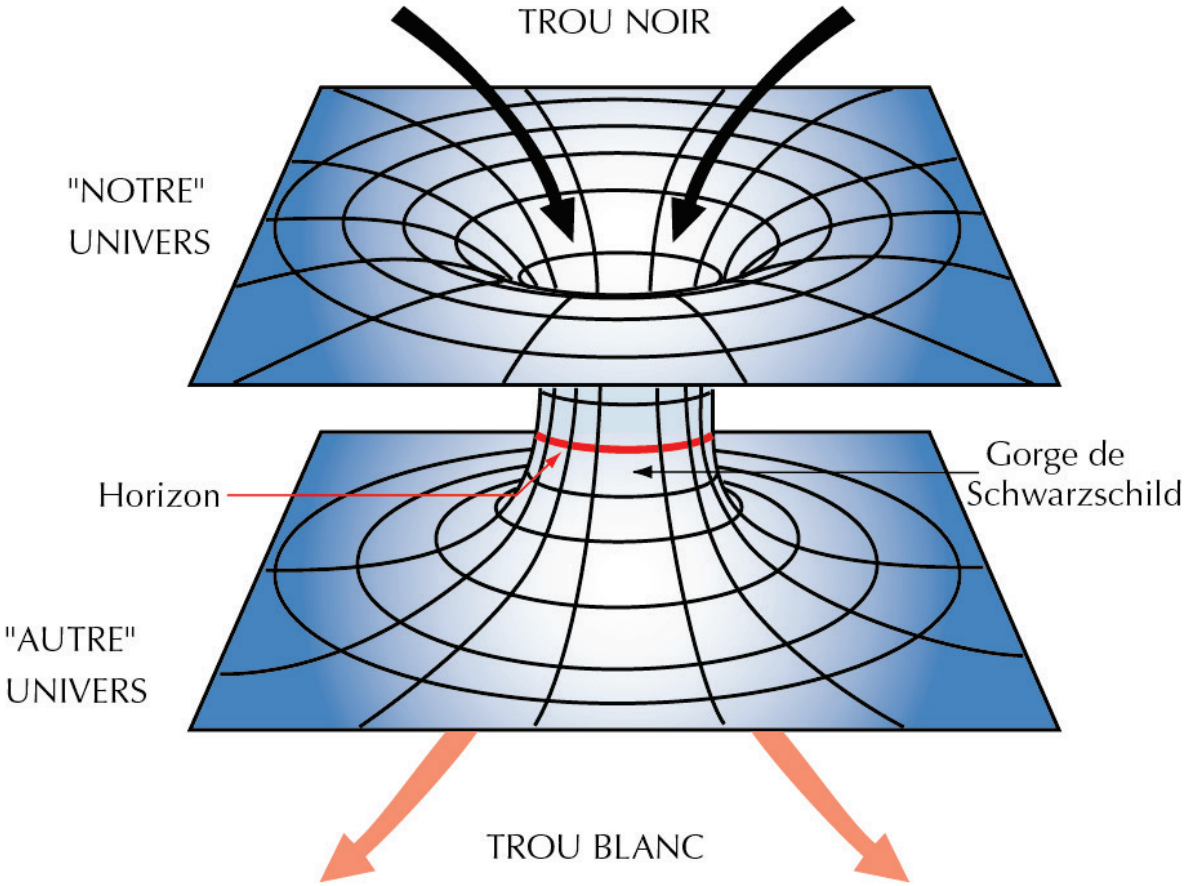
Jeux de cartes, trous de ver & Co

Etoile « normale »

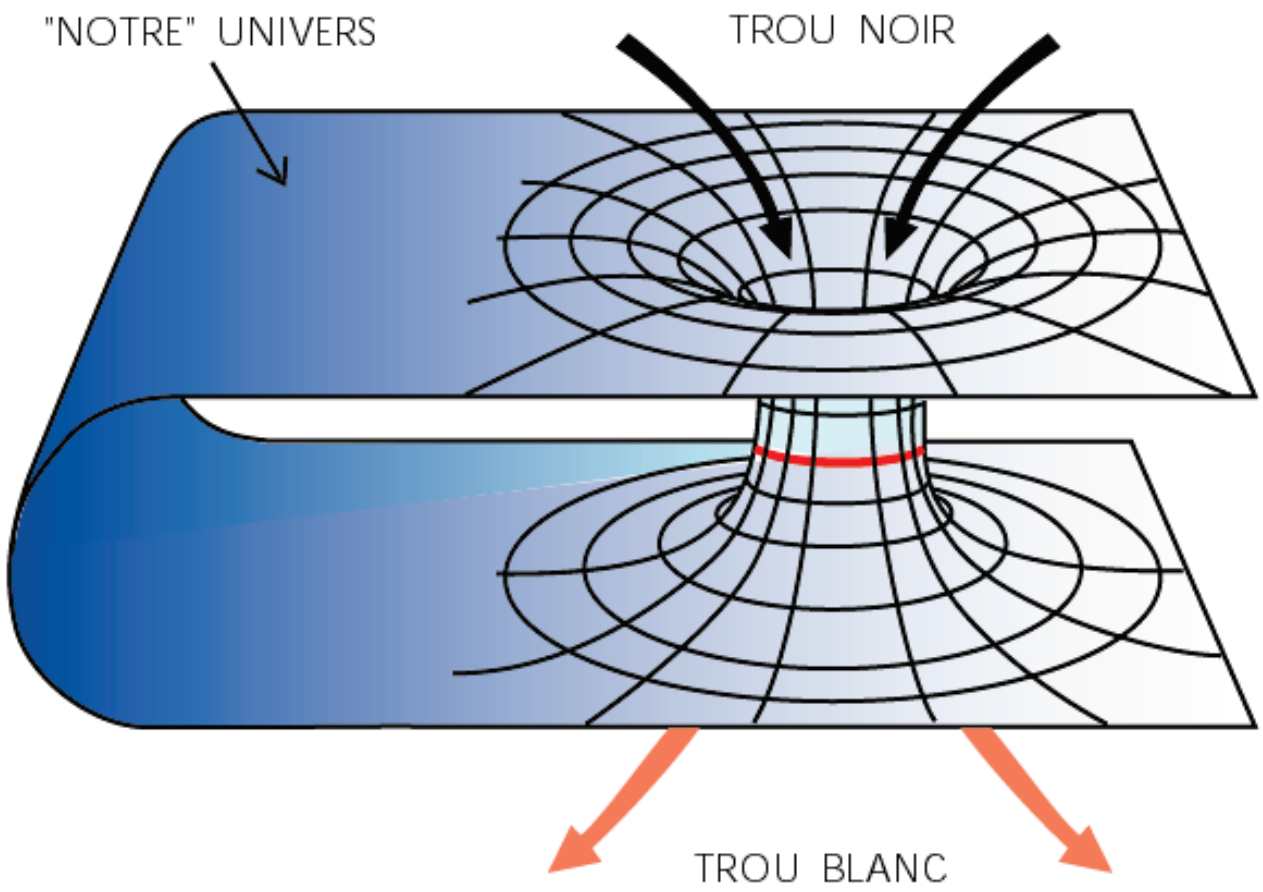


Trou noir de Schwarzschild (1)

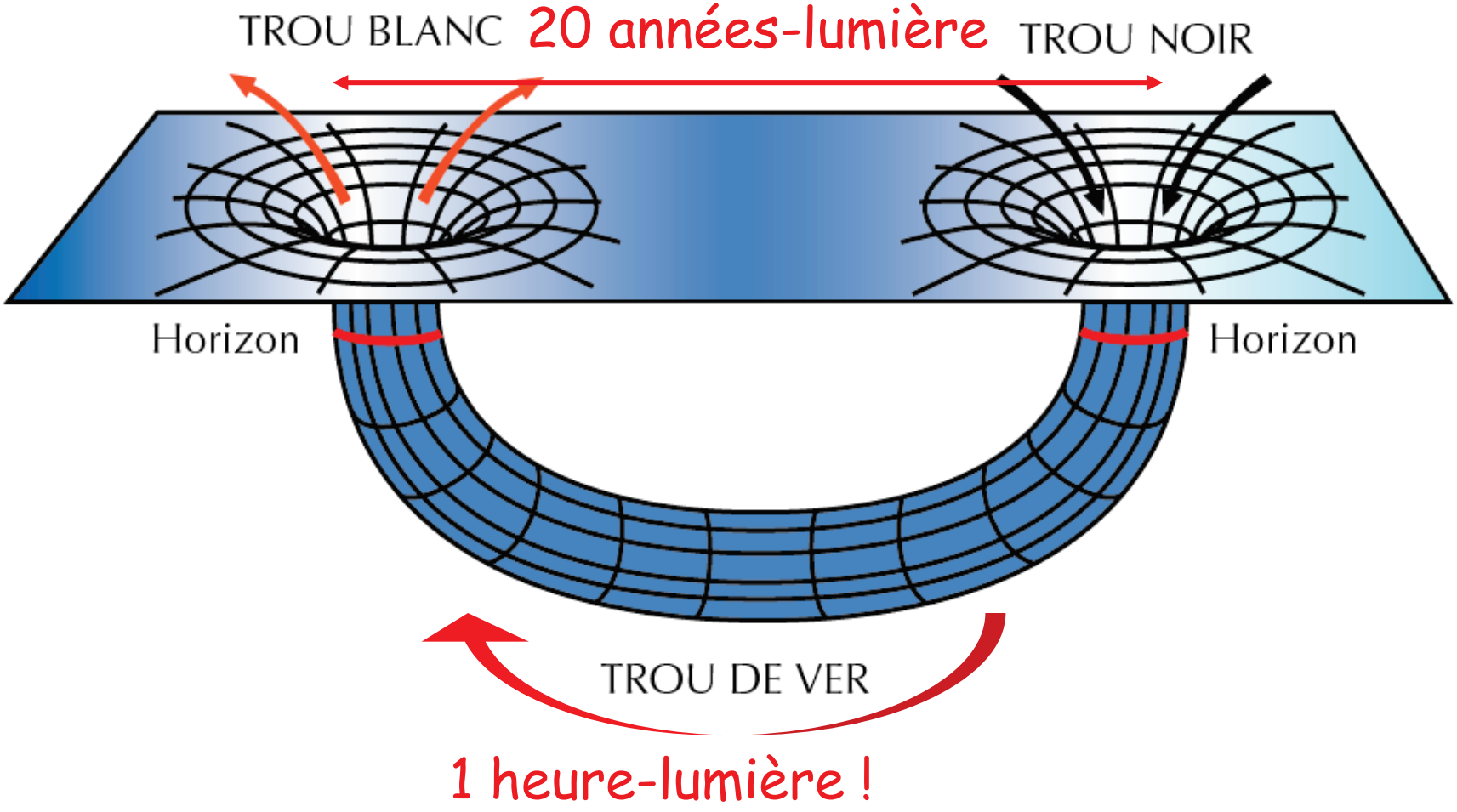
Solution extérieure seulement

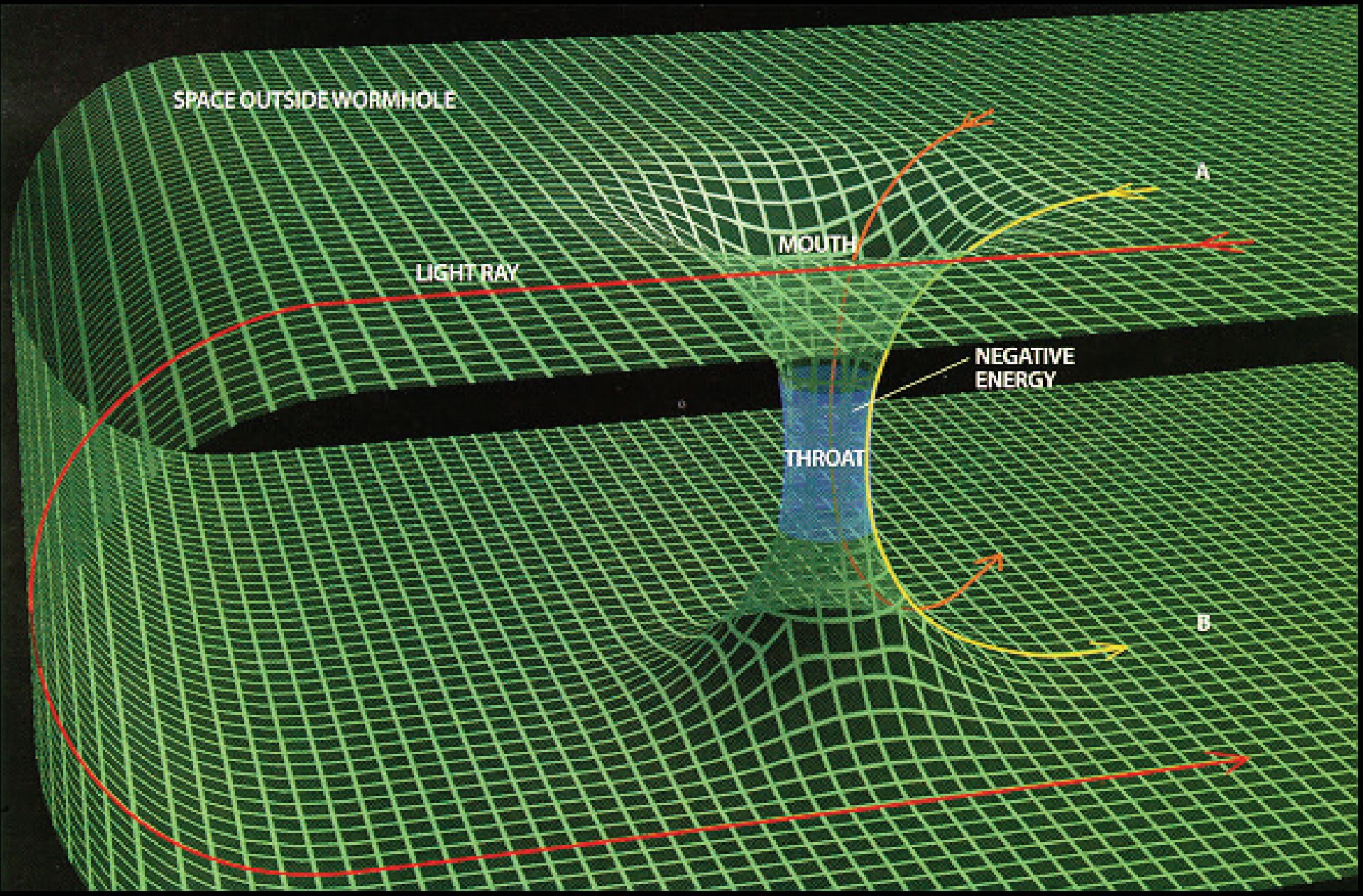


Trou noir de Schwarzschild (2)



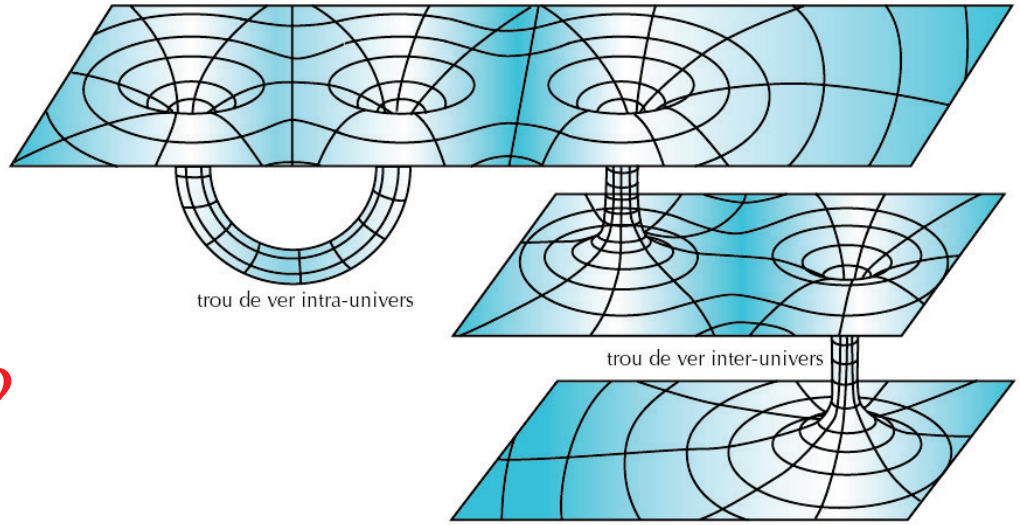
Des raccourcis de l'espace-temps?



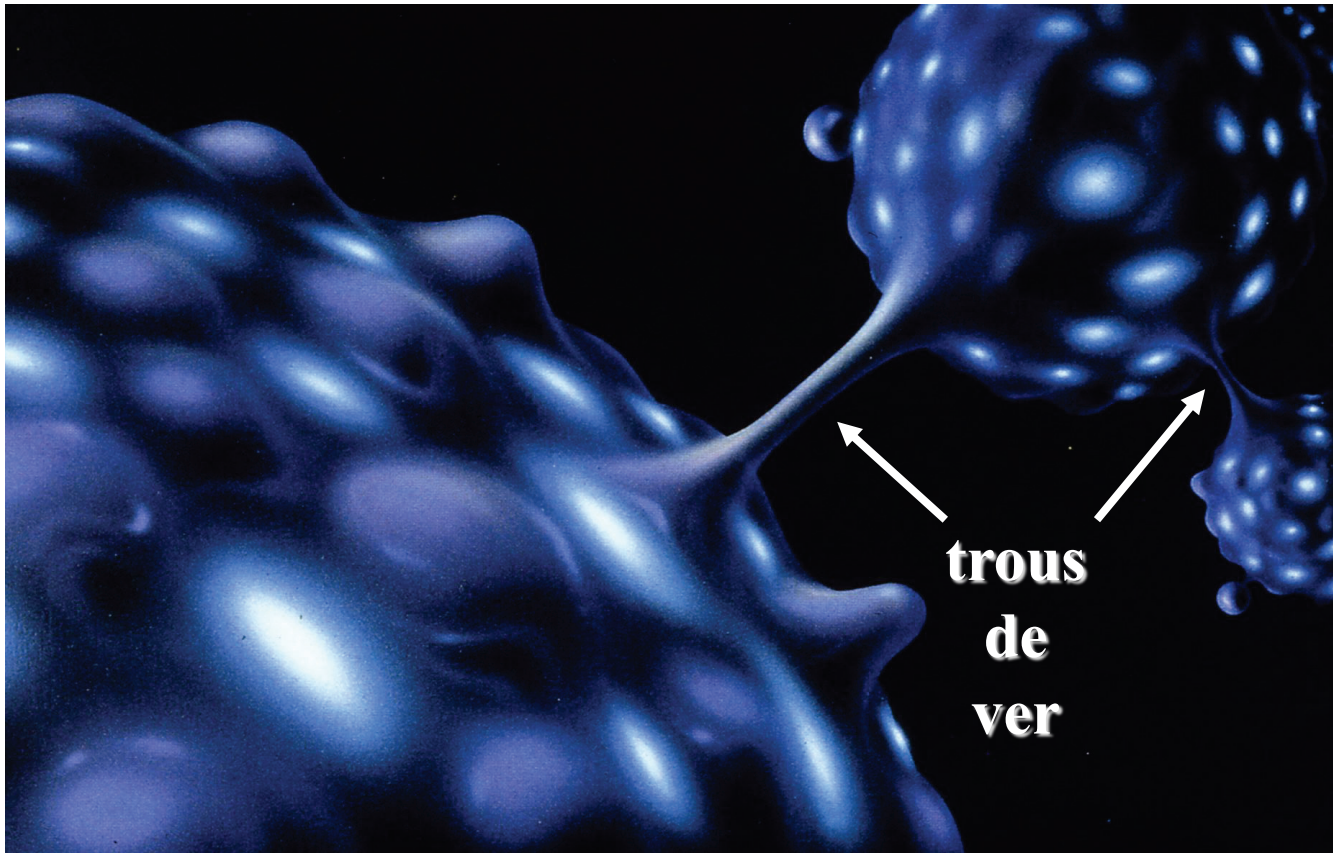

SPACE OUTSIDE WORMHOLE
A
MOUTH
LIGHT RAY
NEGATIVE ENERGY
THROAT
B


Voyage dans un
trou de ver

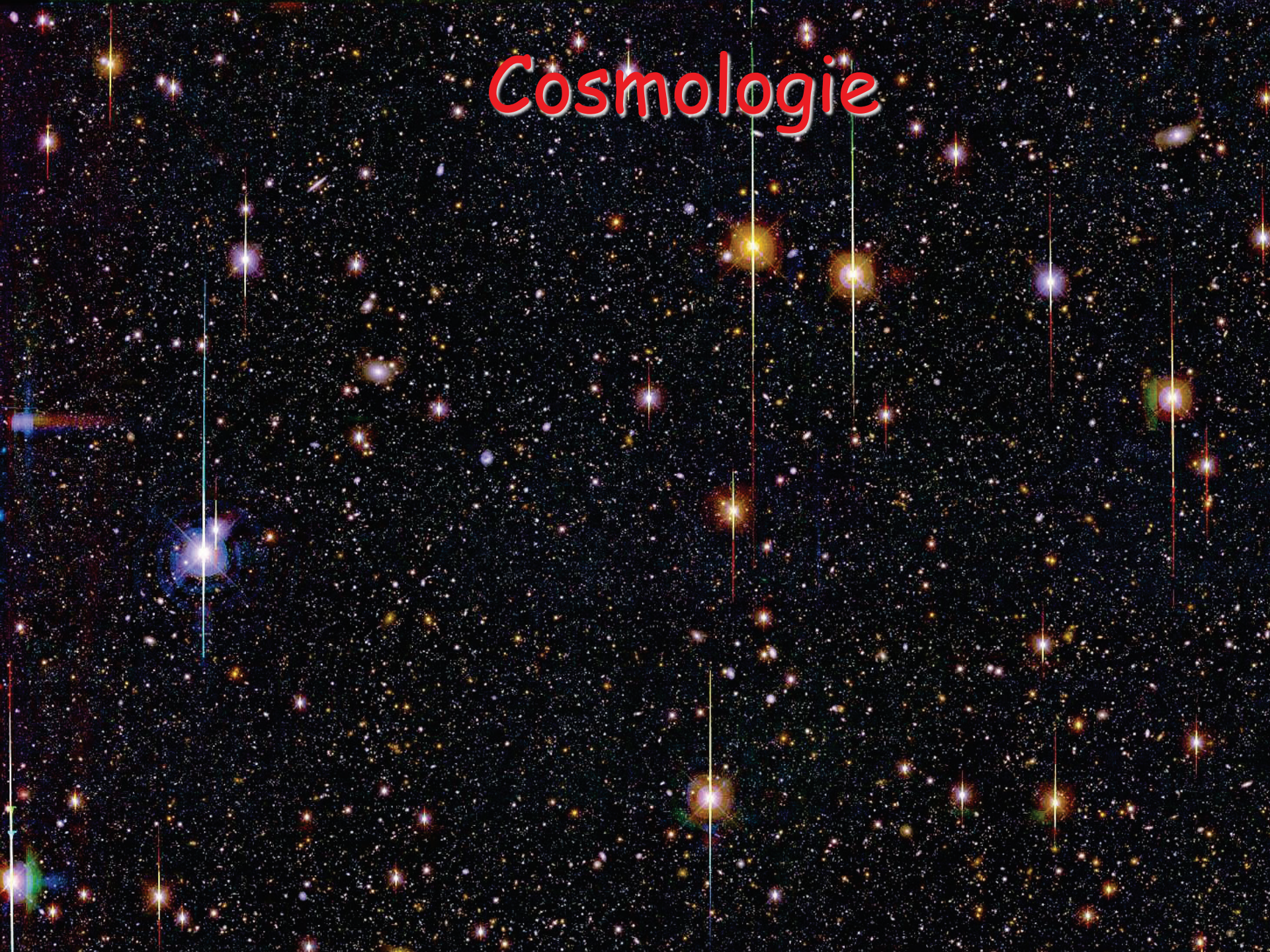
Univers parallèles?



Bébés Univers ?



Cosmologie

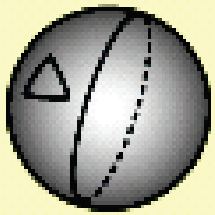
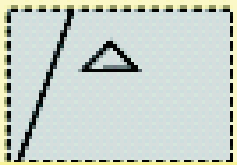
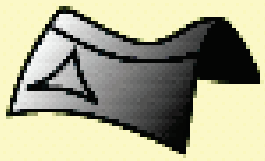


Problème cosmologique:

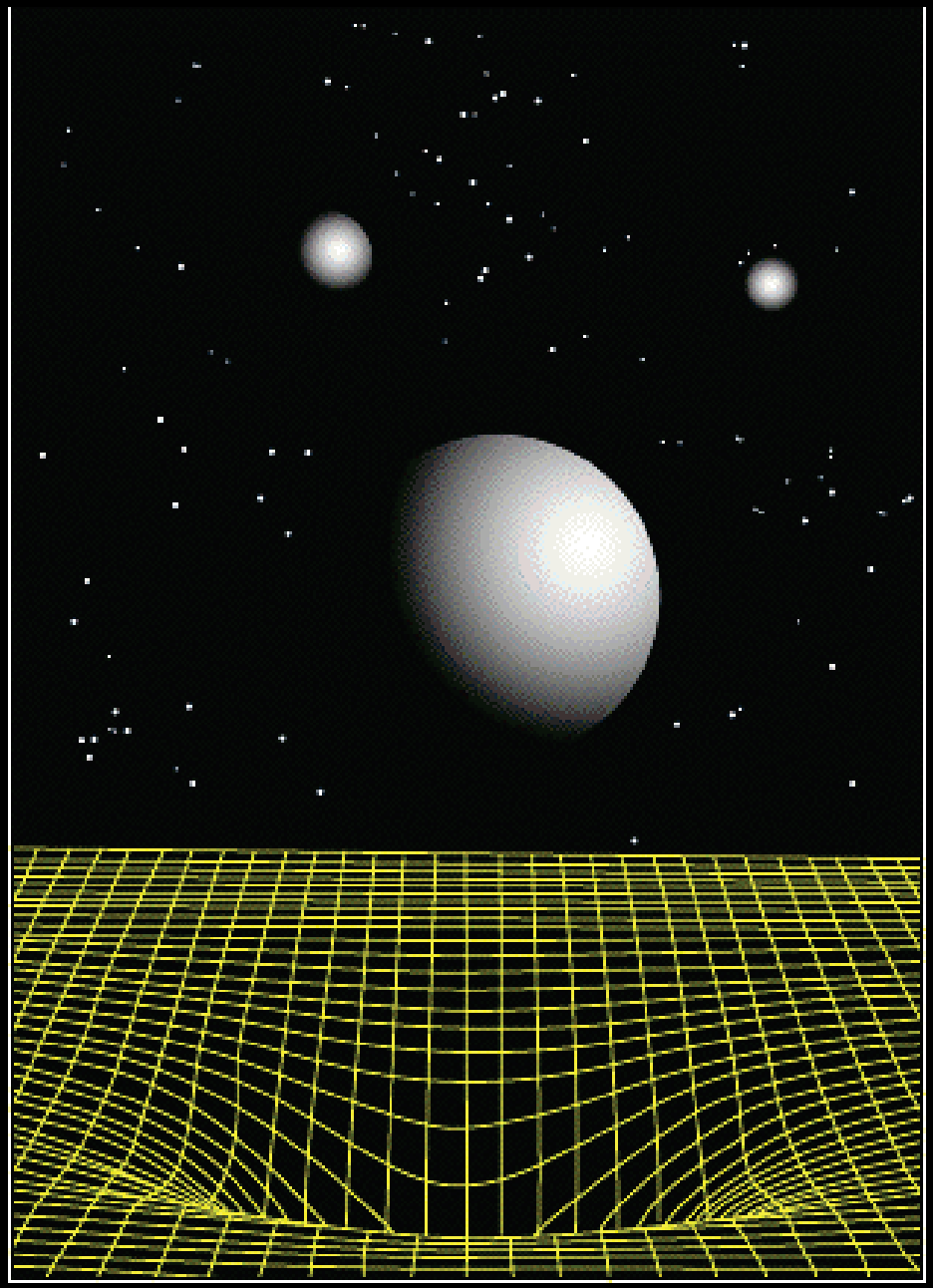
Homogénéité

=>

courbure spatiale constante

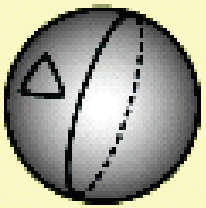
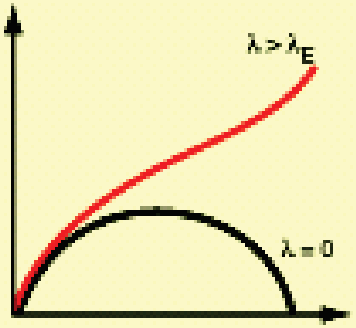
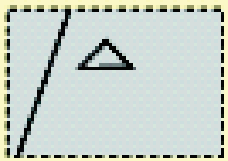
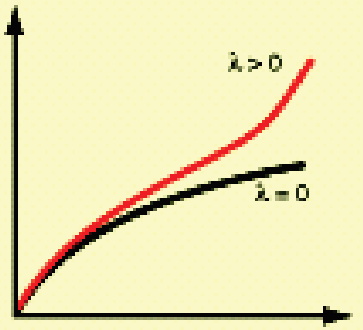
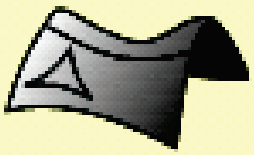
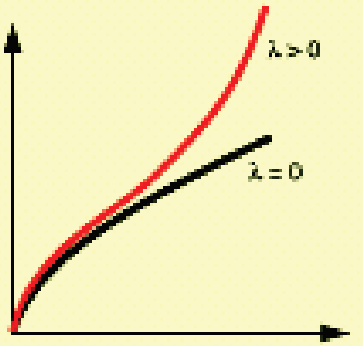
courbure	
K > 0  espace sphérique	fini (sans bord)
K = 0  espace Euclidien	fini ou infini
K < 0  espace hyperbolique	fini ou infini

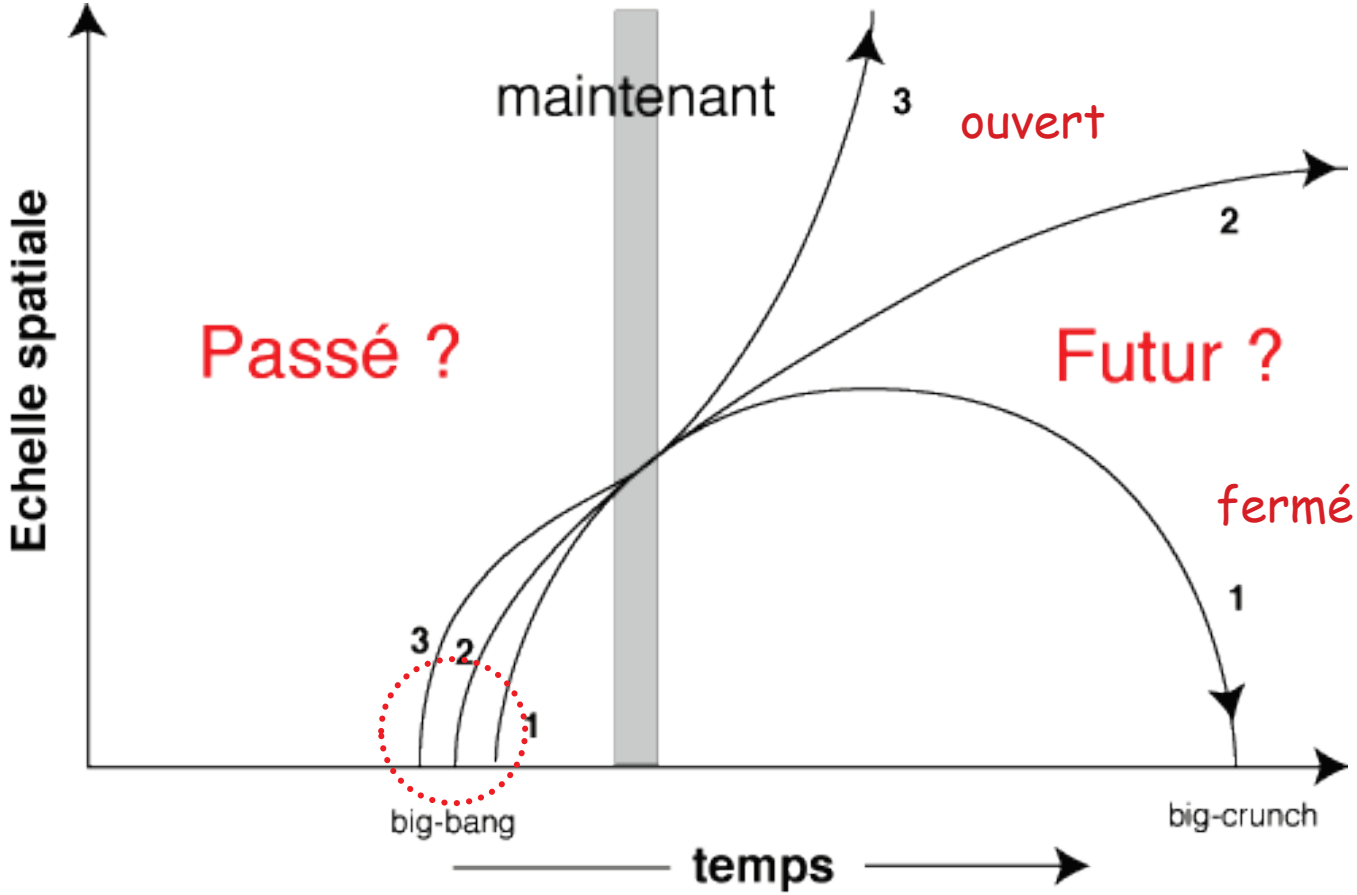
Courbure de l'espace-temps
=> Dynamique !

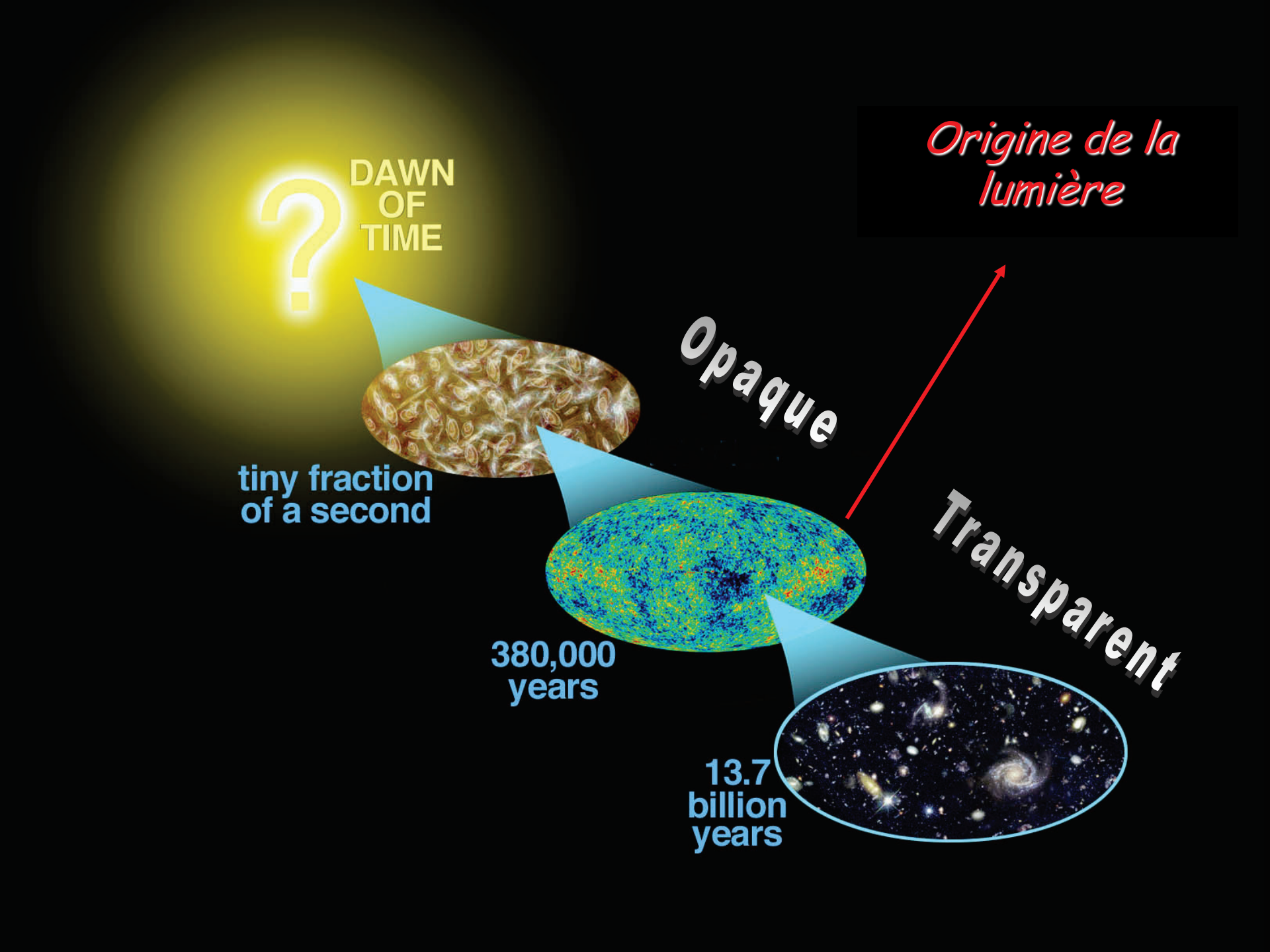


Expansion

Modèles de Friedmann-Lemaître

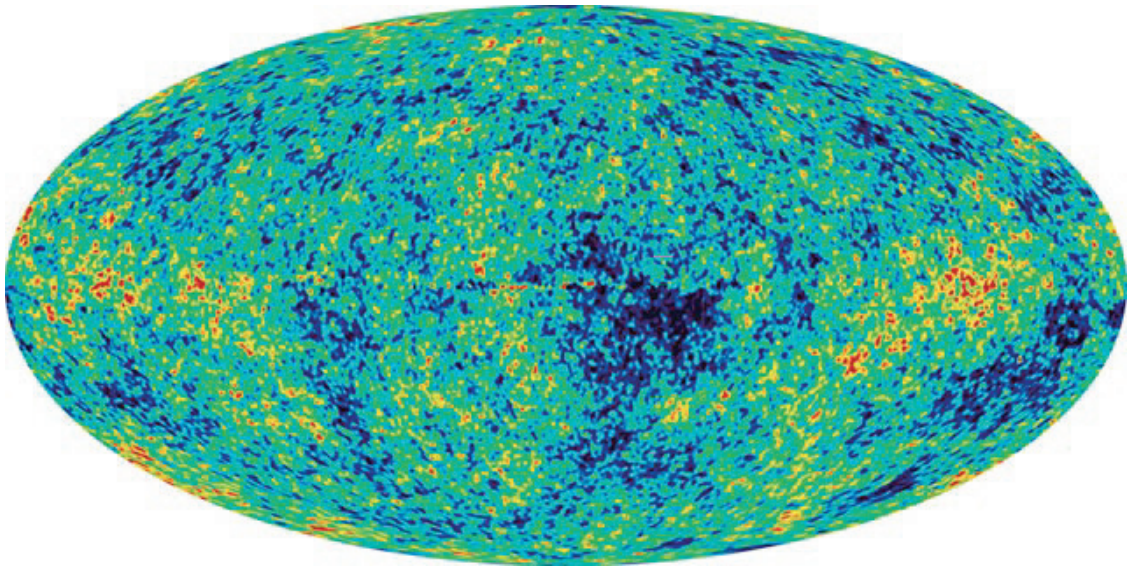
	courbure	dynamique	destin
$\Omega>1$	K > 0  elliptique		ouvert si λ grand fermé
$\Omega=1$	K = 0  Euclidien		ouvert
$\Omega<1$	K < 0  hyperbolique		ouvert


Echelle spatiale
maintenant
3
ouvert
2
Passé ?
Futur ?
fermé
1
3
2
1
big-bang
big-crunch
temps

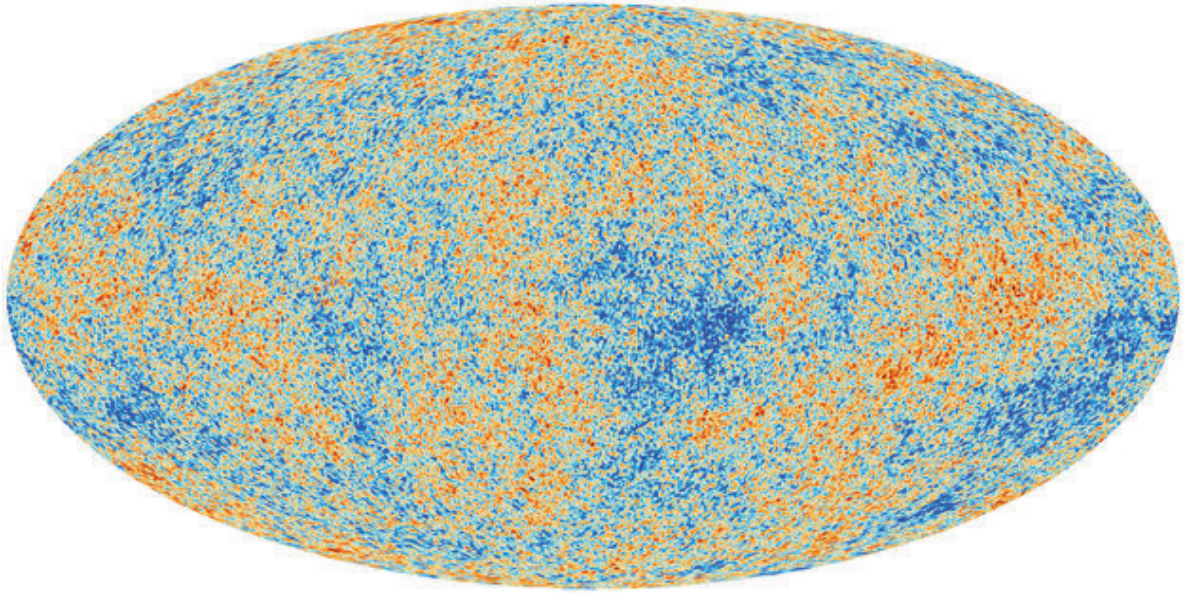

Origine de la lumière
DAWN OF TIME
tiny fraction of a second
Opaque
380,000 years
Transparent
13.7 billion years

Rayonnement fossile

WMAP
2003



Planck
2013

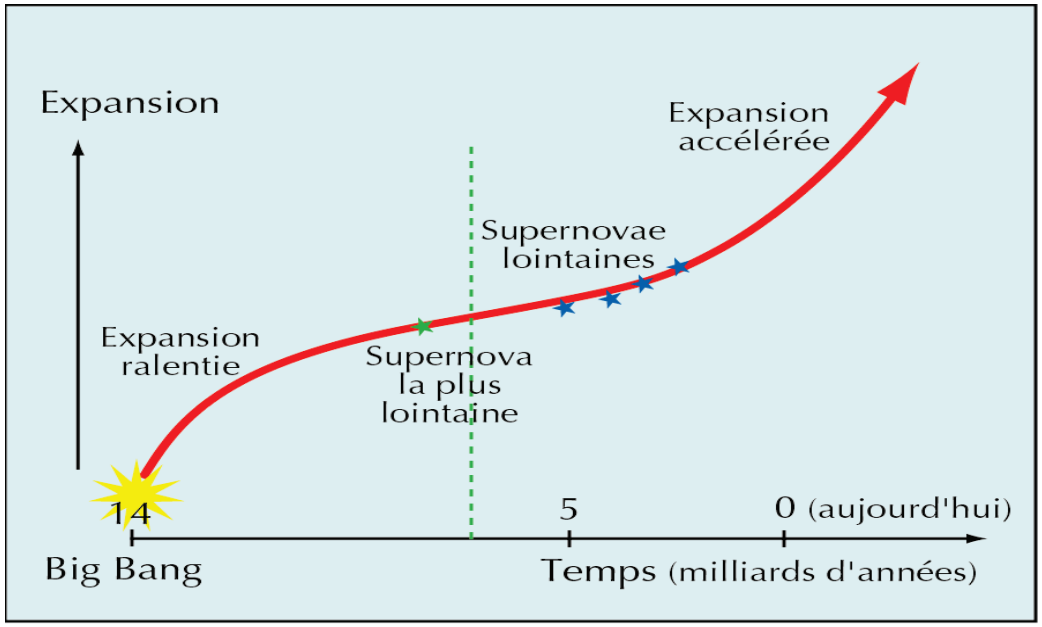


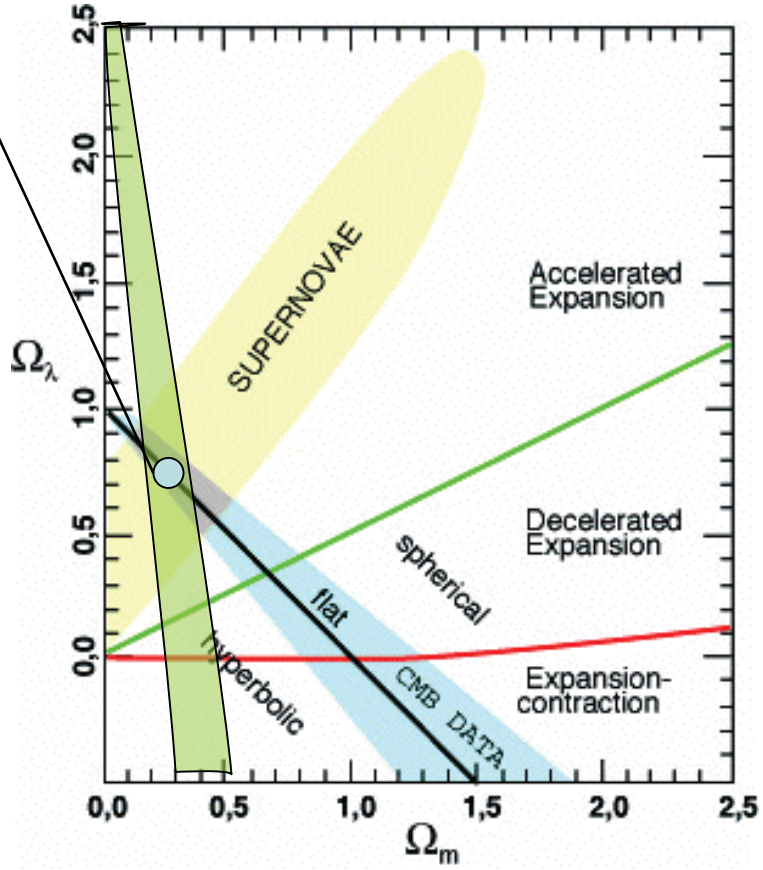
Le modèle de « concordance » (ΛCDM)

Courbure ~0

Energie noire ~70%

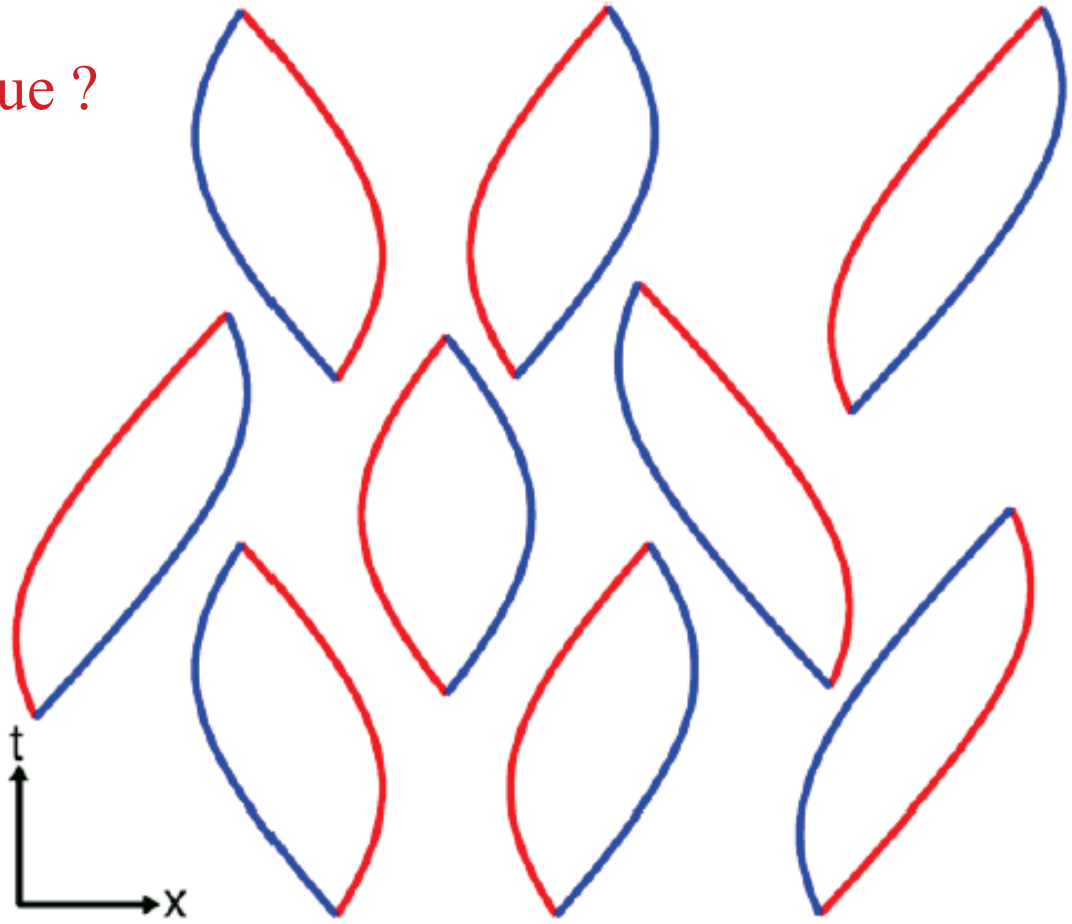
Matière ~30%



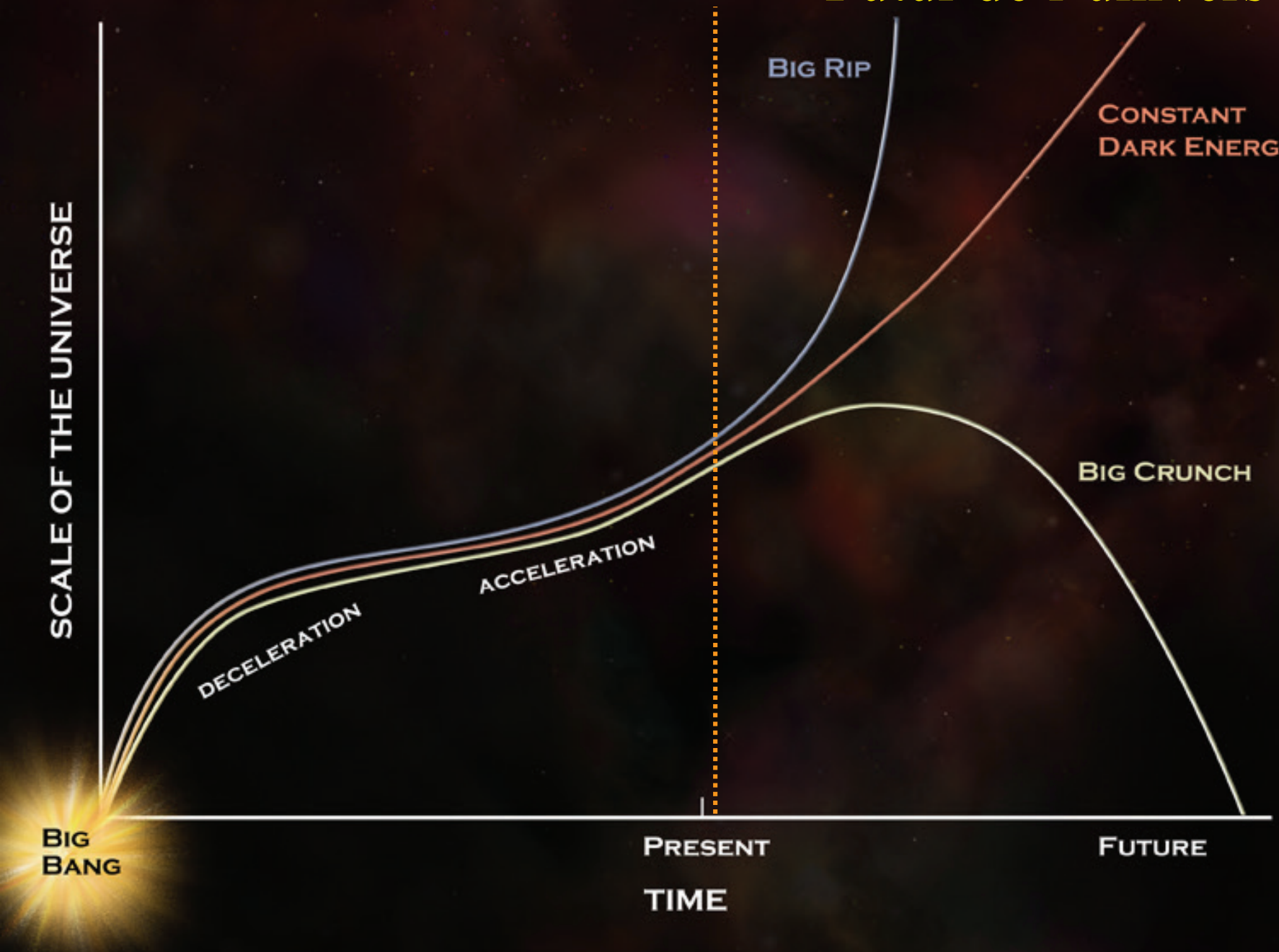


Qu’est-ce que l’énergie noire ?

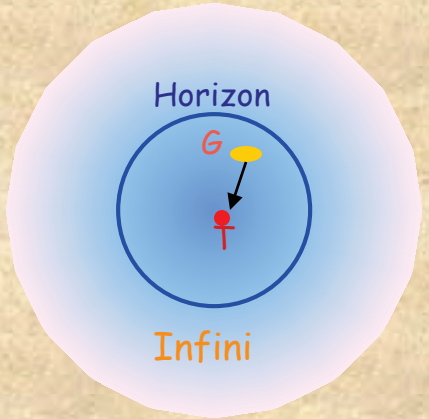
Vide quantique ?

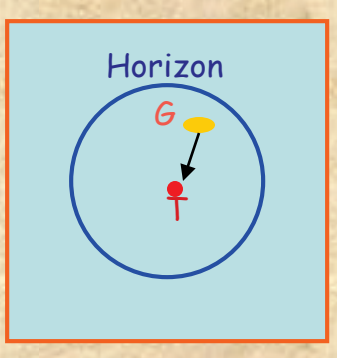


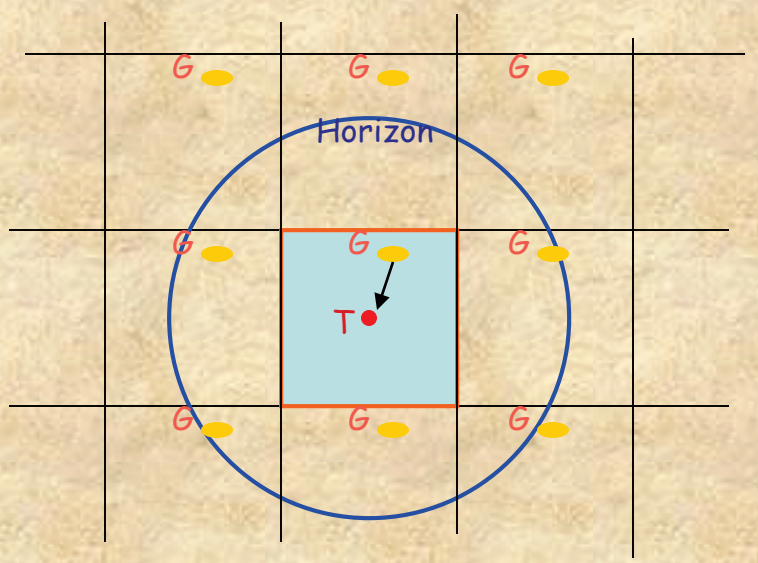
Futur de l'univers ?



Quelle est la taille et la forme de l'univers ?







Hypothèse 1

L'univers est infini

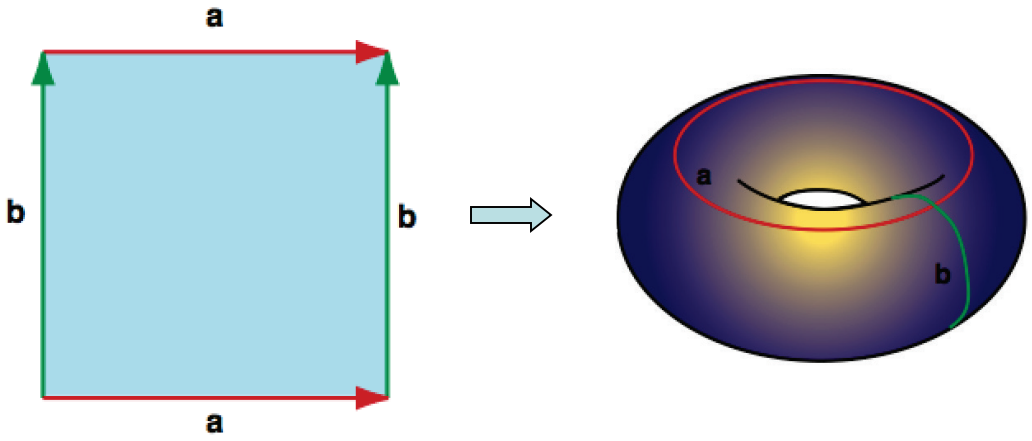
Hypothèse 2

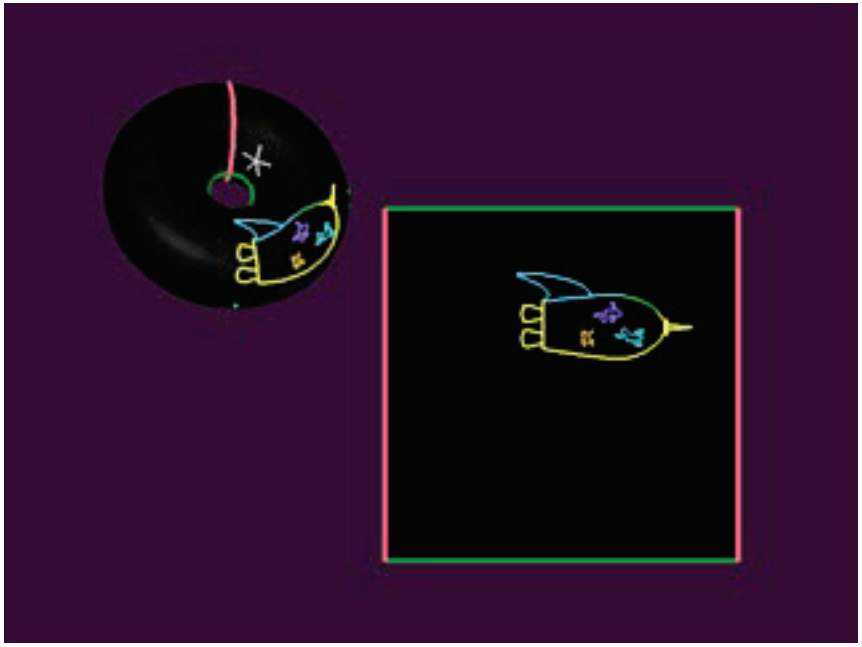
L'univers est fini (sans bord) mais plus grand que l'univers visible

Hypothèse 3

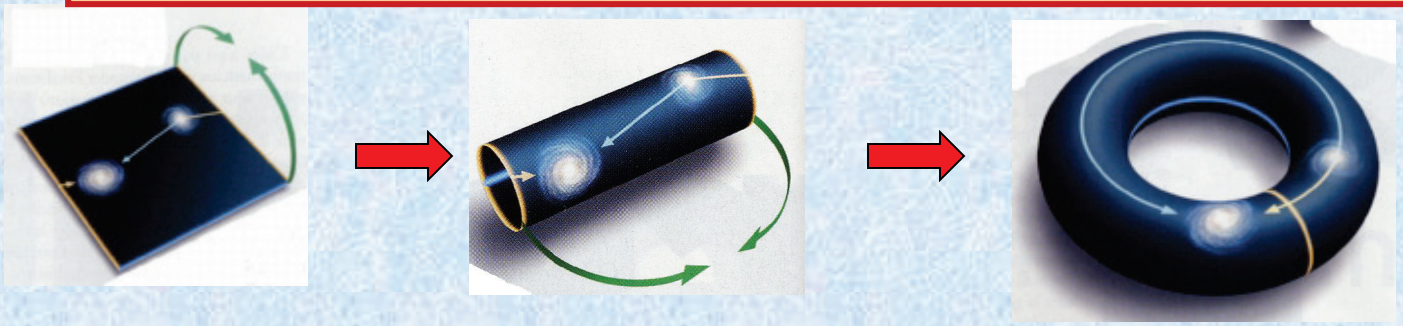
L'univers est fini (sans bord) et plus petit que l'univers visible

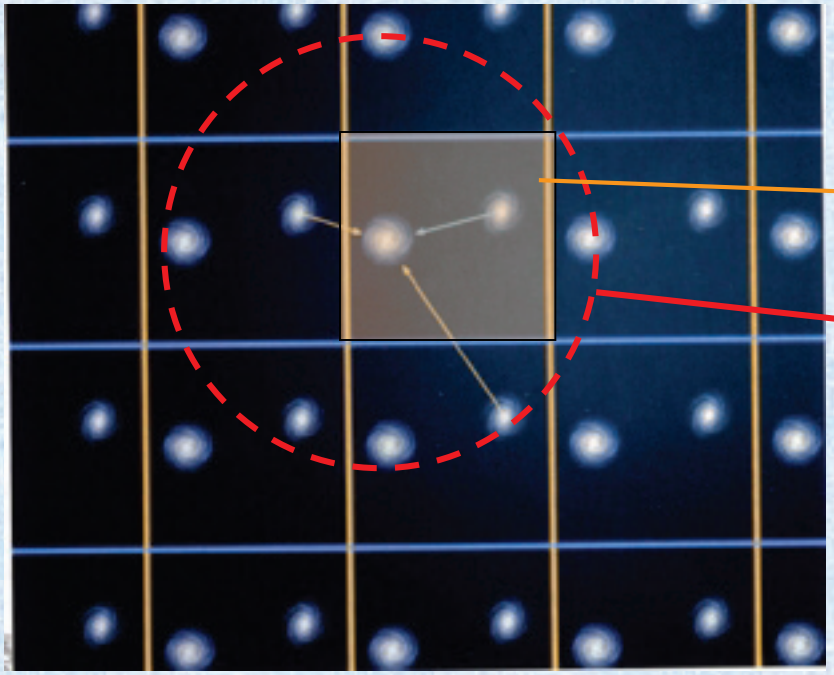
Espace fini sans bord : tore plat

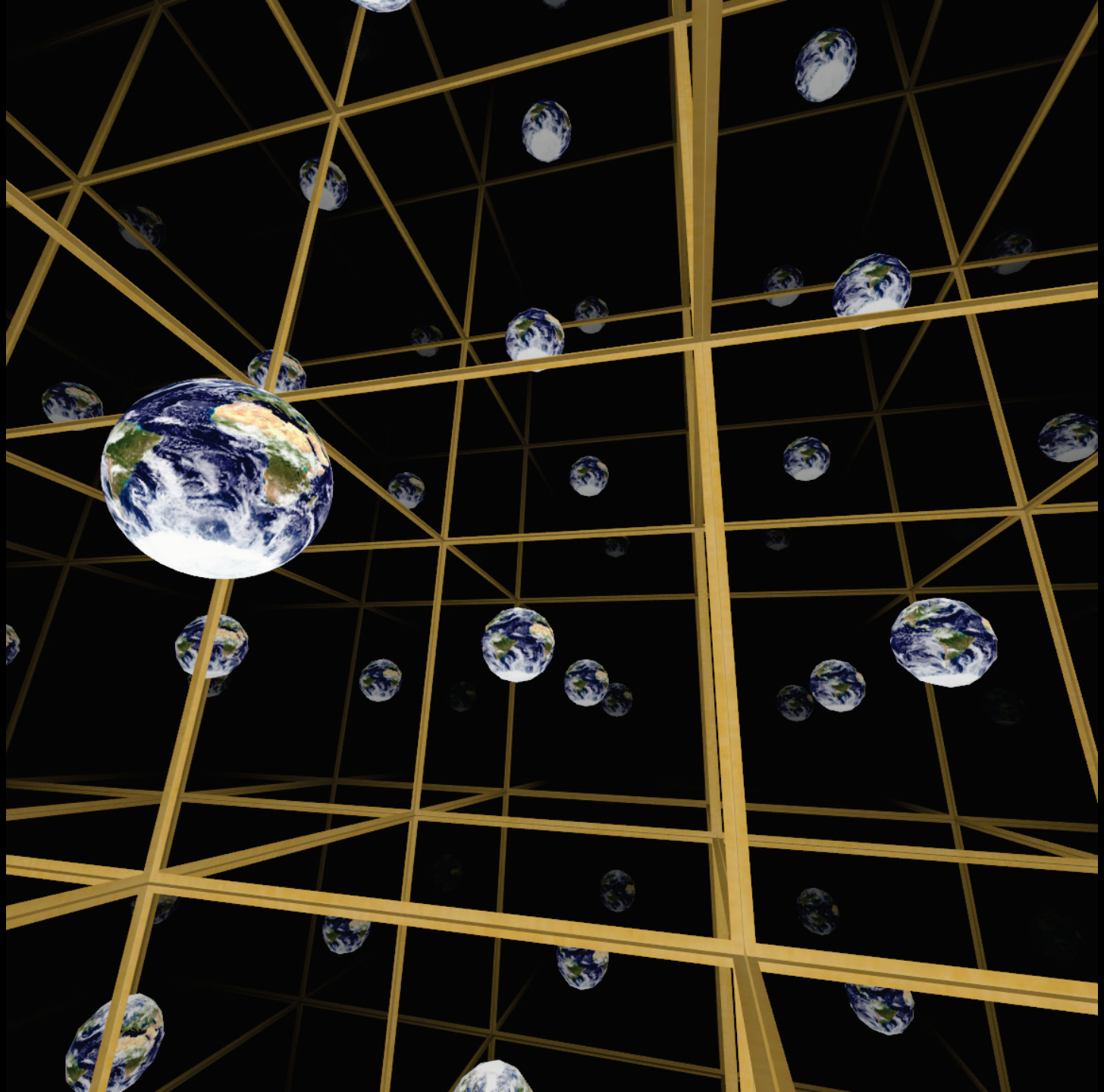




Effet de mirage topologique

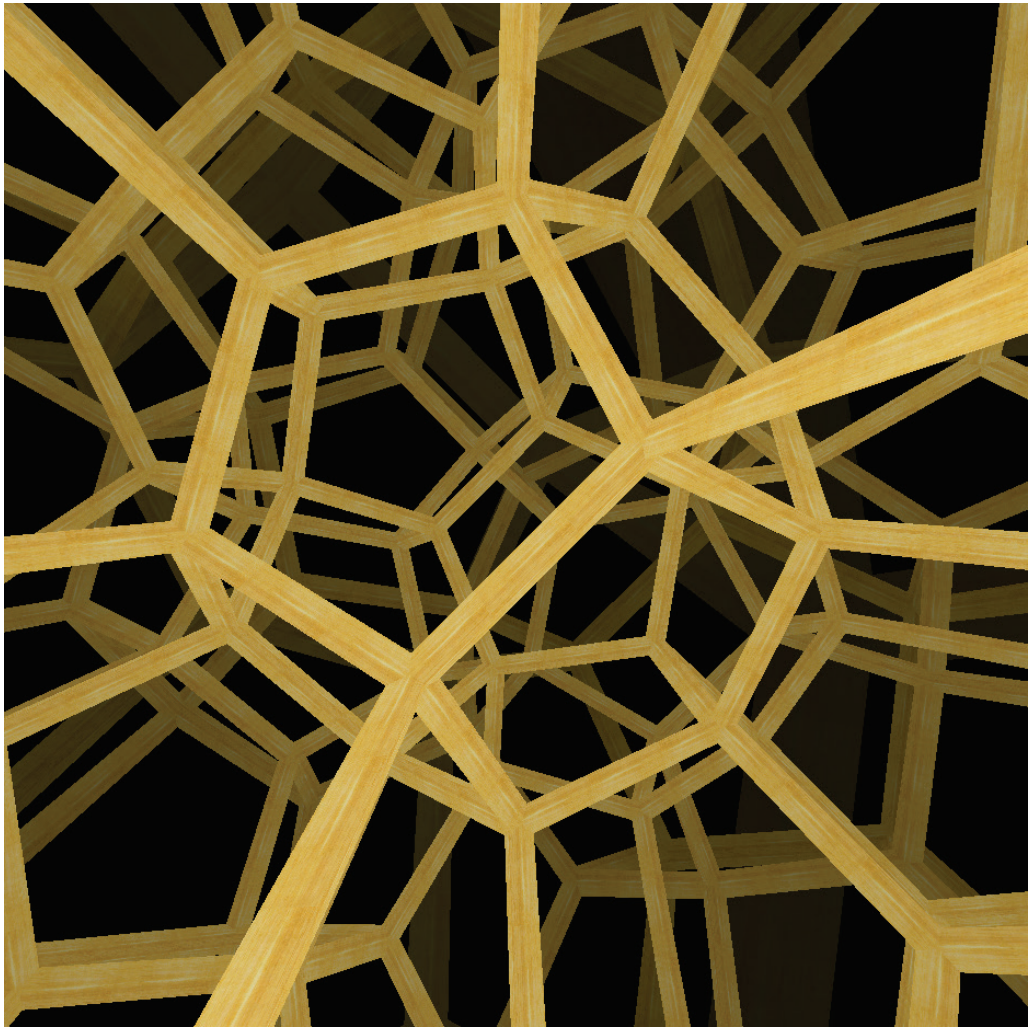




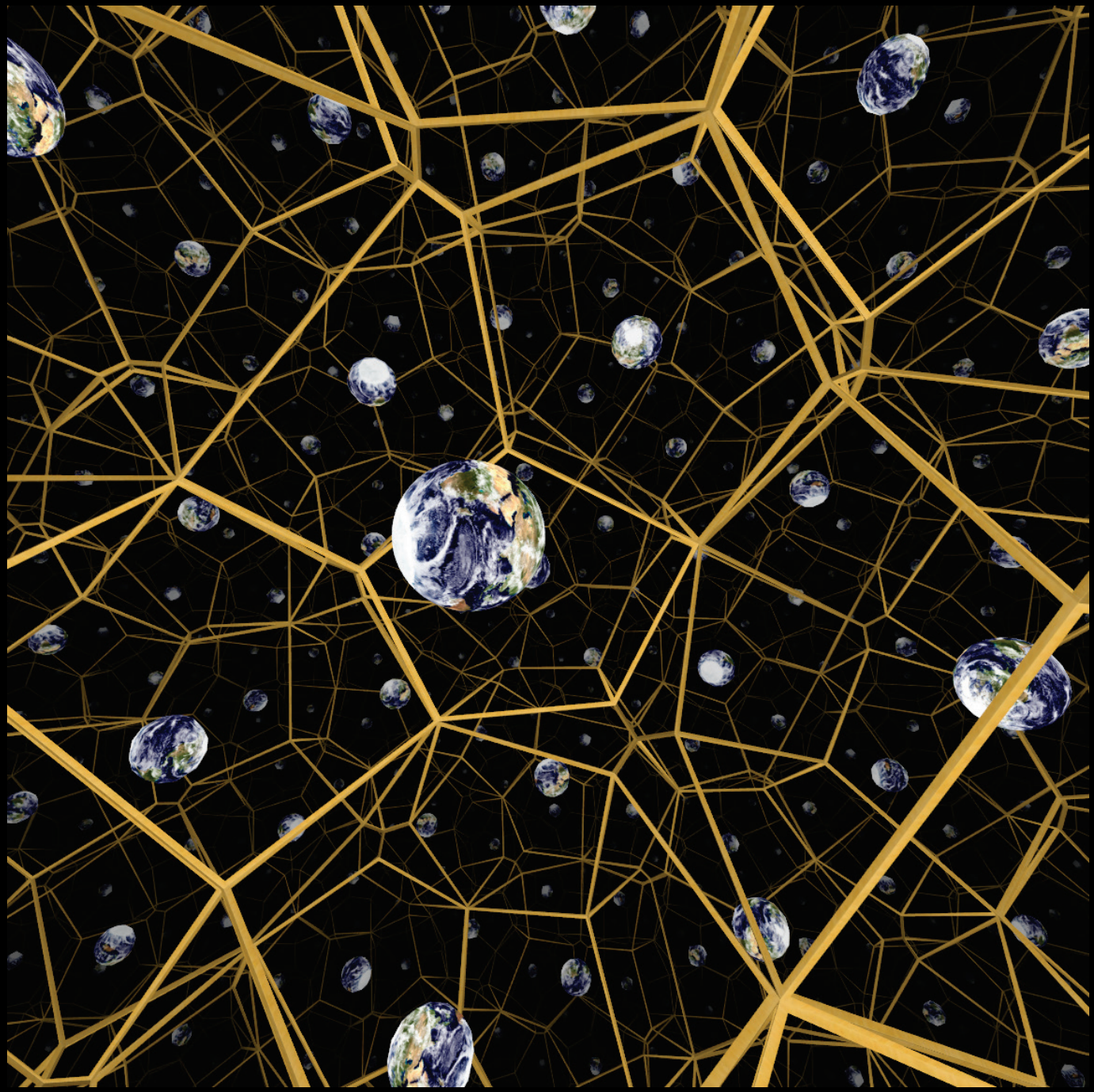


René Magritte

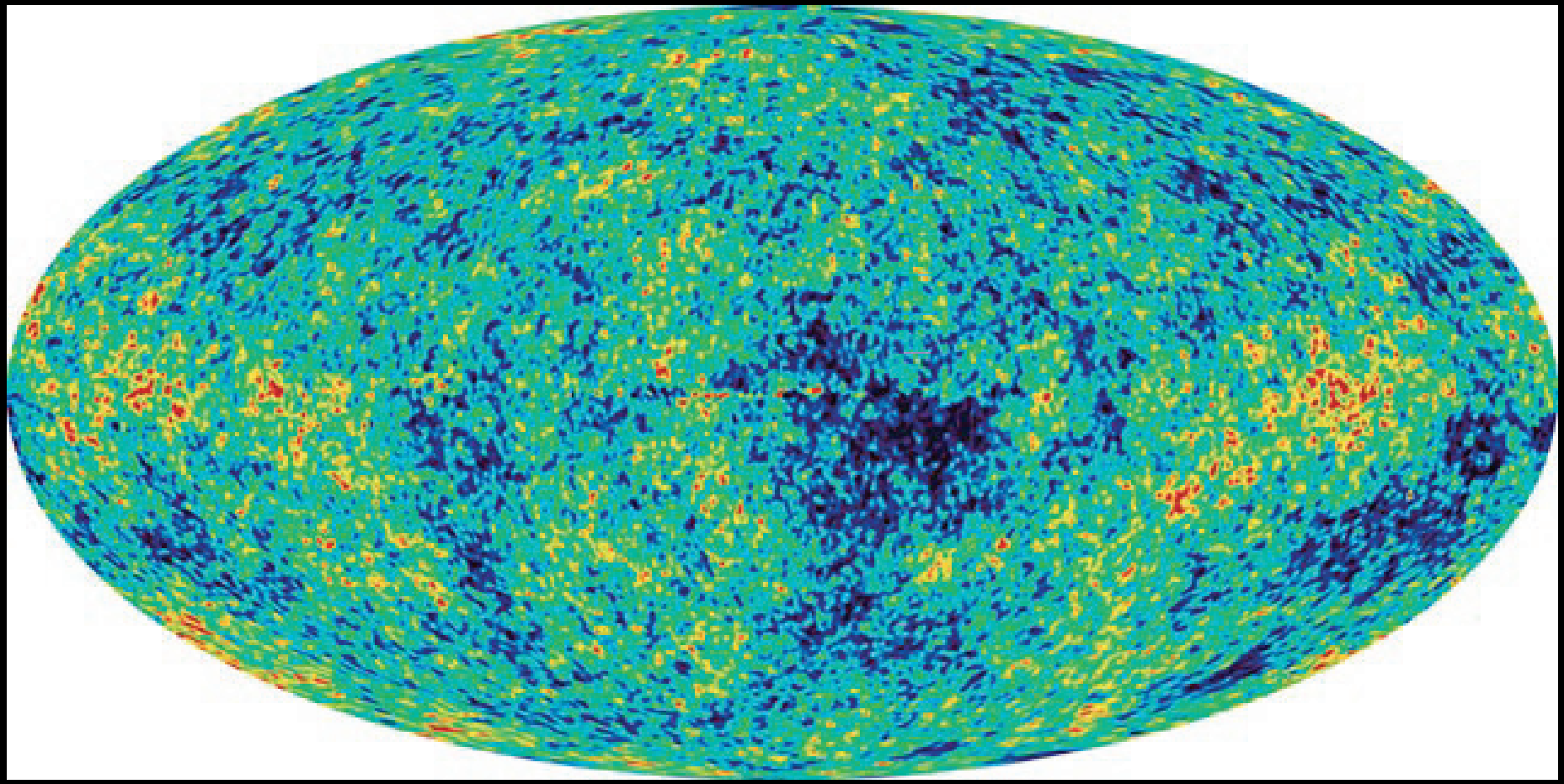
Espace Sphérique Dodécaédrique



Curved Spaces Program

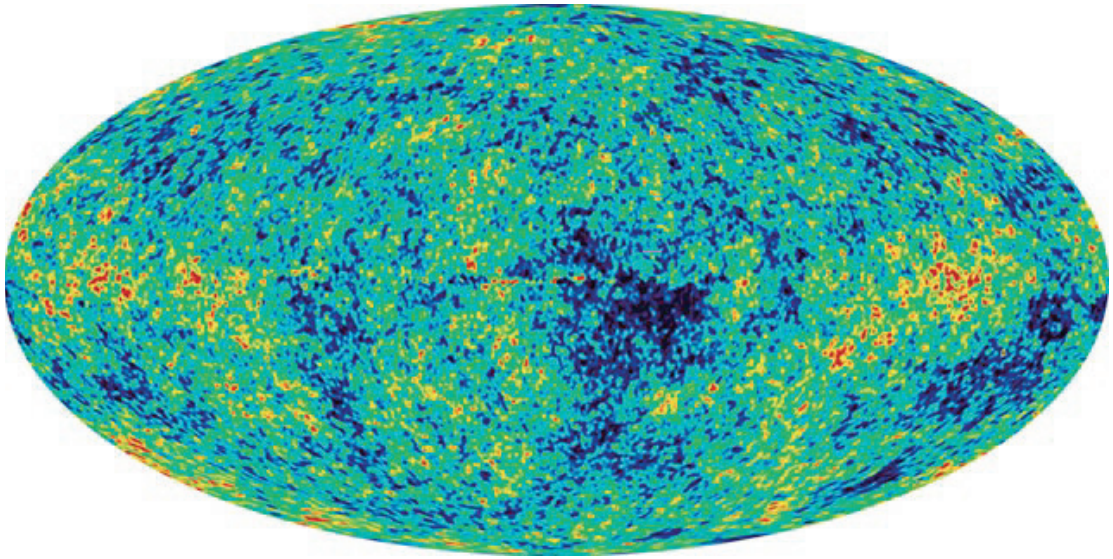


Le rayonnement fossile

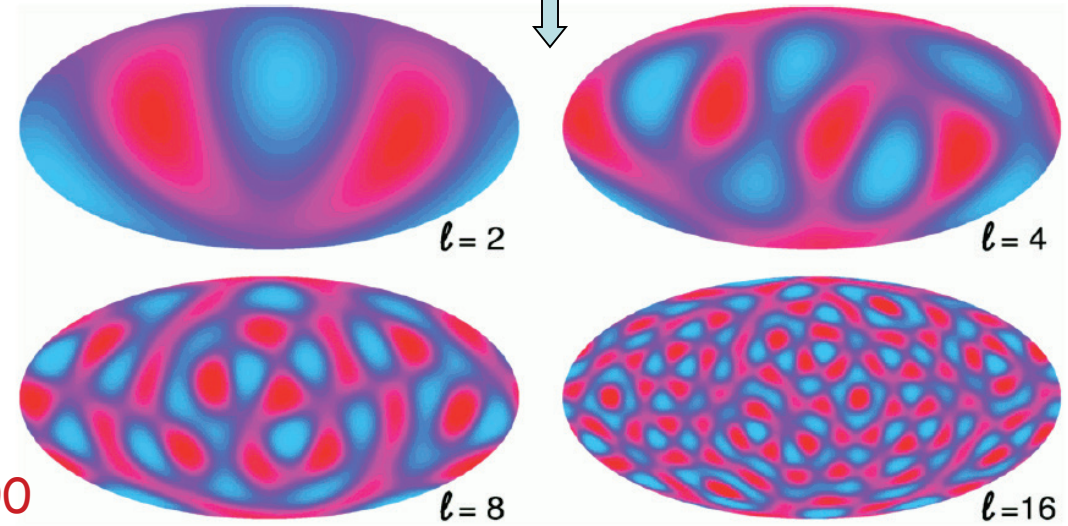


L' univers comme « tambour cosmique »

Décomposition harmonique en multipoles



Quadrupole

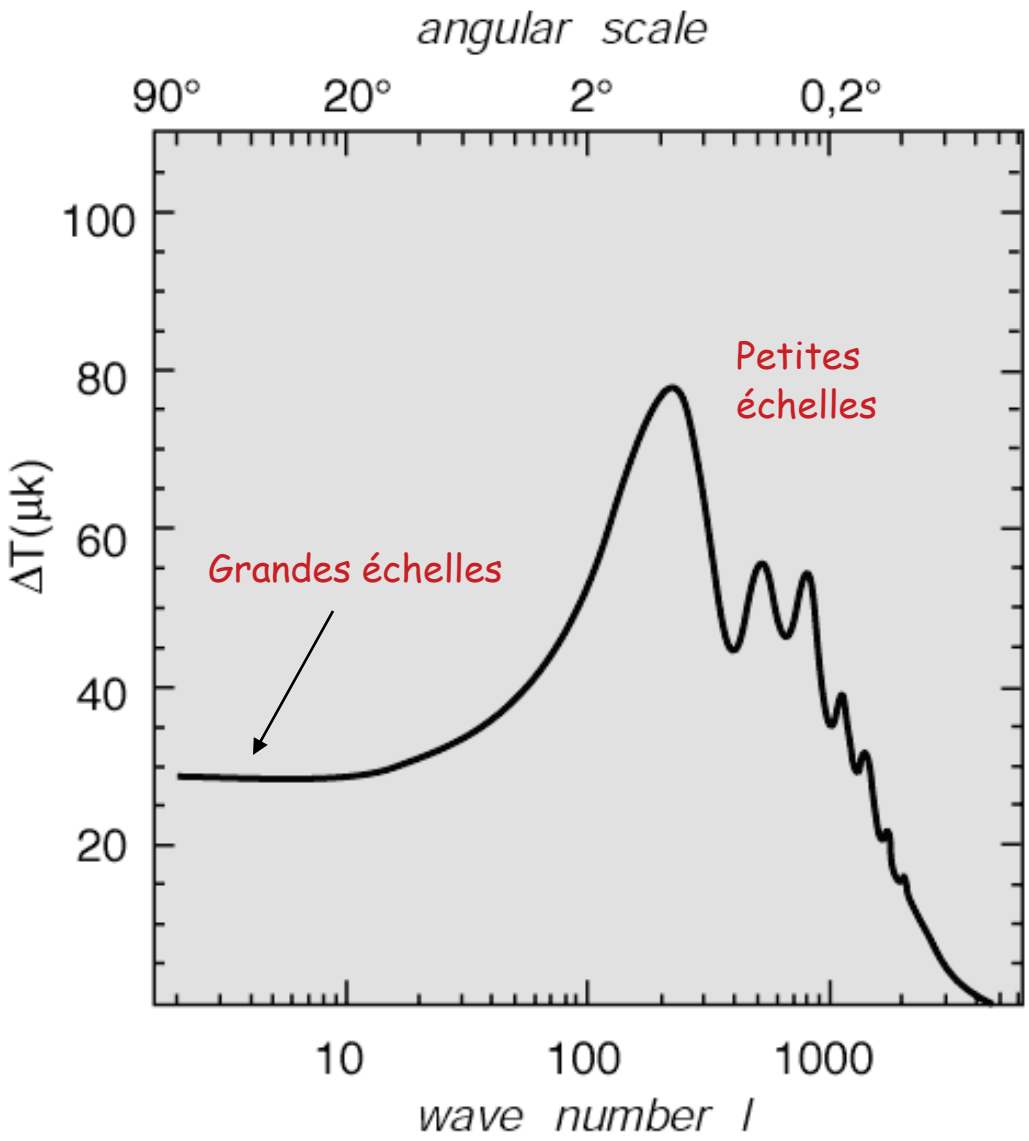


Octupole

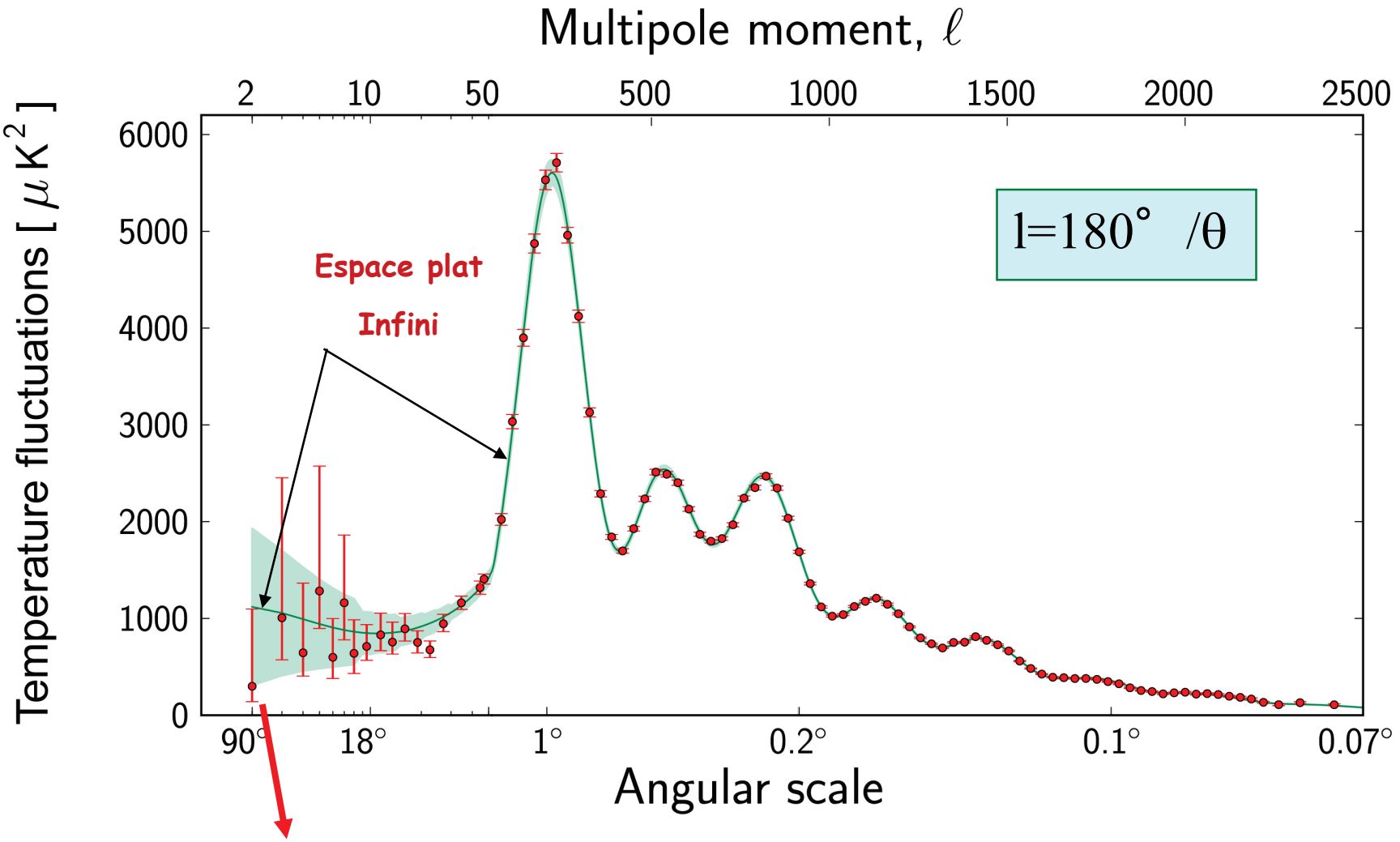
…jusqu' à l ~10 000

Spectre de puissance

l=180° / θ



Observations

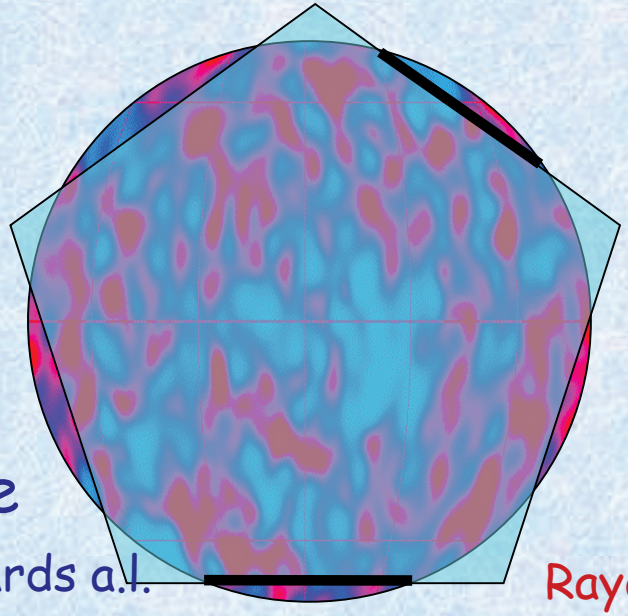


Espace fini ?

L'univers « ballon de foot »

*Luminet et al., Nature **425**, 593 (2003)*

L'espace dodécaédrique en « 2D »



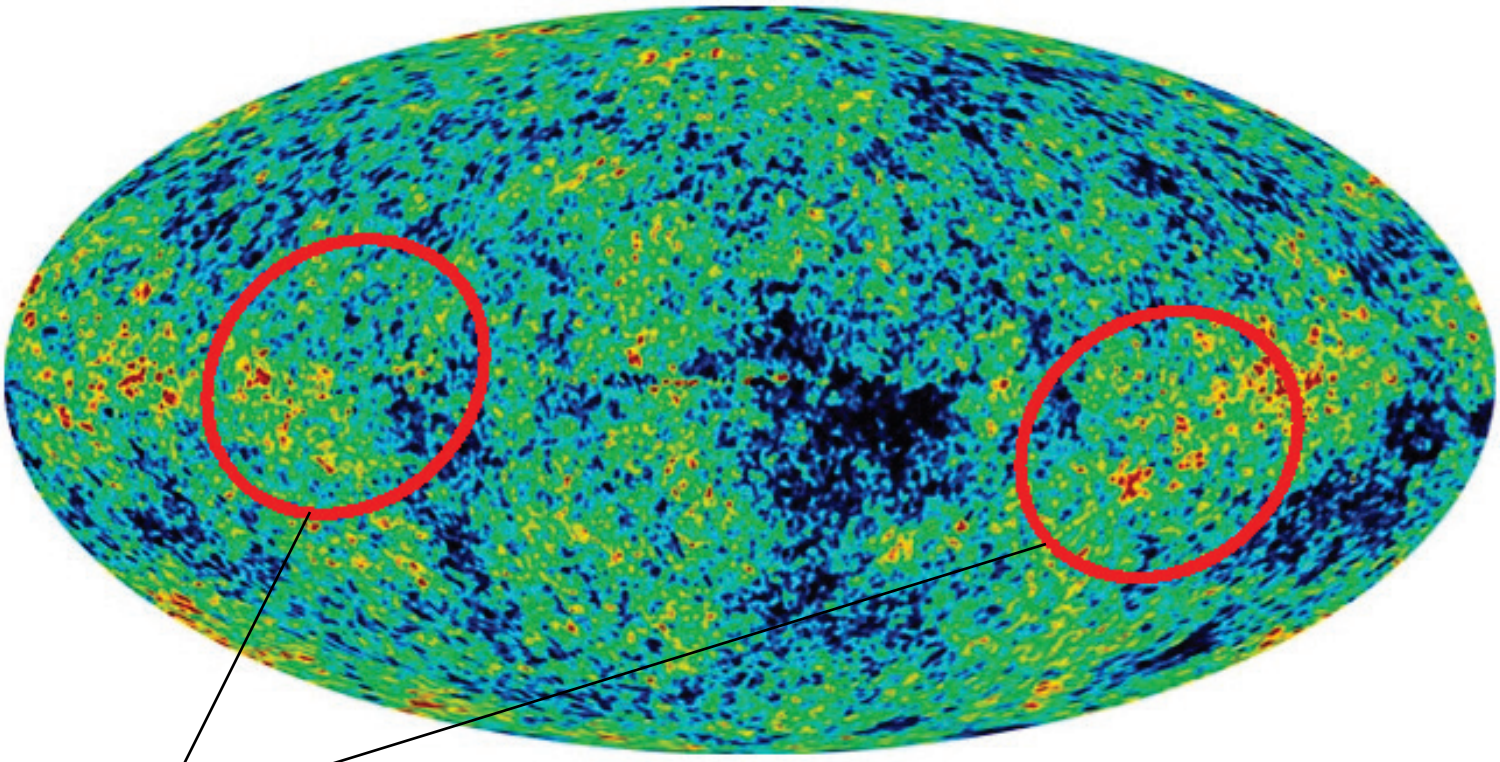
Espace physique

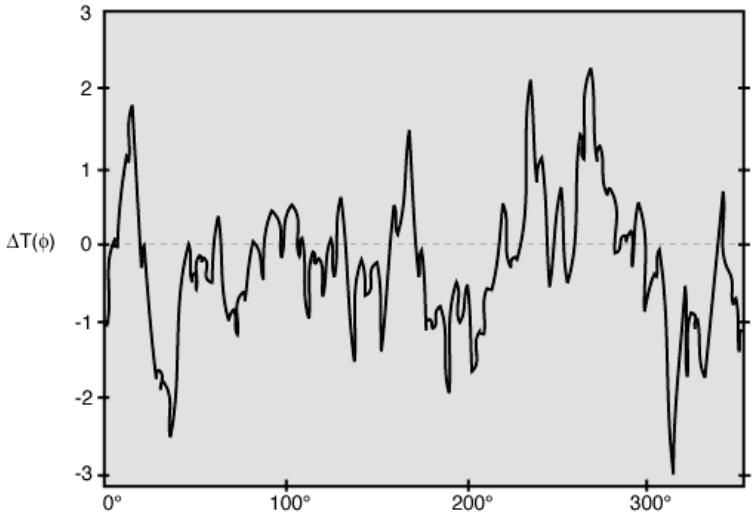
Rayon = 43 milliards a.l.

Univers observable

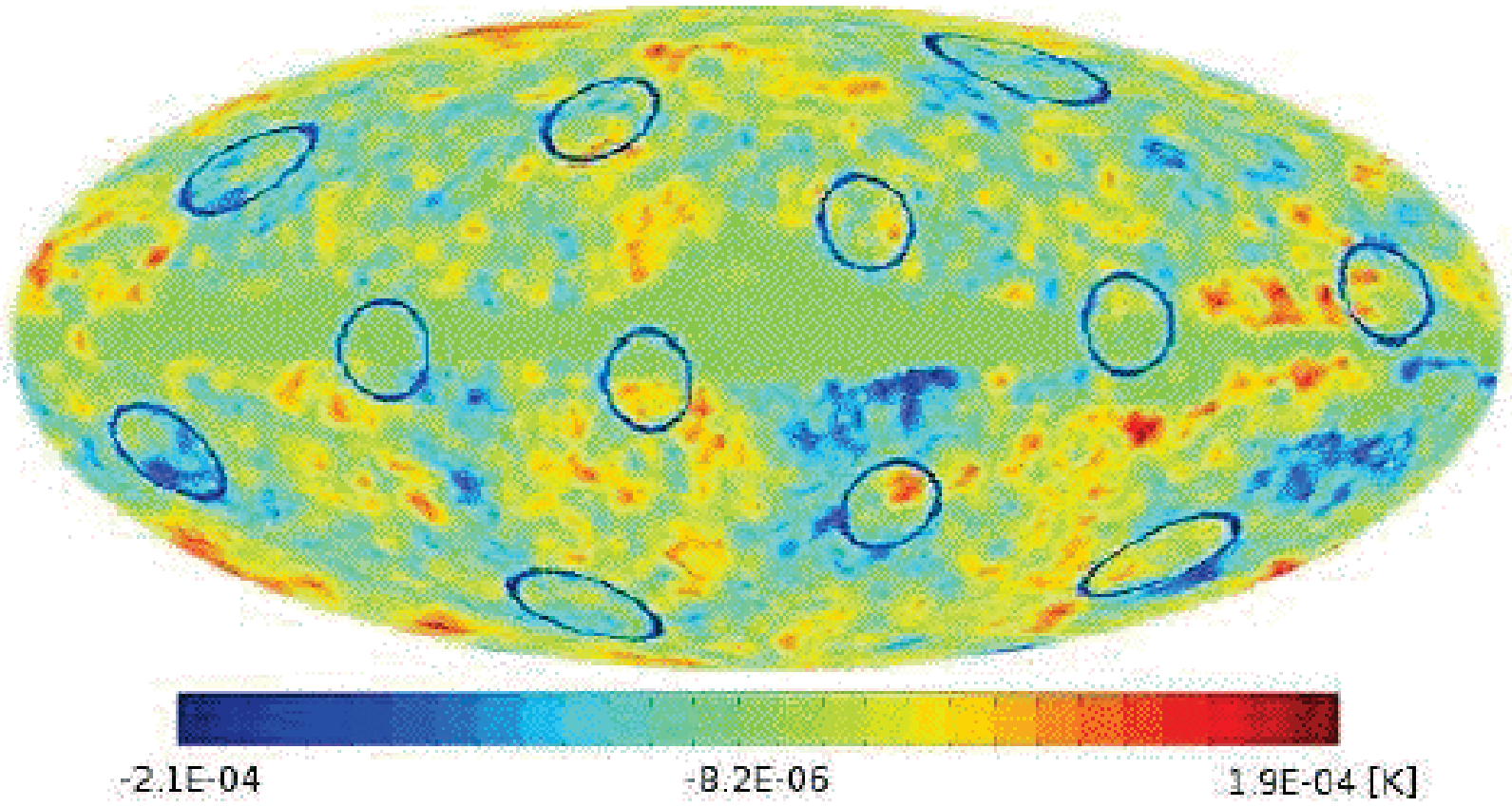
Rayon = 53 milliards a.l.

Volume(Espace) = 80 % Vol(U_{obs}) → Mirage topologique!





Chercher des paires de cercles identiques dans le ciel

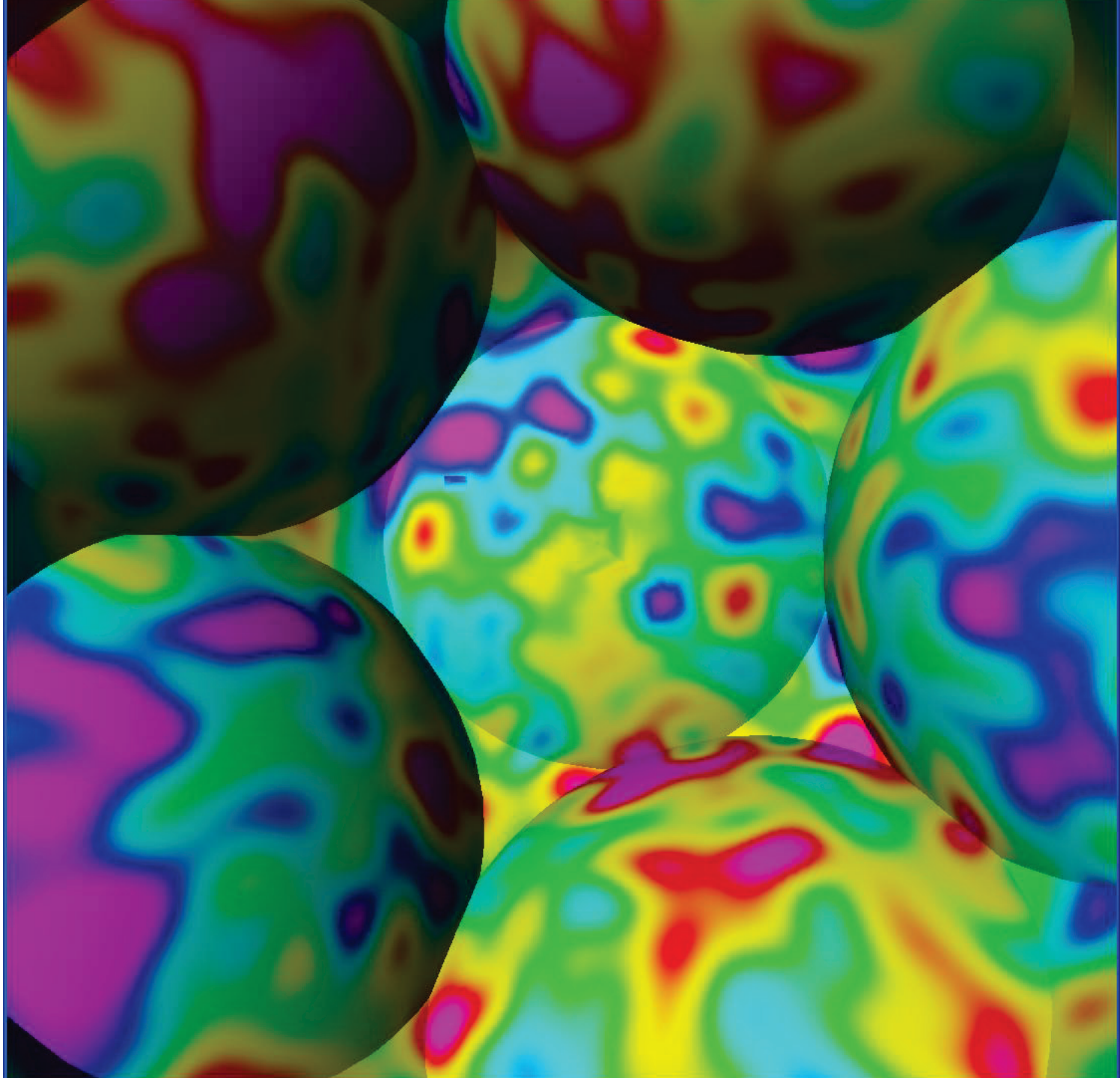


PDS : Six paires de cercles corrélés, antipodaux, déphasés de 36°

Paires de cercles calculées dans PDS

pour

$\Omega = 1.018$



Planck 2013 results. XXVI. Background geometry and topology of the Universe

Planck Collaboration: P. A. R. Ade[82], N. Aghanim[56], C. Armitage-Caplan[87], M. Arnaud[69], M. Ashdown[66,6], F. Atrio-Barandela[18], J. Aumont[56],

http://arxiv.org/abs/1303.5086

ISSN 0202-2893, Gravitation and Cosmology, 2014, Vol. 20, No. 1, pp. 15–20. © *Pleiades Publishing, Ltd., 2014.*

Cosmic Topology: Twenty Years After[1]

Jean-Pierre Luminet*

Laboratoire Univers et Théories, Observatoire de Paris-CNRS-Université Paris Diderot, France

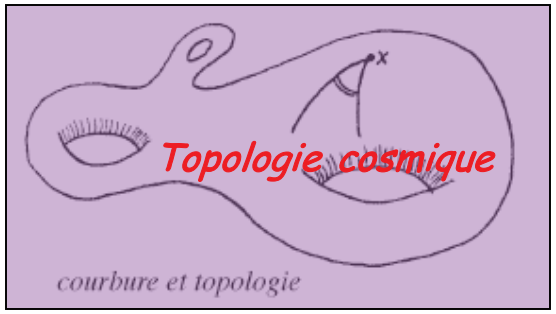
Received October 4, 2013

http://arxiv.org/abs/1310.1245

4 niveaux de la géométrie

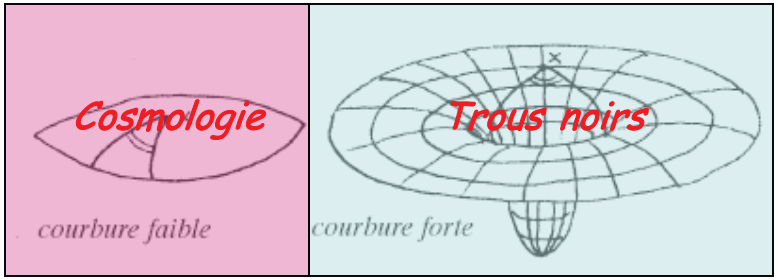
?

Niveau 1



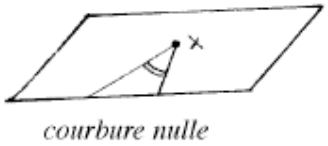
Topologie cosmique

Niveau 2



Relativité générale, cosmologie

Niveau 3



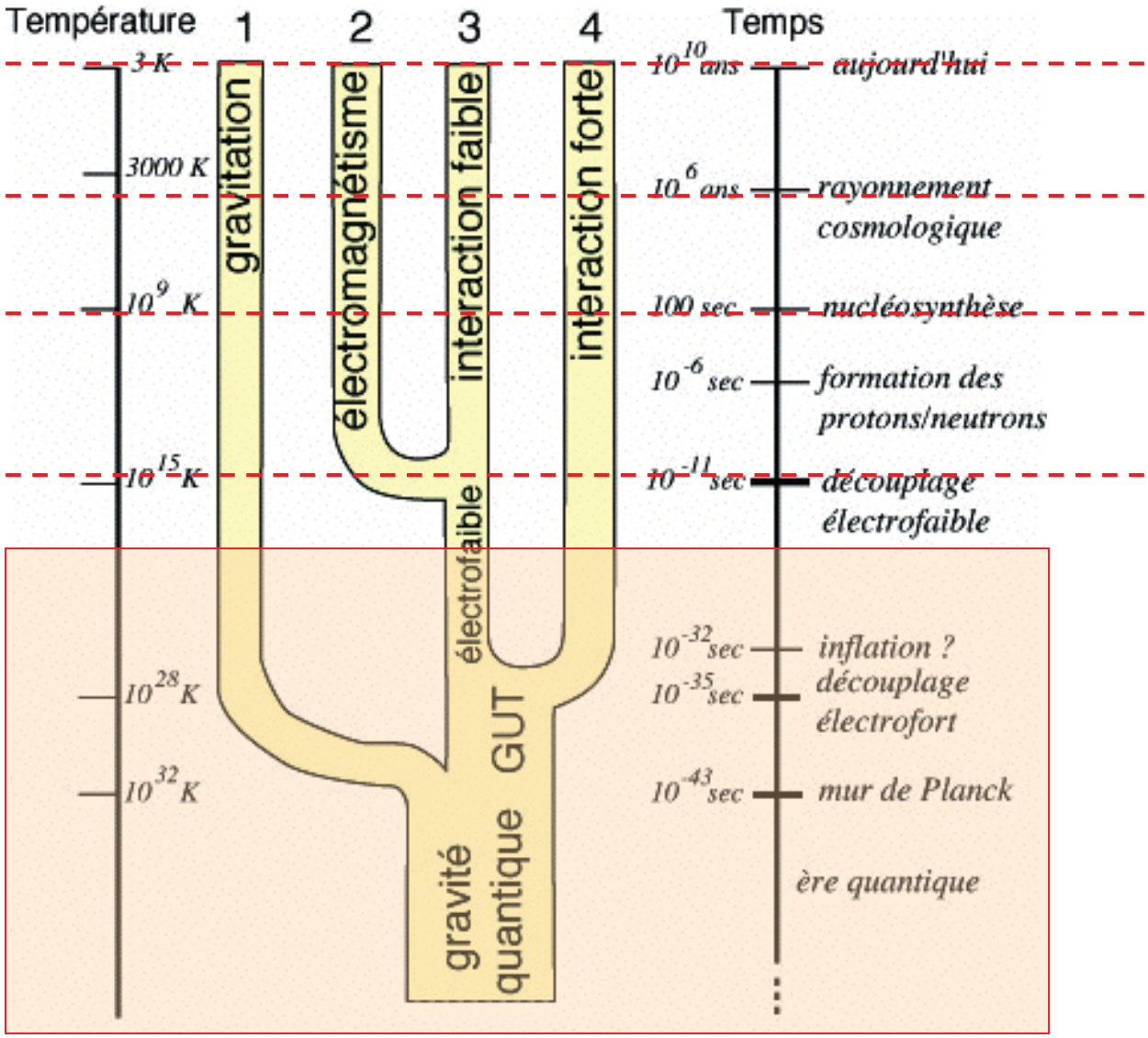
Mécanique classique, Relativité restreinte

Niveau 4

Gravitation quantique, Théories d'unification


Une vision unifiée ?

Unification des interactions fondamentales



Observation des galaxies

Observation micro-ondes

Observation des abondances

Expériences CERN

Modèles théoriques

Deux conceptions du monde:
Relativité générale / mécanique quantique

- Chacune est incomplète
- Cadres mathématiques différents
- l'espace-temps n'est pas quantifié comme la matière
- la gravitation n'est pas quantifiée comme les autres interactions

Solutions ?

Réduire la géométrie à la matière

Supercordes

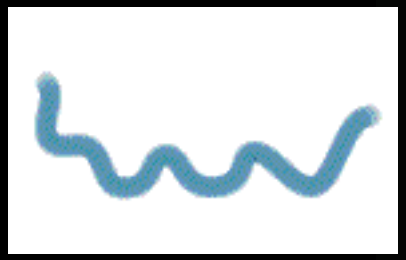
branes

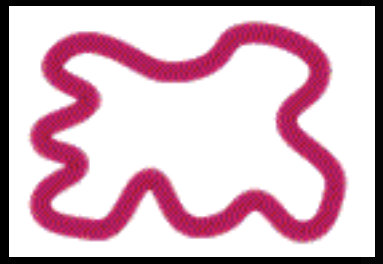
Réduire la matière à la géométrie

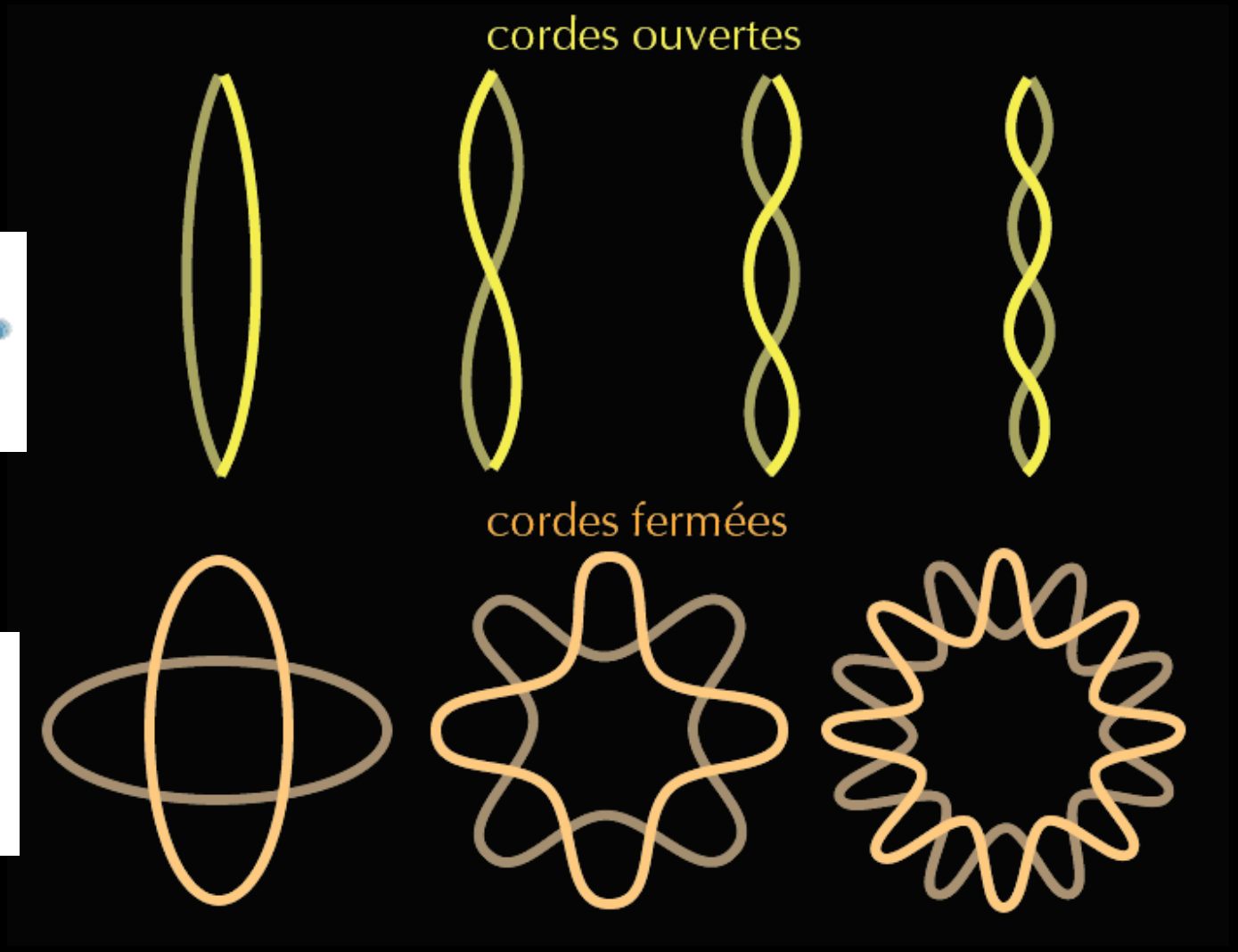
Gravité quantique à boucles

Théorie des cordes

taille ~10^{-33} cm



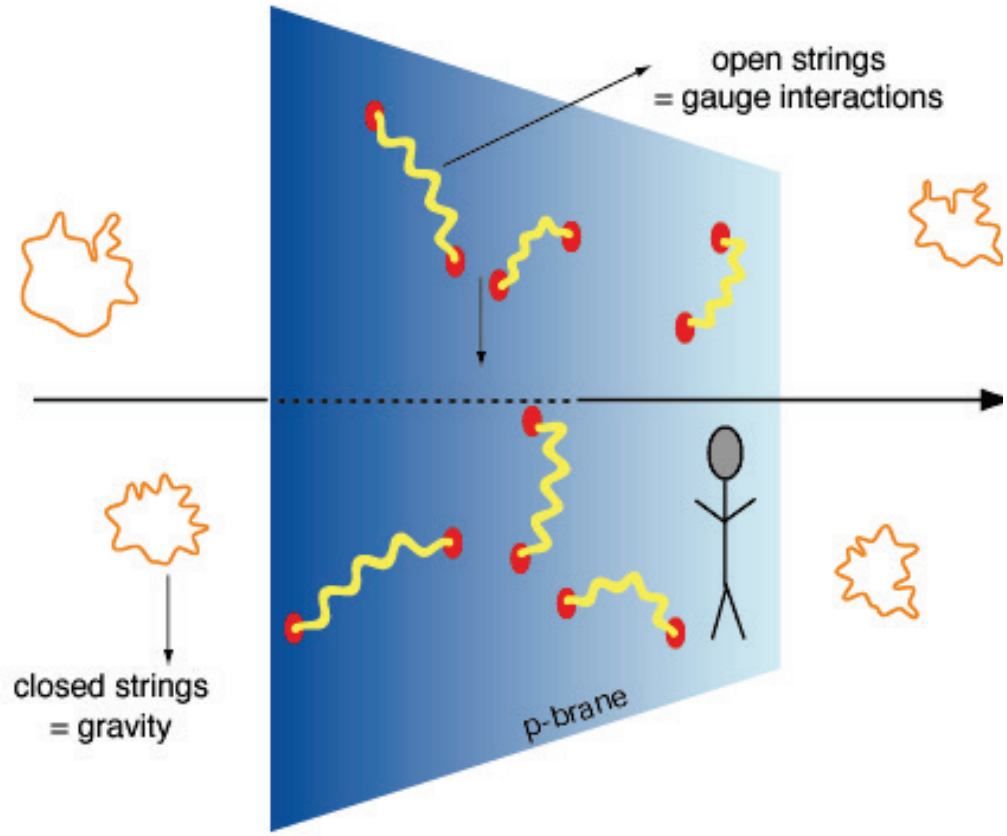


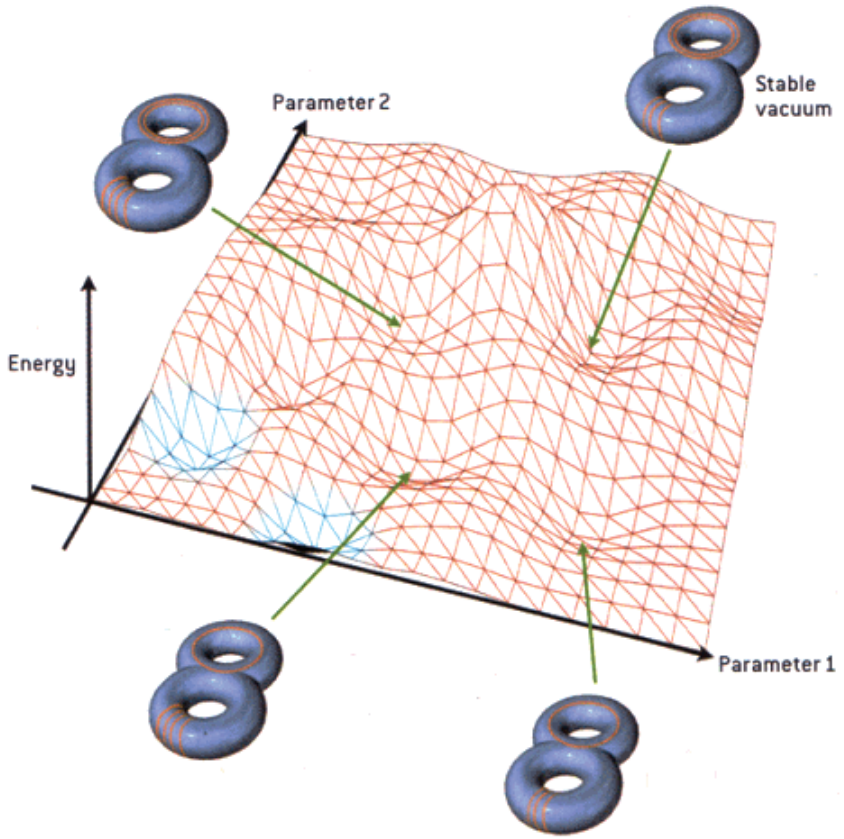


Théorie des cordes

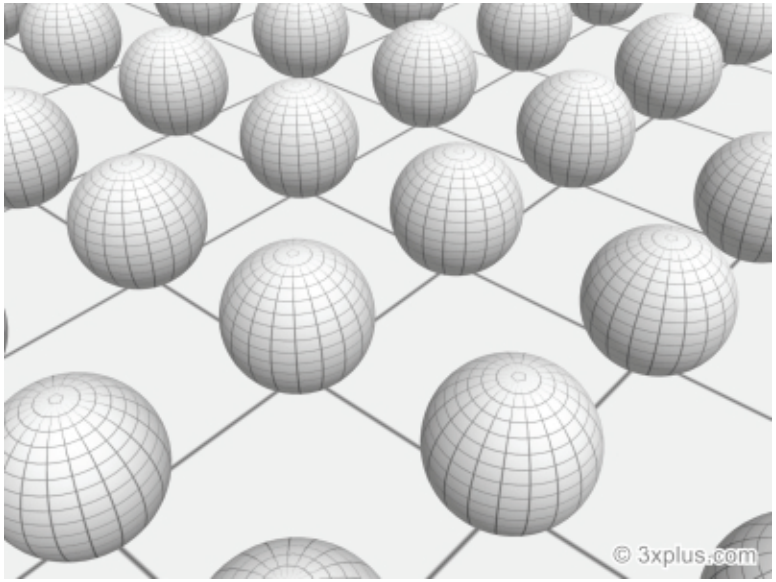
Prix à payer 1 :
Dimensions supplémentaires

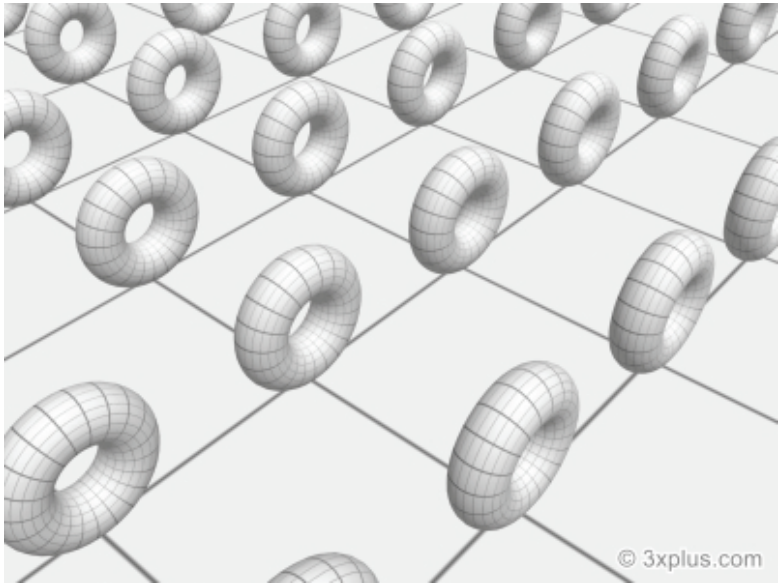
Prix à payer 2 :
10^{500} solutions

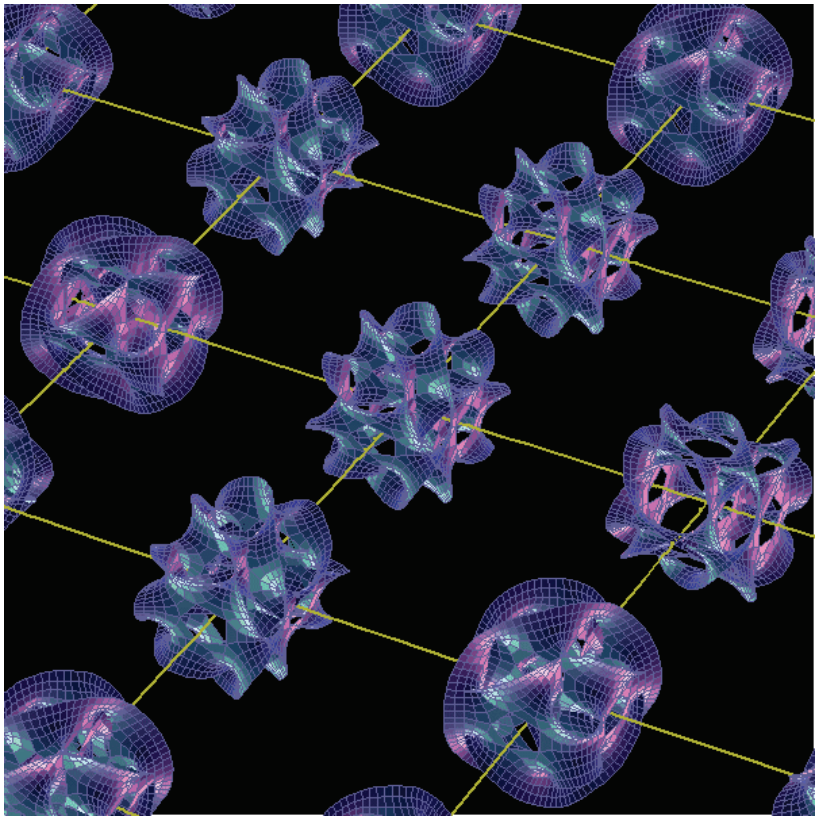




Théories des Cordes





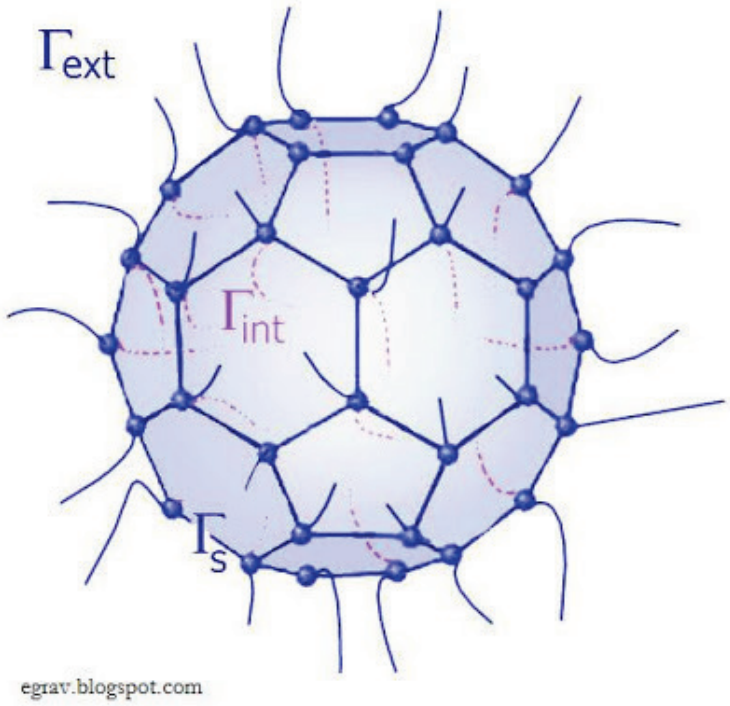


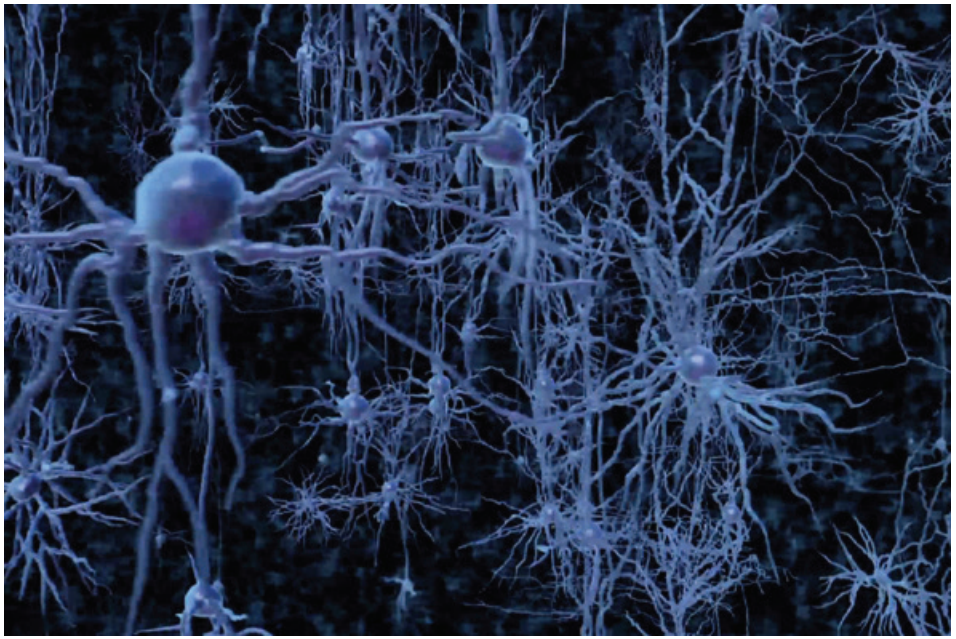
La topologie des espaces de Calabi-Yau engendre

les familles de particules..

Gravité quantique à boucles

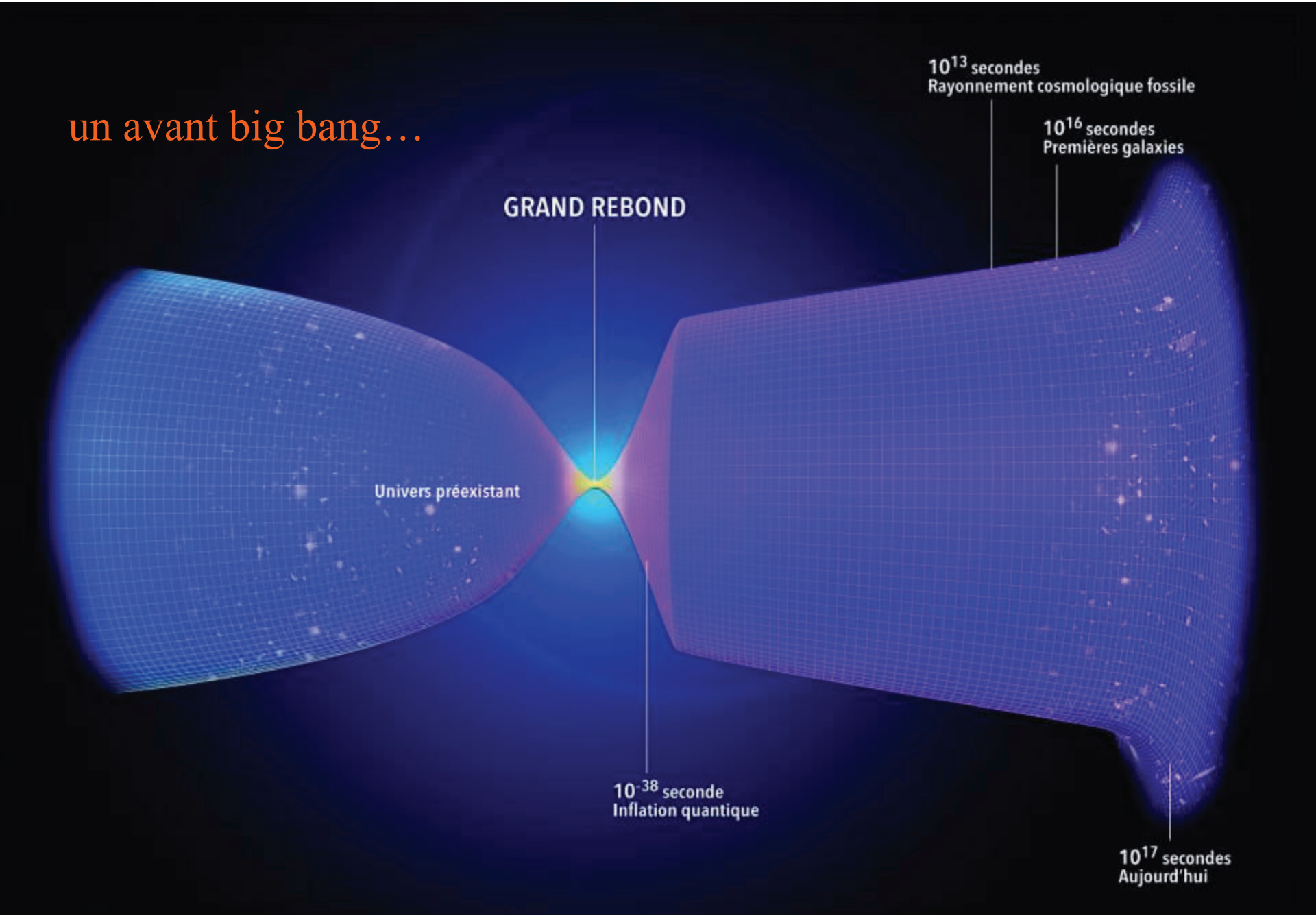
Atomes d' espace : vol ~ 10^{-99} cm^3





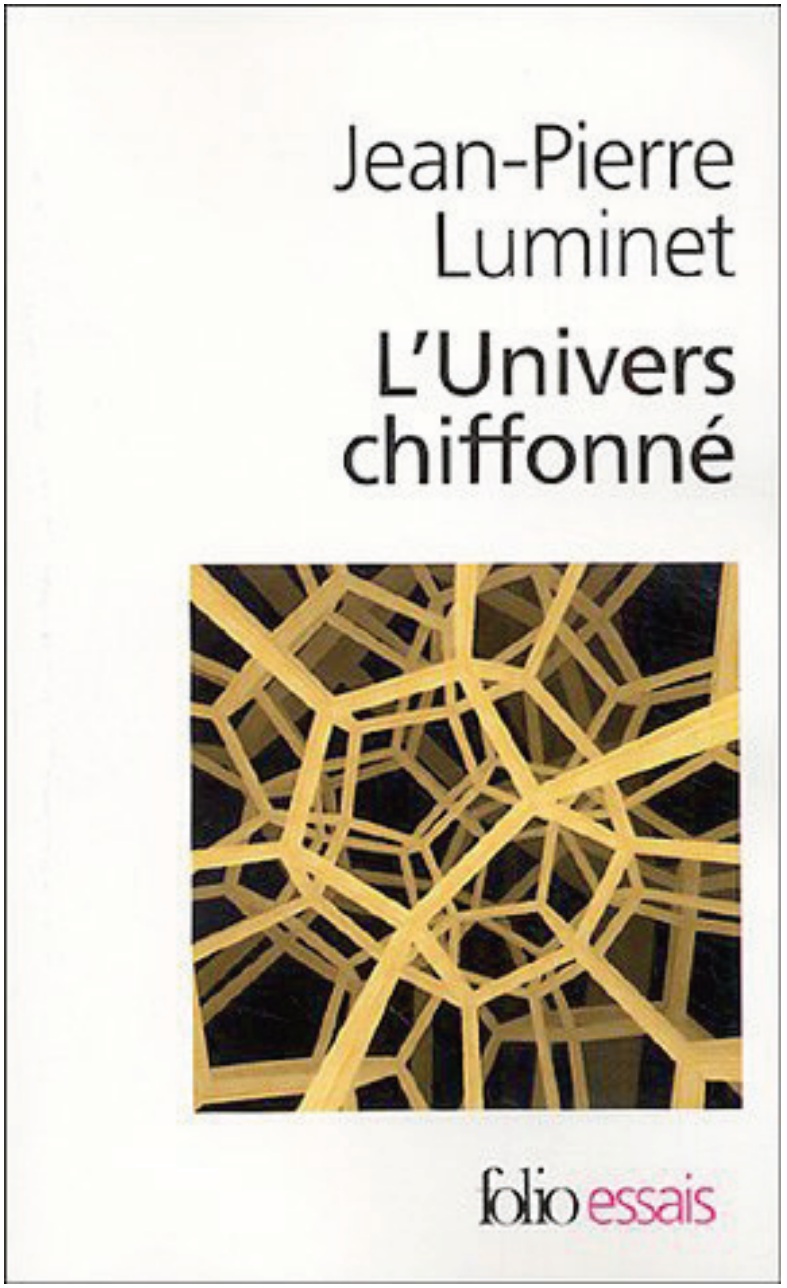
Formalisme : Réseaux de spins

un avant big bang…




Si Dieu m'avait consulté
avant de s'embarquer dans
la Création du Monde, je lui
aurais conseillé quelque
chose de plus simple...
Alphonse X « le Sage », Roi de Castille


JEAN-PIERRE LUMINET
Le destin de l'univers
Trous noirs et énergie sombre
Le temps des sciences
fayard


Jean-Pierre Luminet
L'Univers chiffonné
folio essais