Le Big Bang et la naissance du temps en Relativité Générale

CPPM
2014

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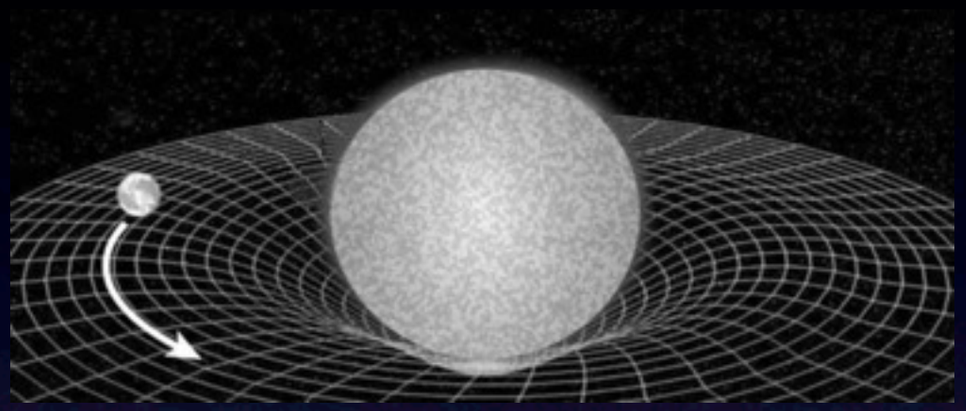
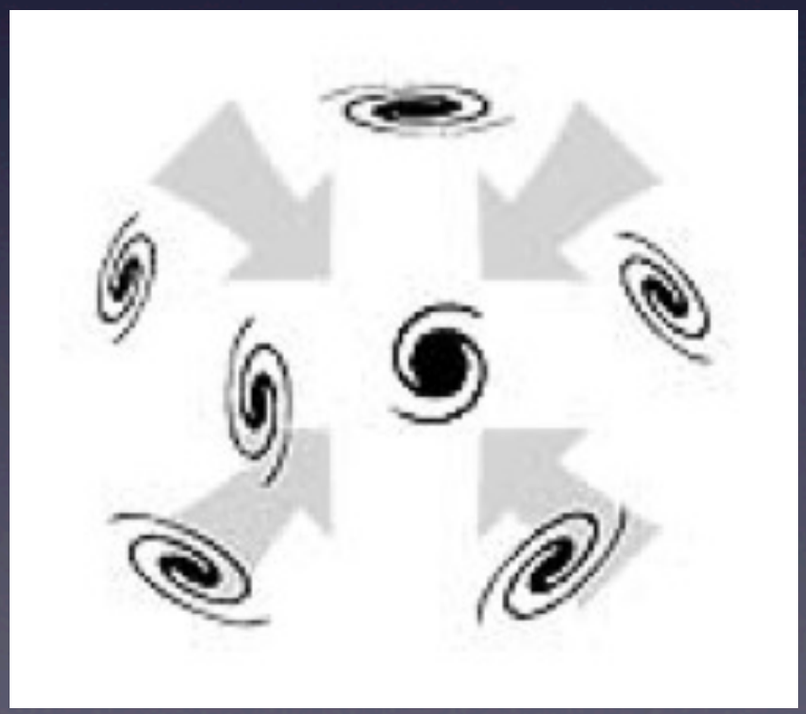
Evidence Observationnelle

Einstein (1916)

$$R_{ab} - \frac{1}{2} R \, g_{ab} = T_{ab}$$

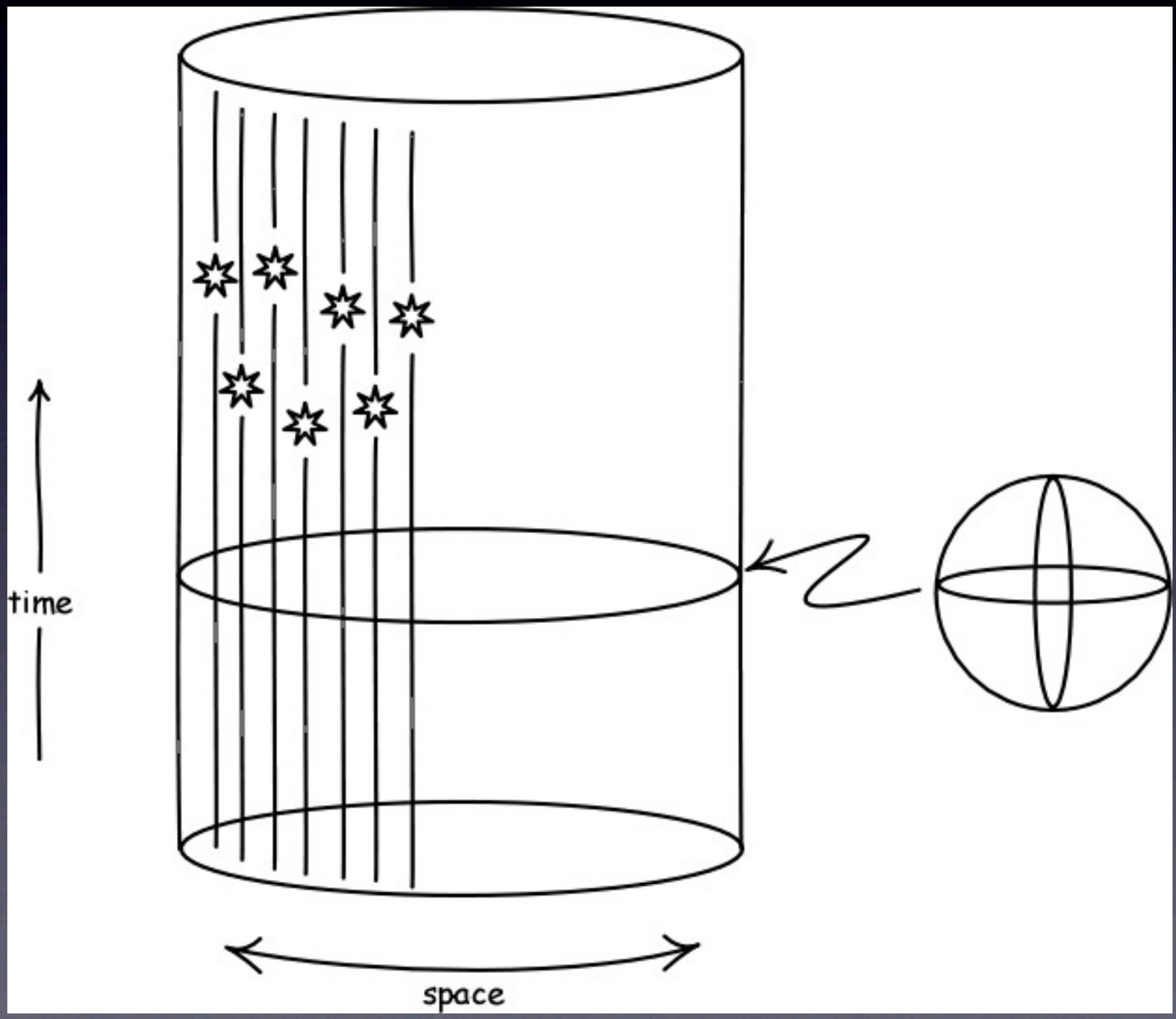




Einstein (1916)

$$R_{ab} - \frac{1}{2} R \; g_{ab} = T_{ab} + \Lambda \; g_{ab}$$

Einstein (1917)

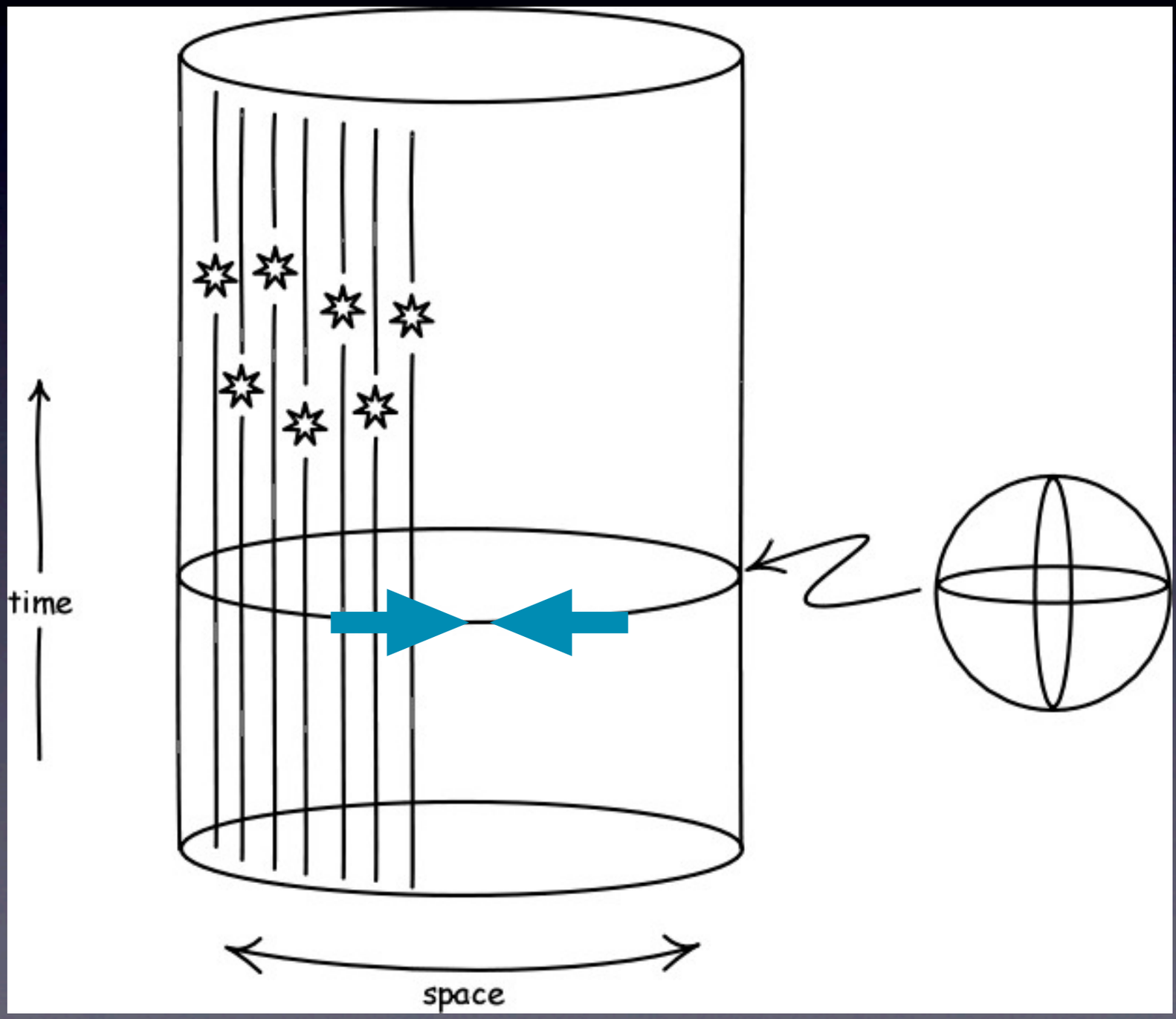


Einstein (1916)

$$R_{ab} - \frac{1}{2} R\, g_{ab} = T_{ab} + \Lambda\, g_{ab}$$

Matiere normale

Einstein (1917)



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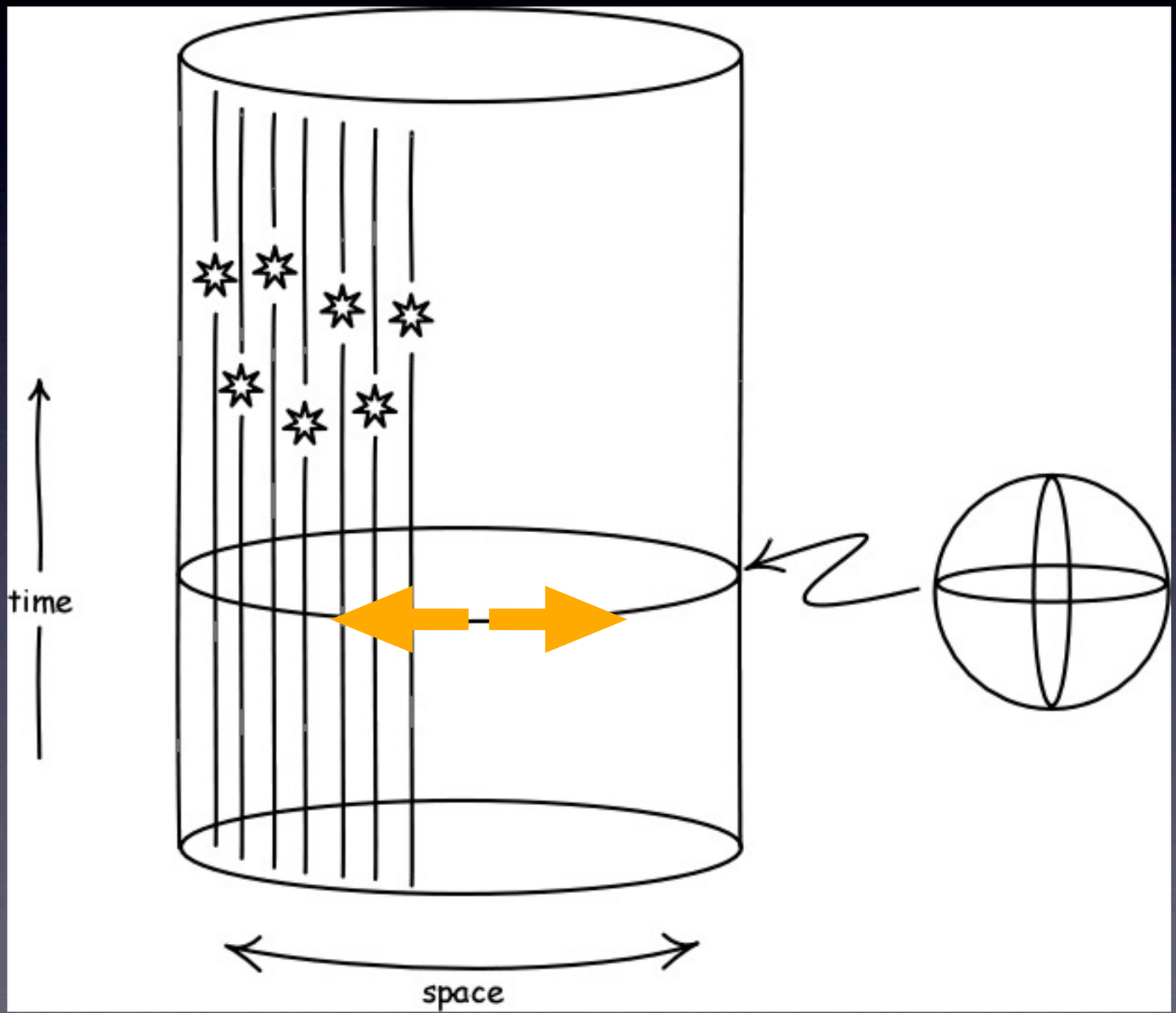
$$R_{ab} - \frac{1}{2} R \, g_{ab} = T_{ab} + \Lambda \, g_{ab}$$

Constante cosmologique: Energie Noir

Einstein (1917)

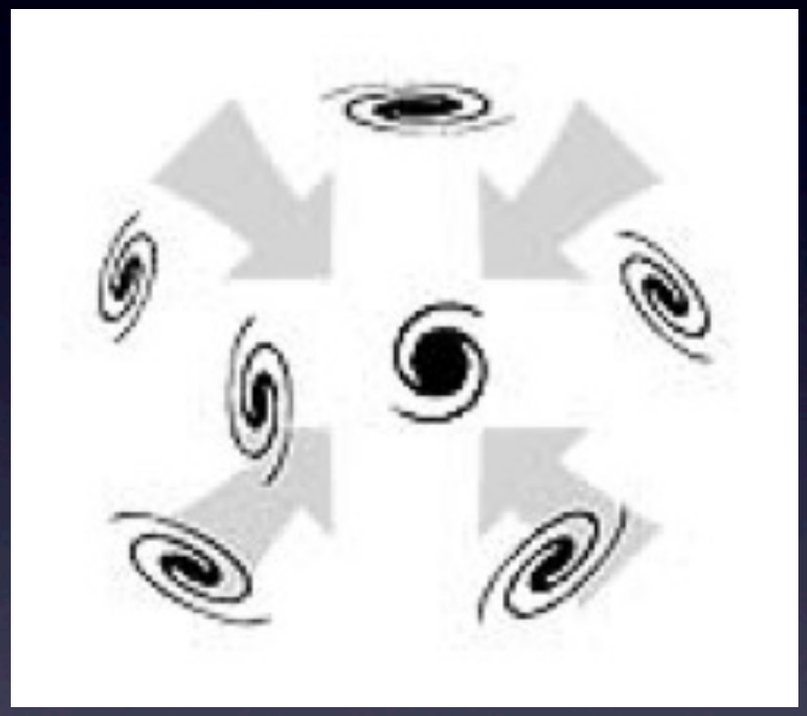


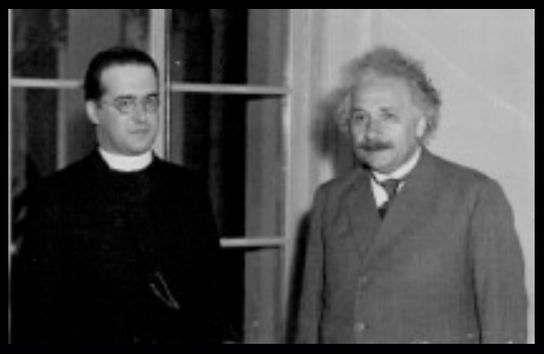
Expansion

La constante cosmologique et la « plus grande bêtise de ma vie»
A. Einstein

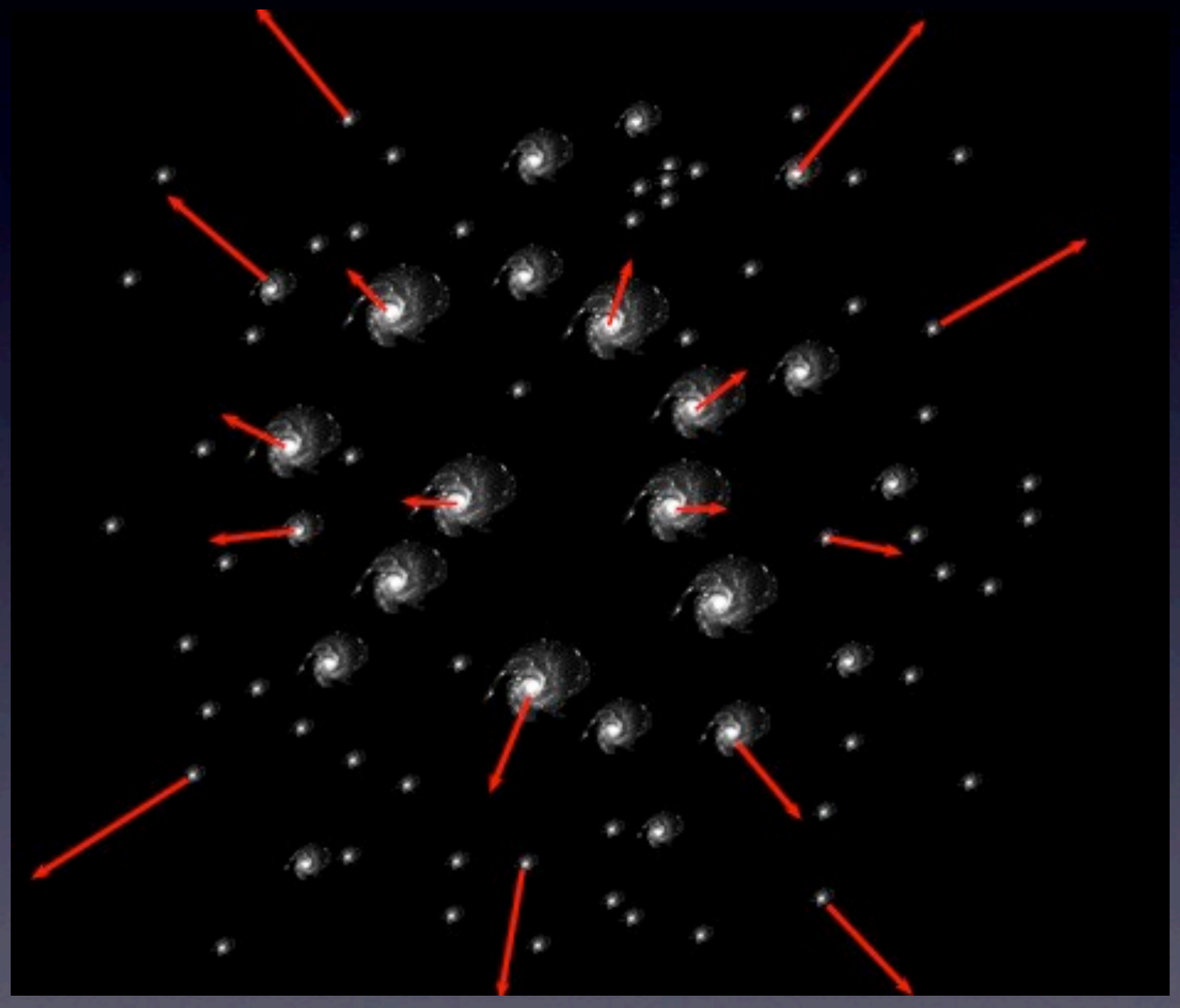
Einstein (1916)

$$R_{ab} - \frac{1}{2} R \; g_{ab} = T_{ab}$$





Lemaître (1927)



L'effet Doppler

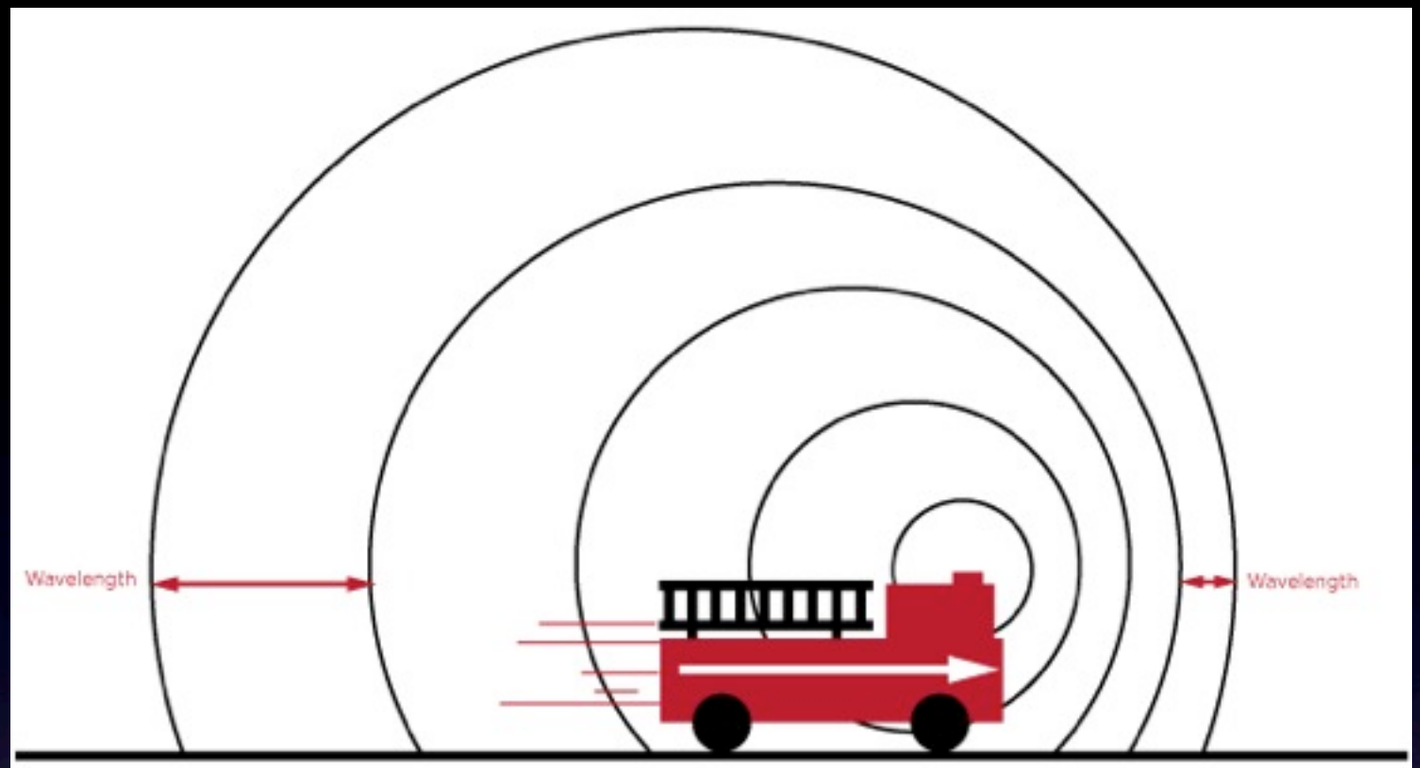
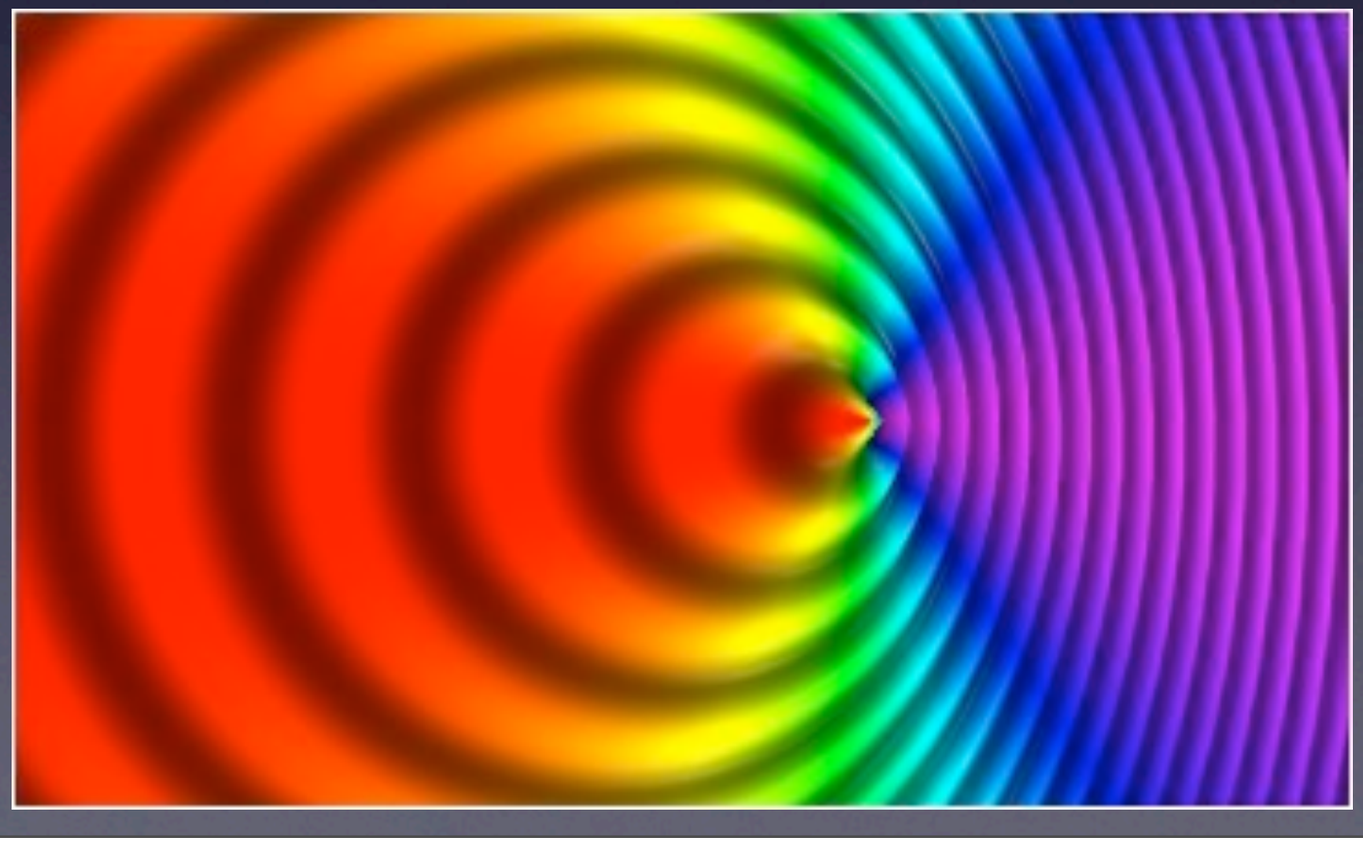
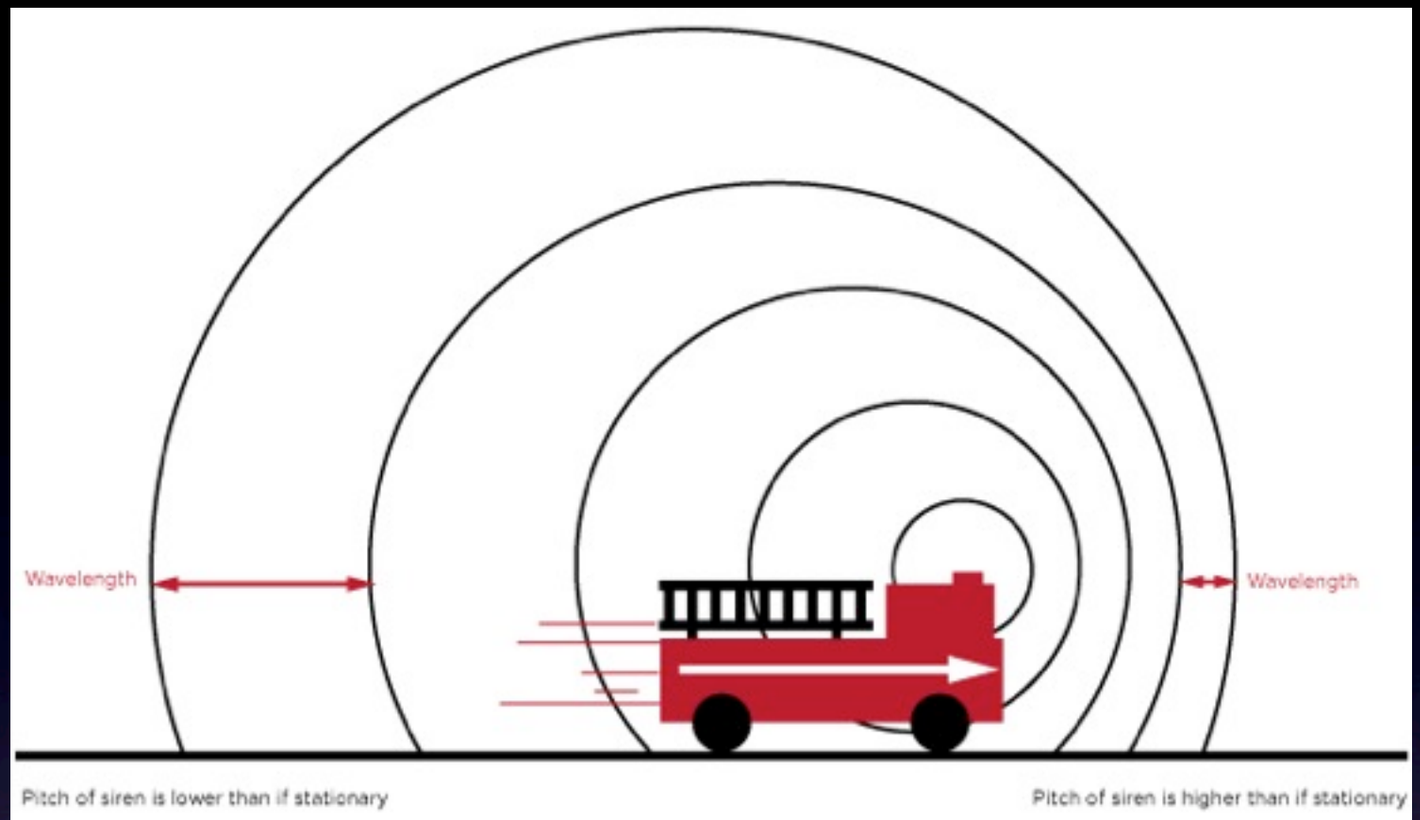


FIG 2. THE DOPPLER EFFECT FOR A MOVING SOUND SOURCE



L'effet Doppler



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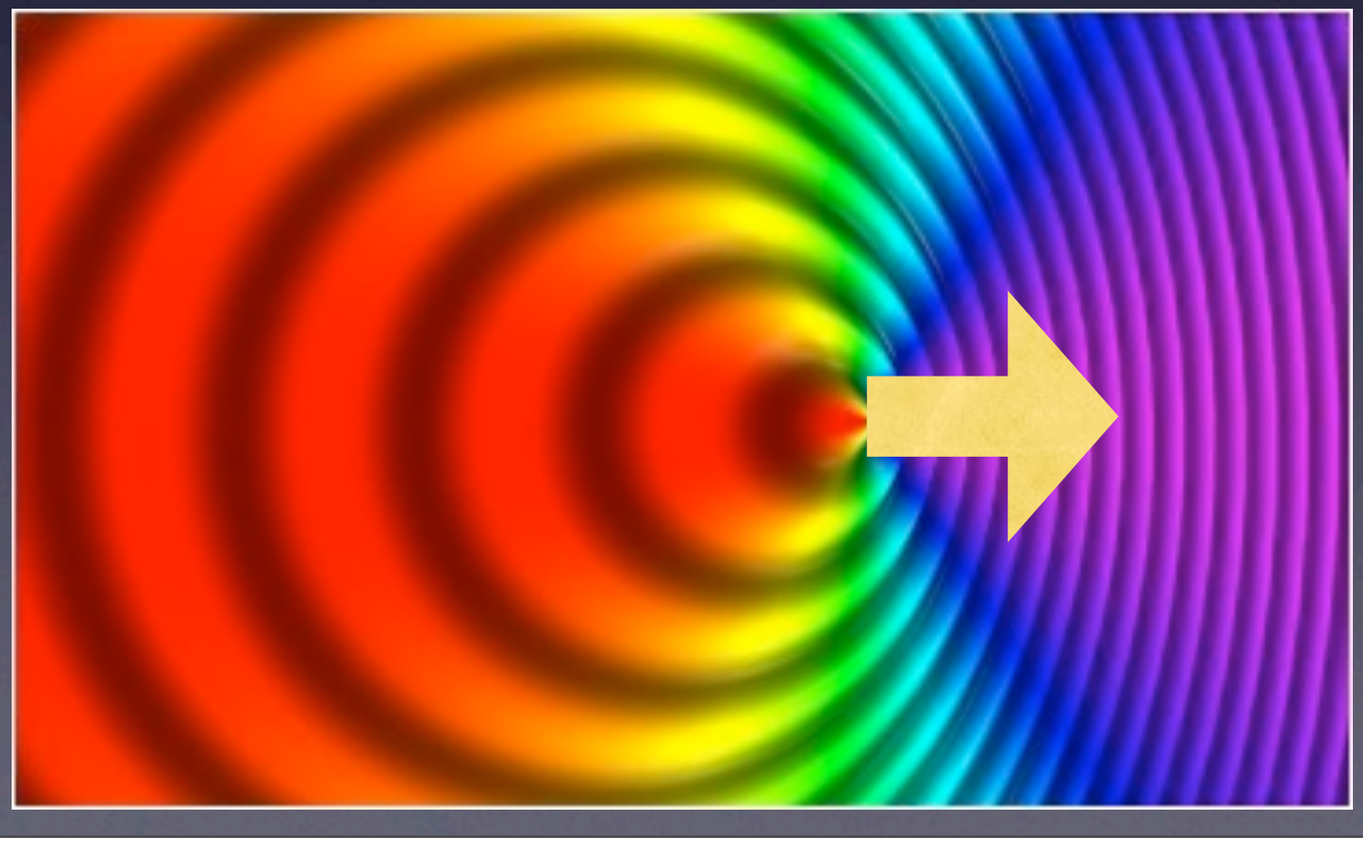
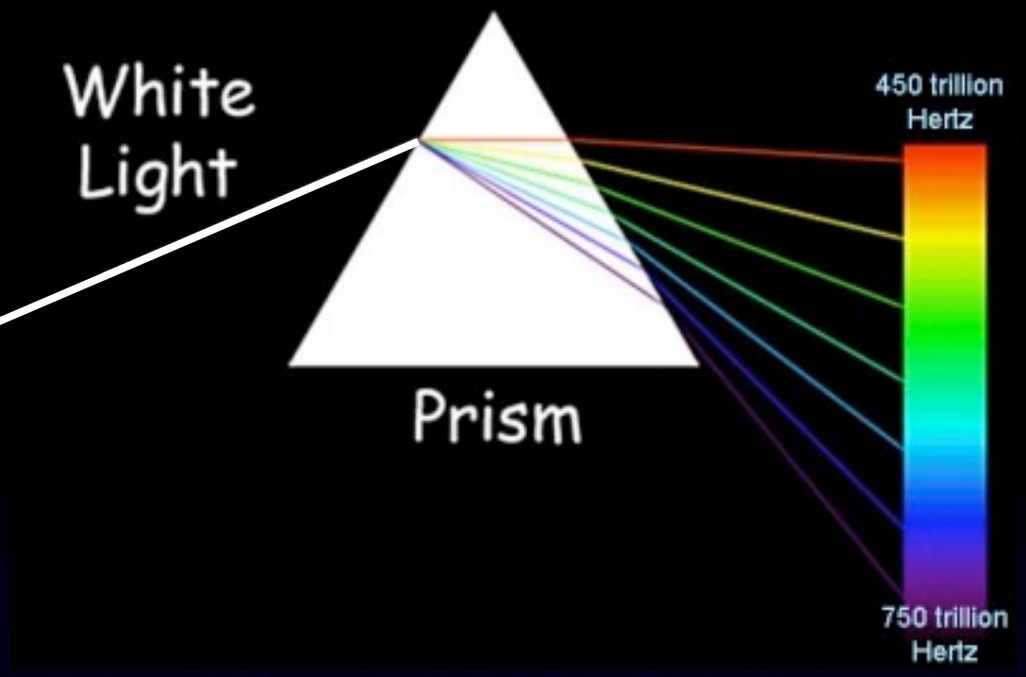
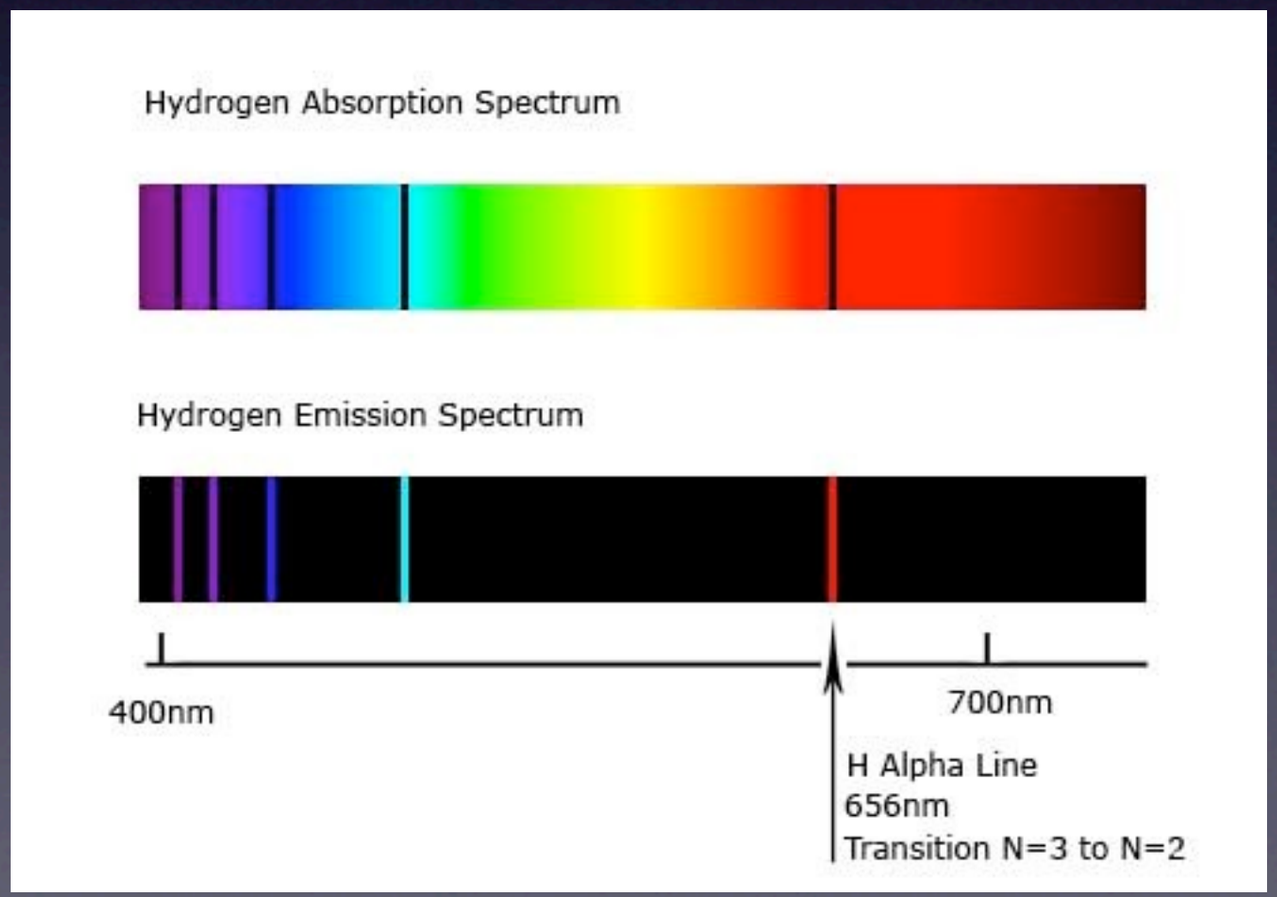
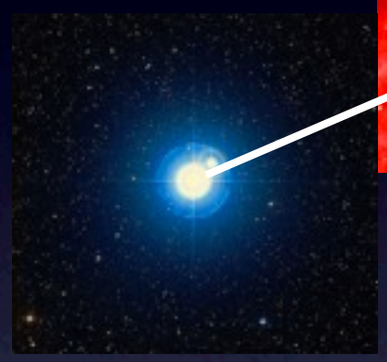


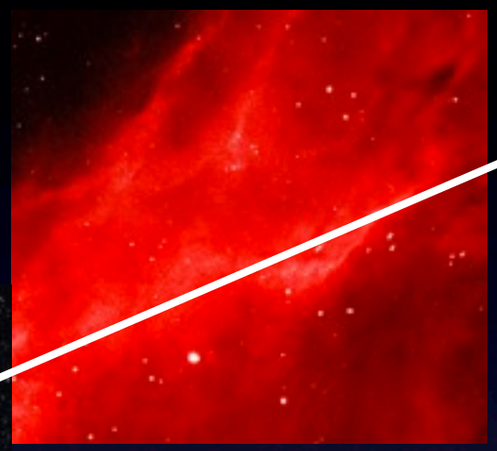

White
Light
Prism
450 trillion
Hertz
750 trillion
Hertz

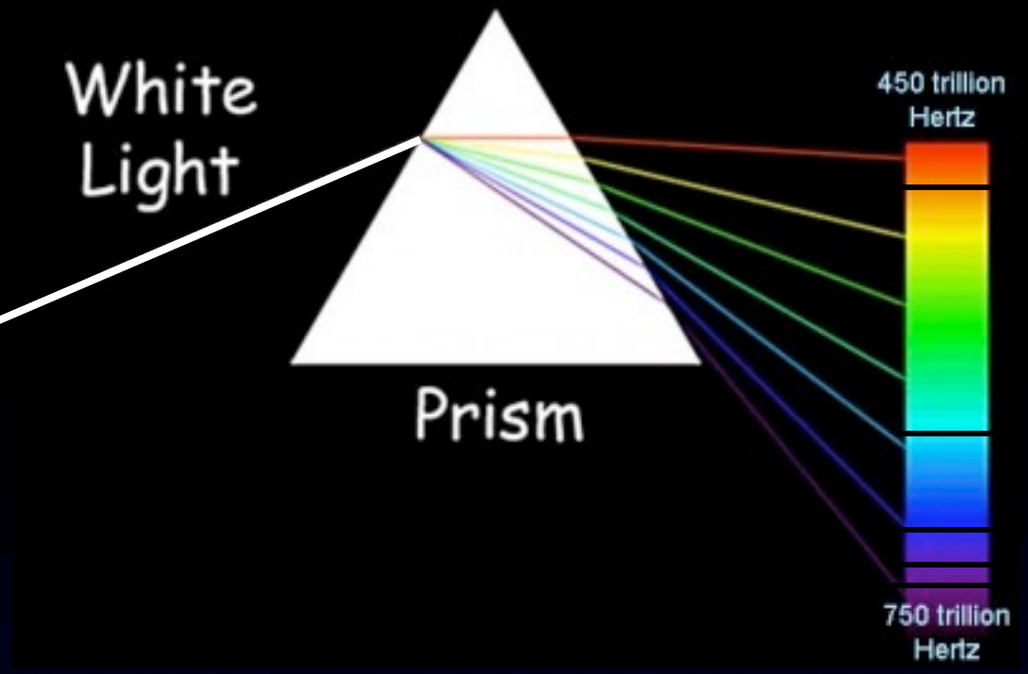

Hydrogen Absorption Spectrum
Hydrogen Emission Spectrum
400nm
700nm
H Alpha Line
656nm
Transition N=3 to N=2

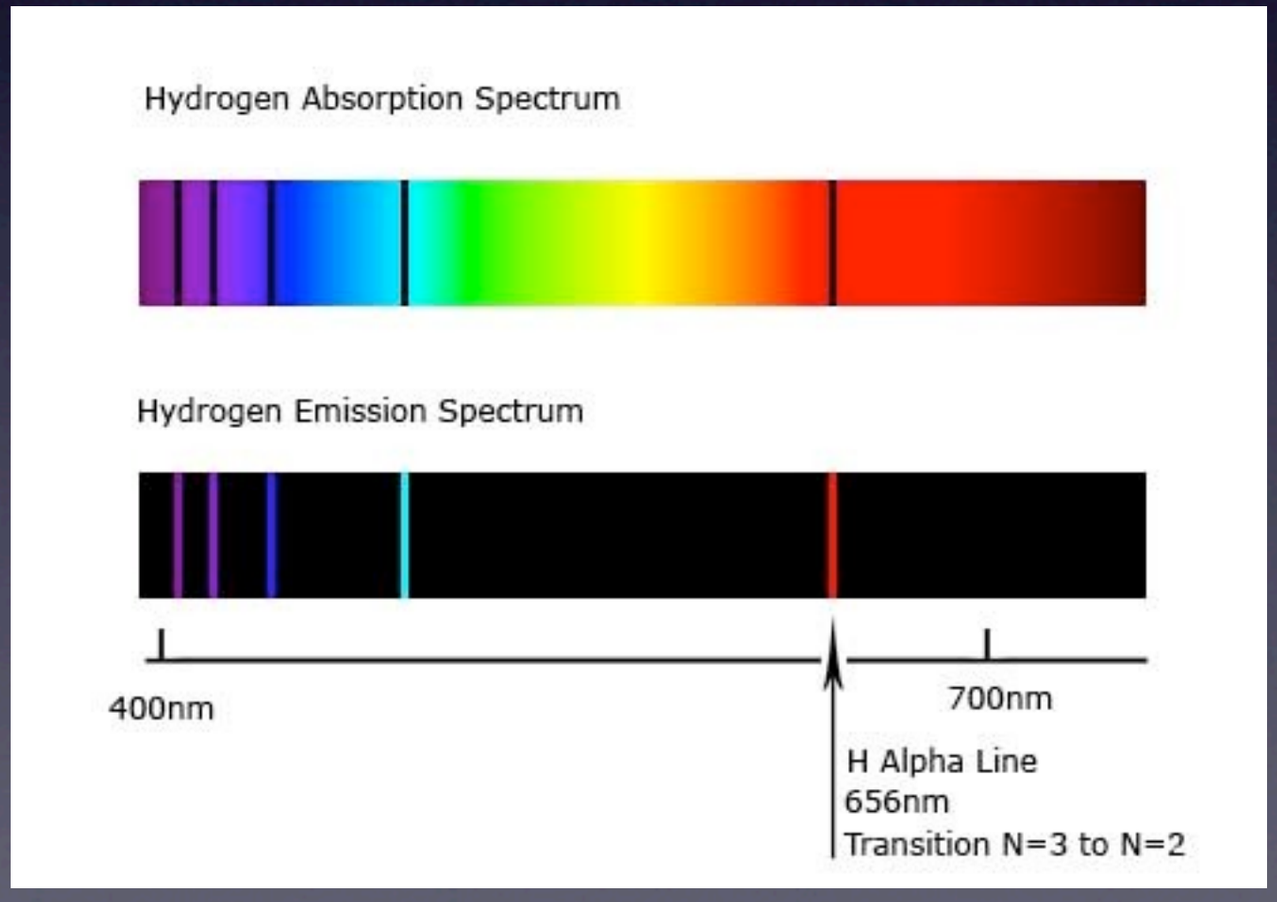
Etoile observée

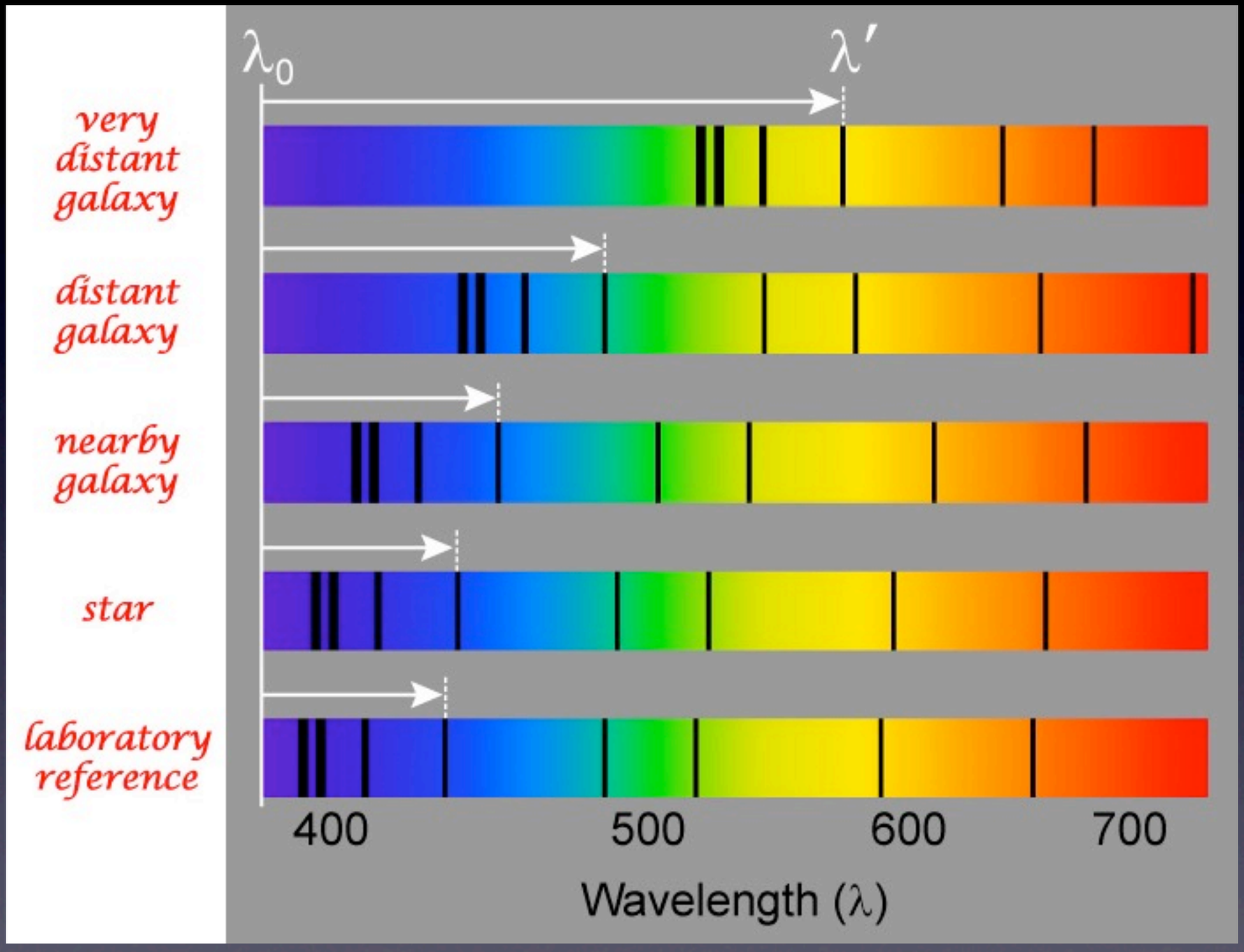


Hydrogène interstellaire

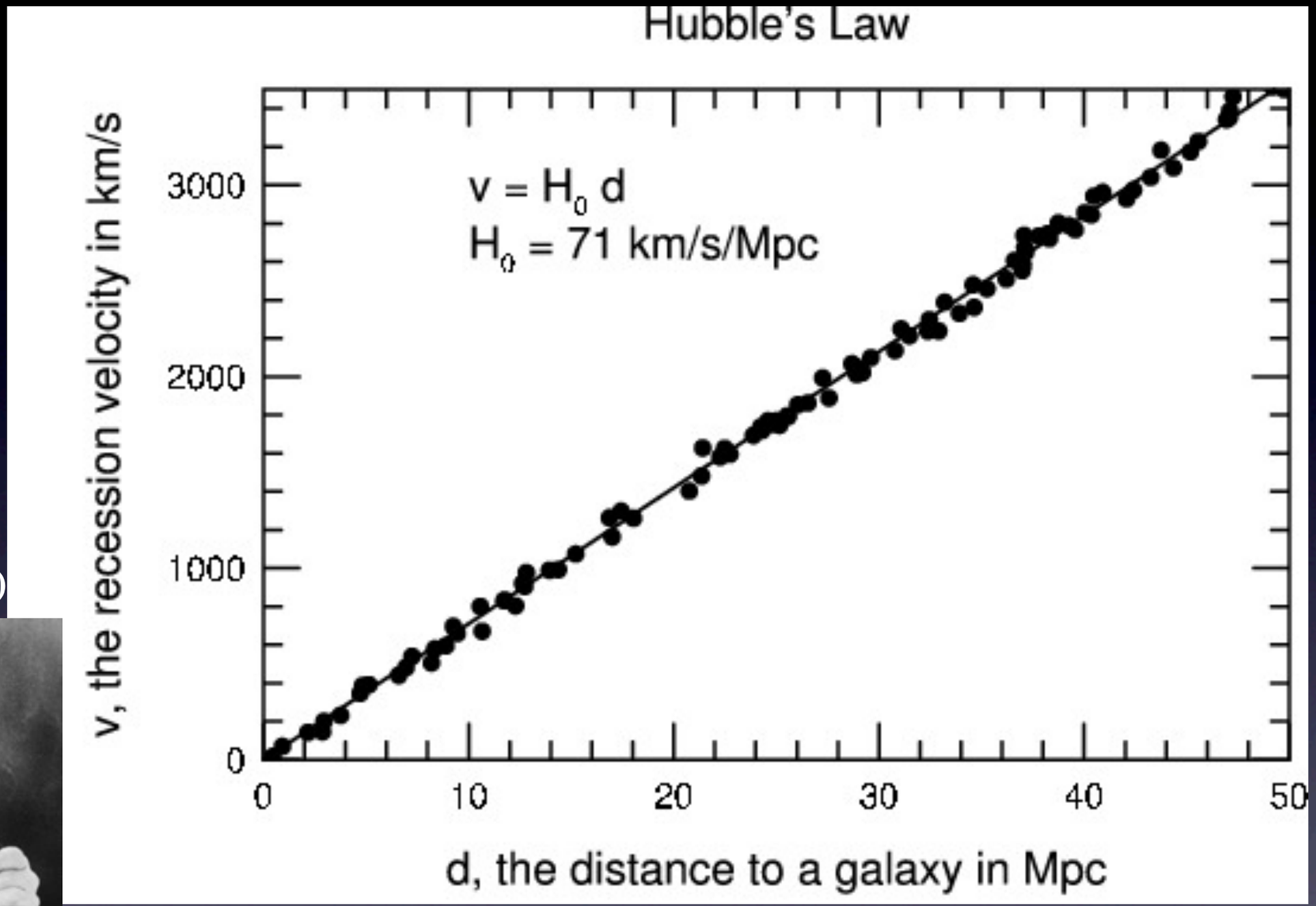






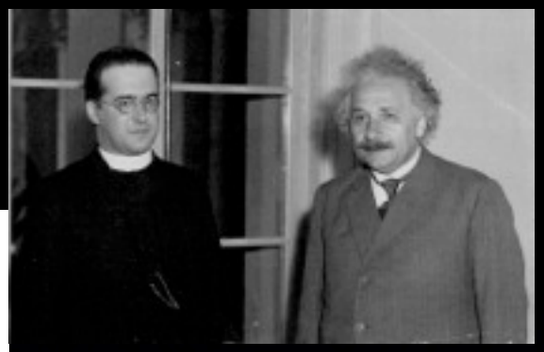

λ0
λ′
very distant galaxy
distant galaxy
nearby galaxy
star
laboratory reference
400
500
600
700
Wavelength (λ)

Hubble (1929)



$$Mpc \approx 3 \times 10^{22} m \approx 3 \times 10^{6} ly$$

Univers en expansion



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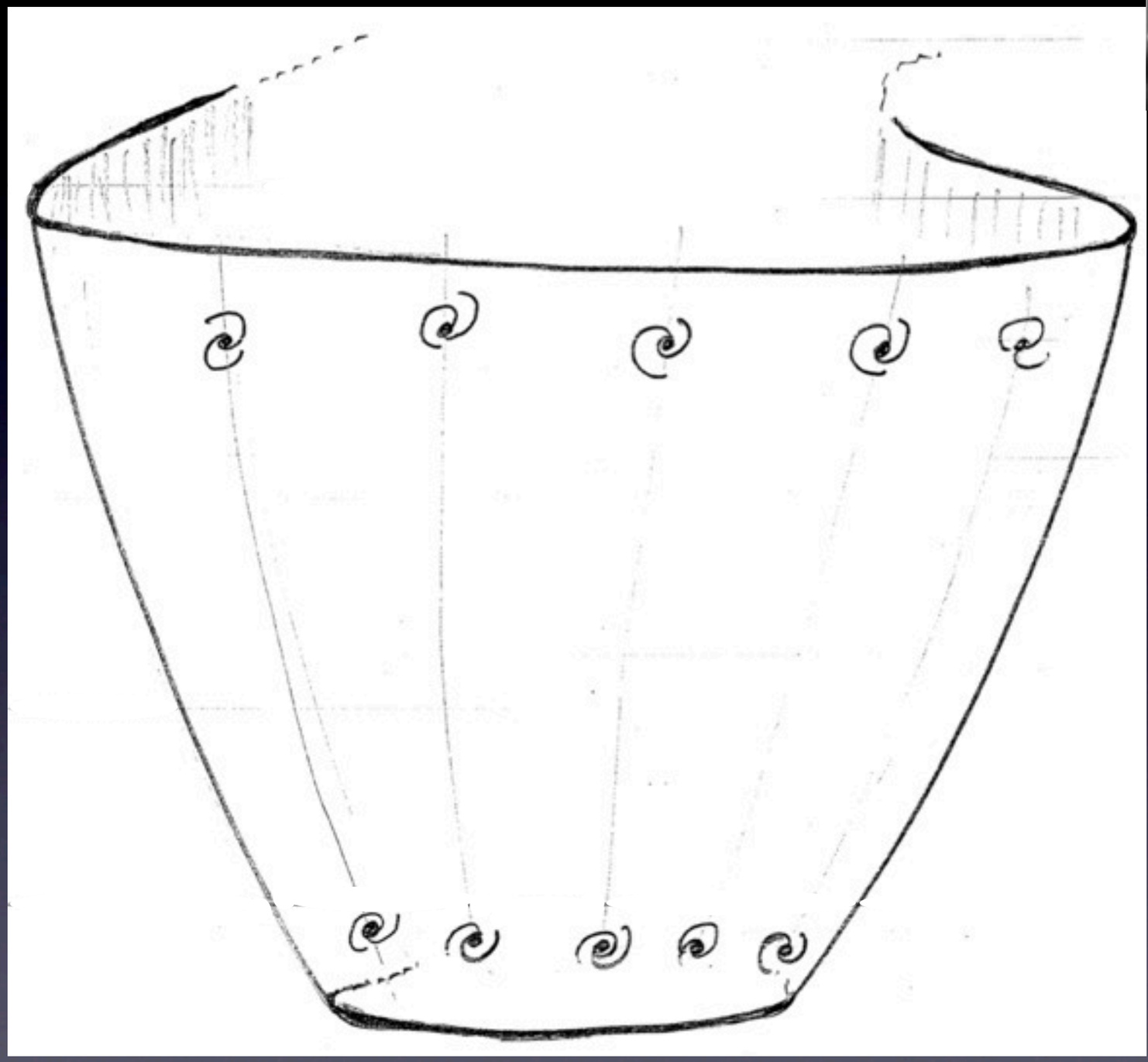
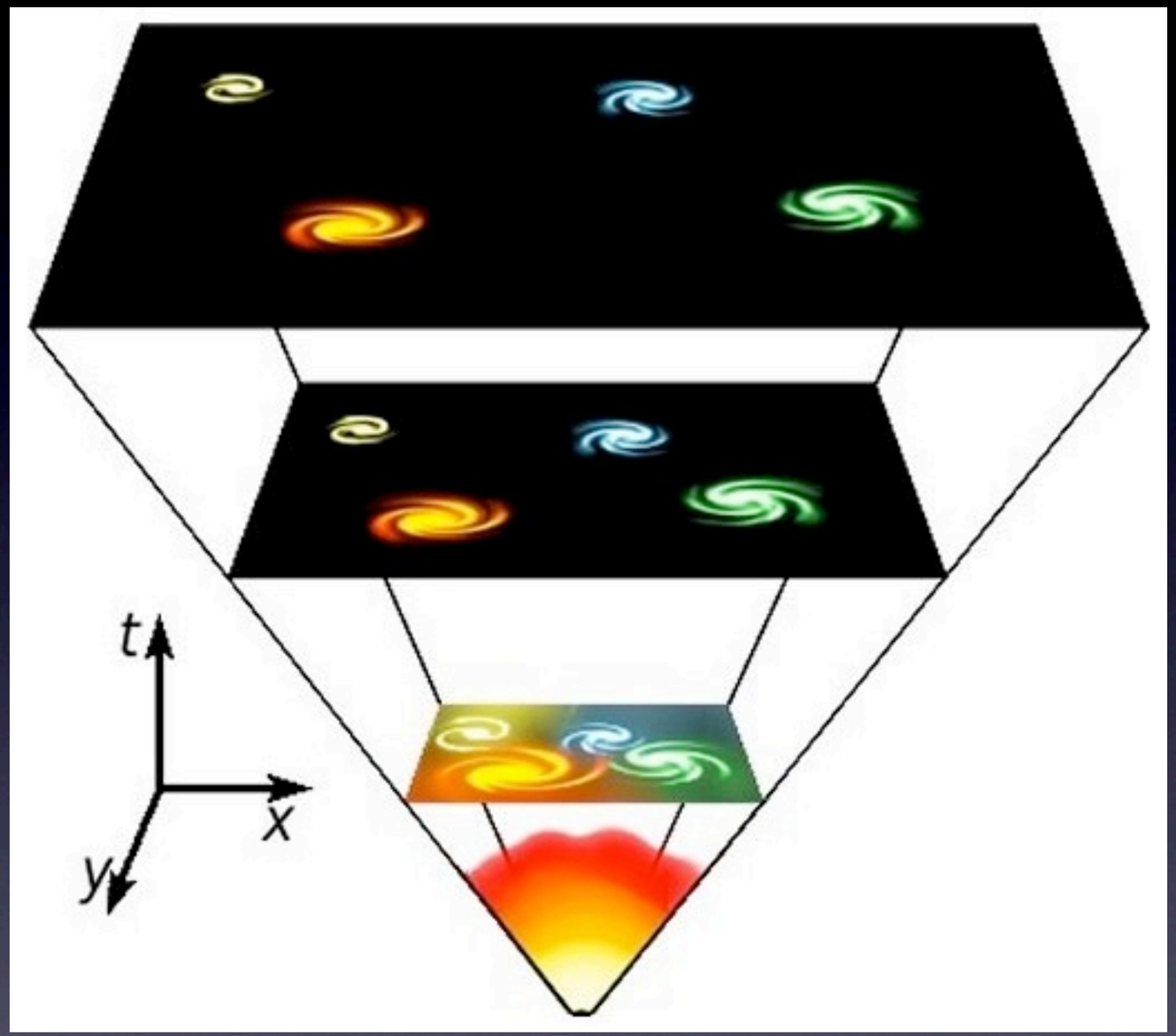


Temps

Le Big-Bang se serait accompagnée de
l'émission d'un intense rayonnement



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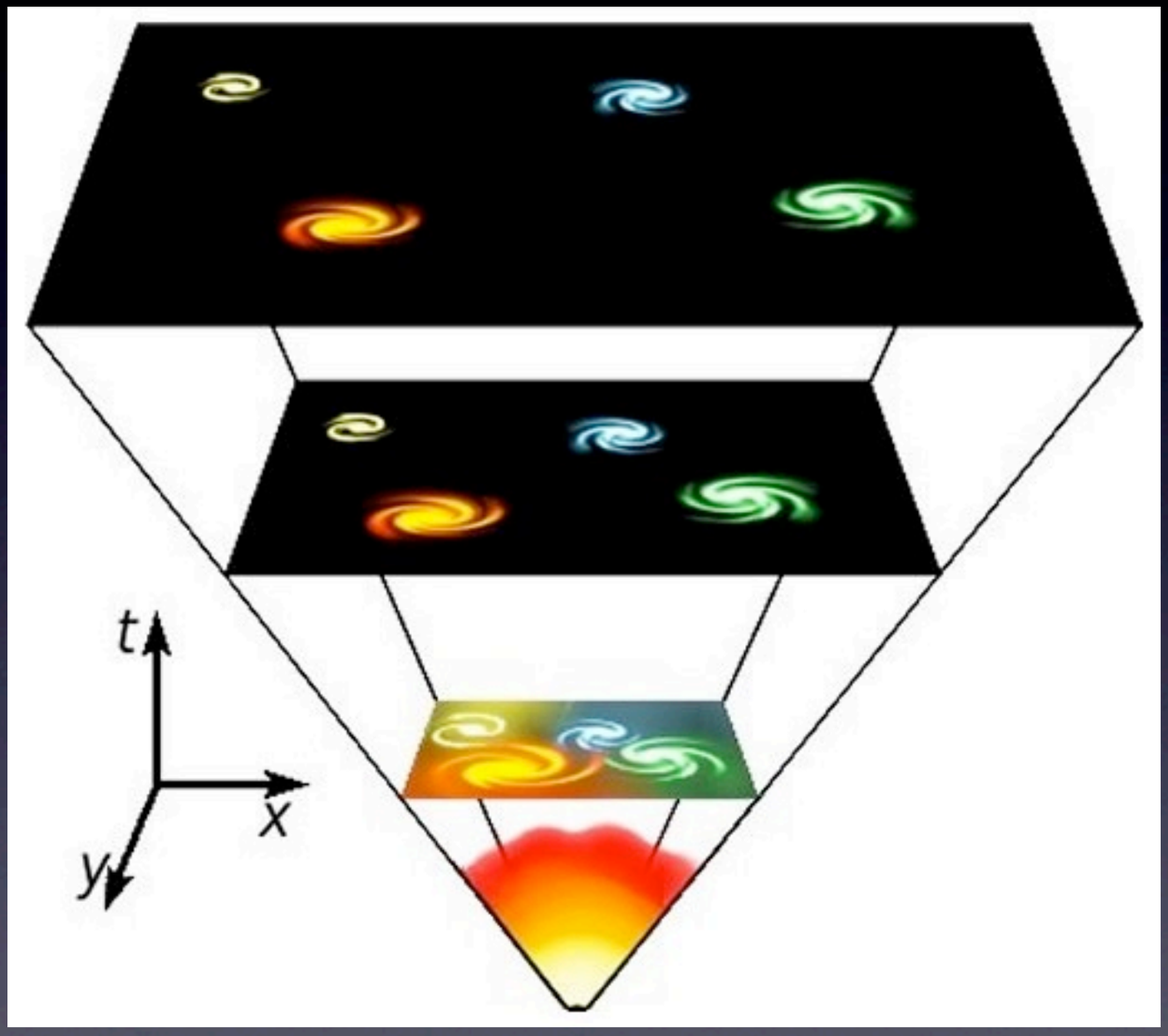
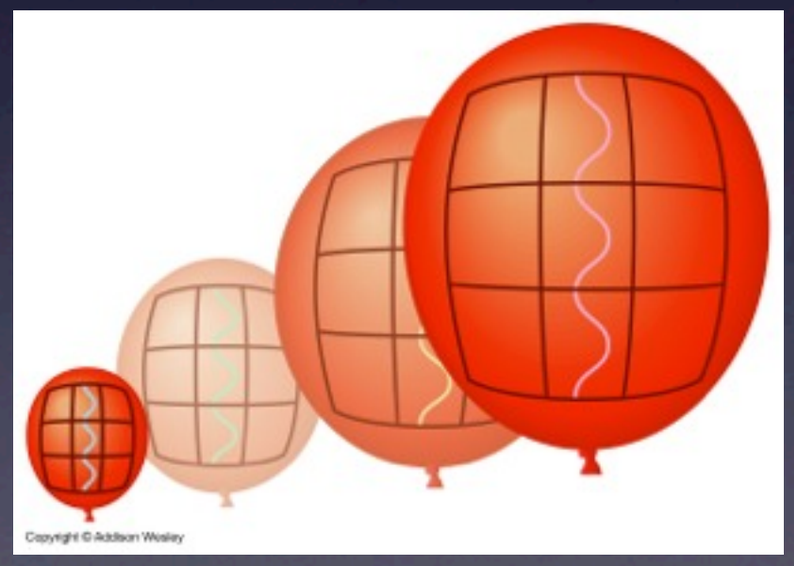
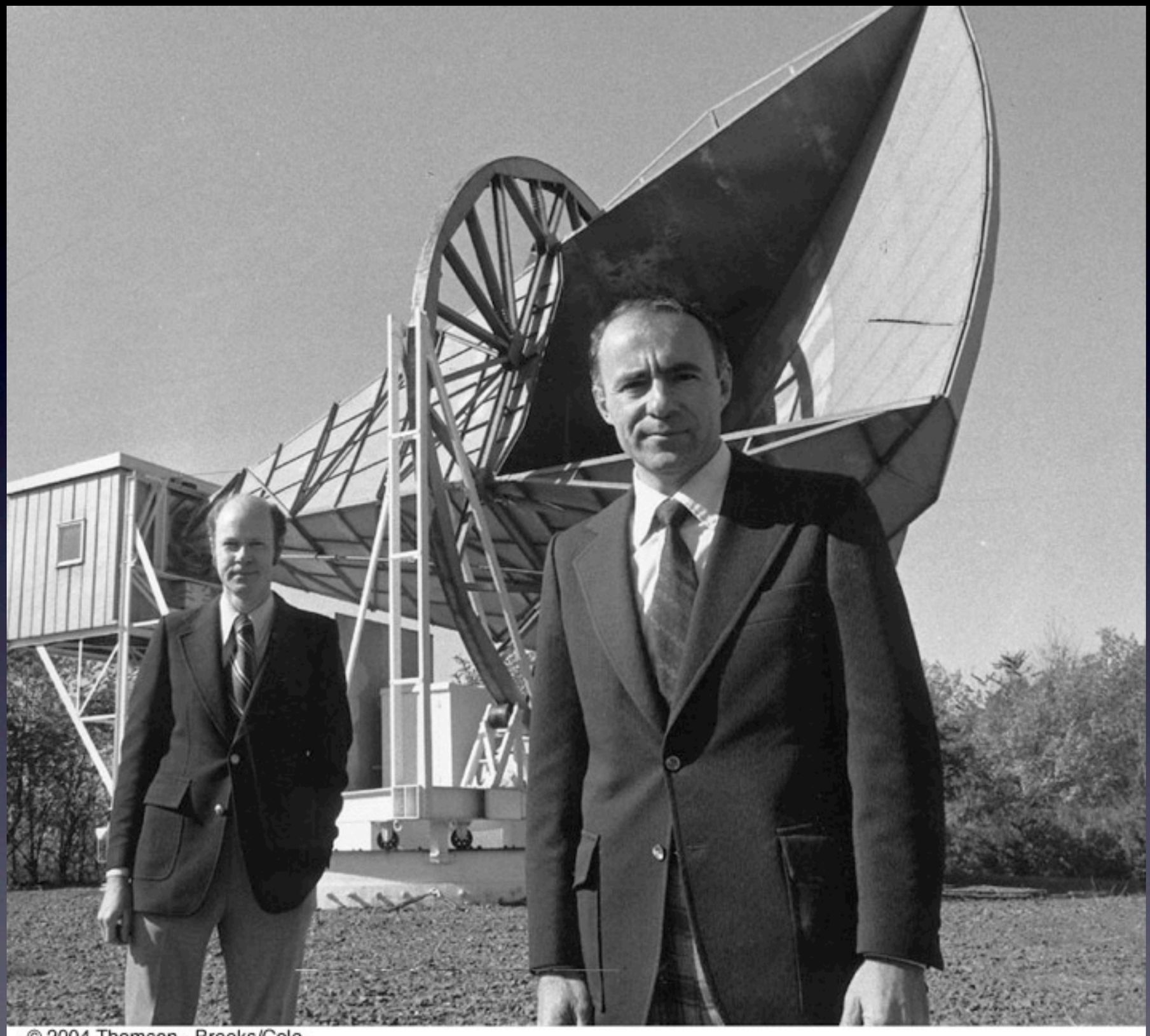




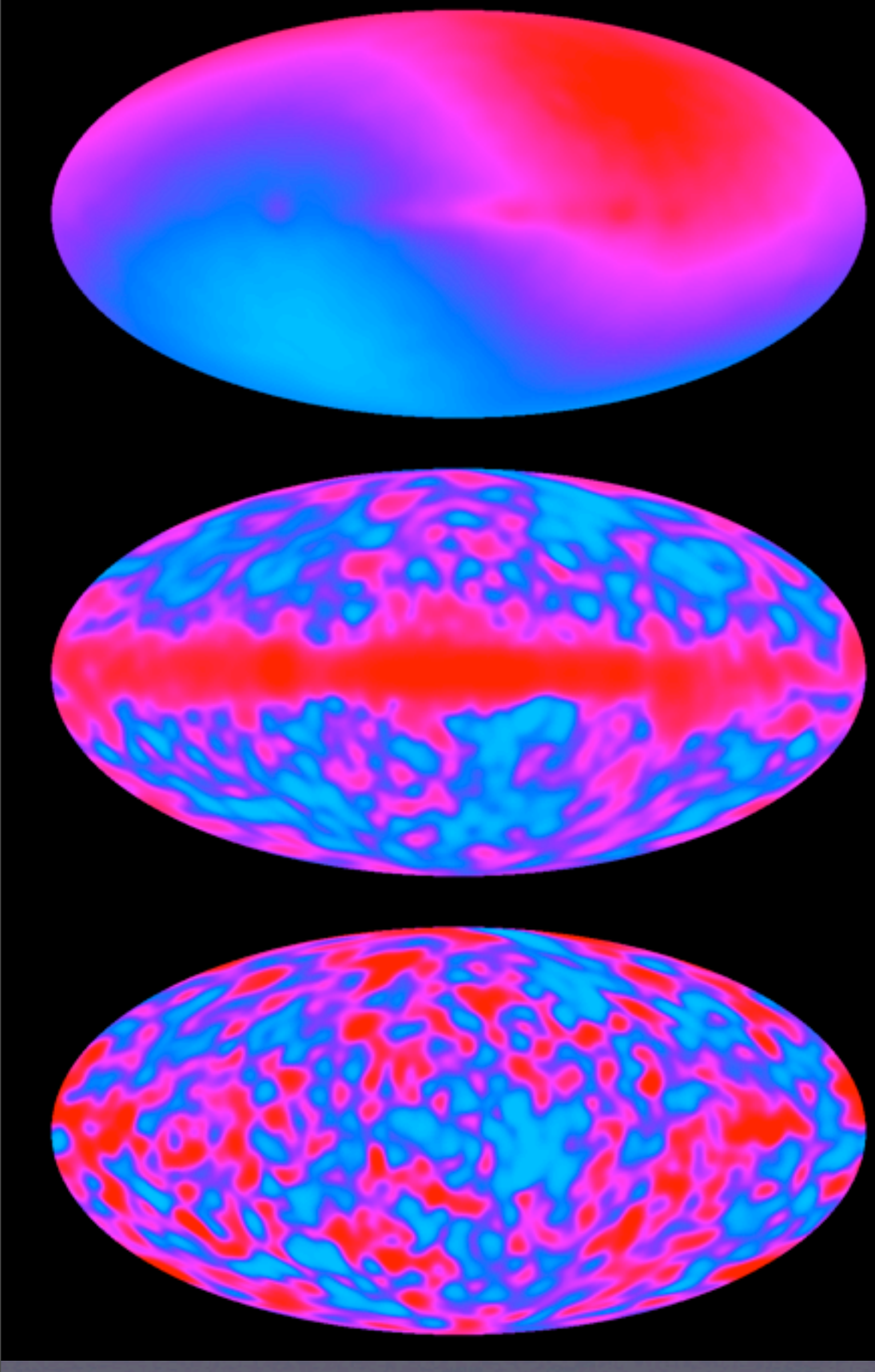
Peut on observer "rayonnement fossile" du Big-Bang?

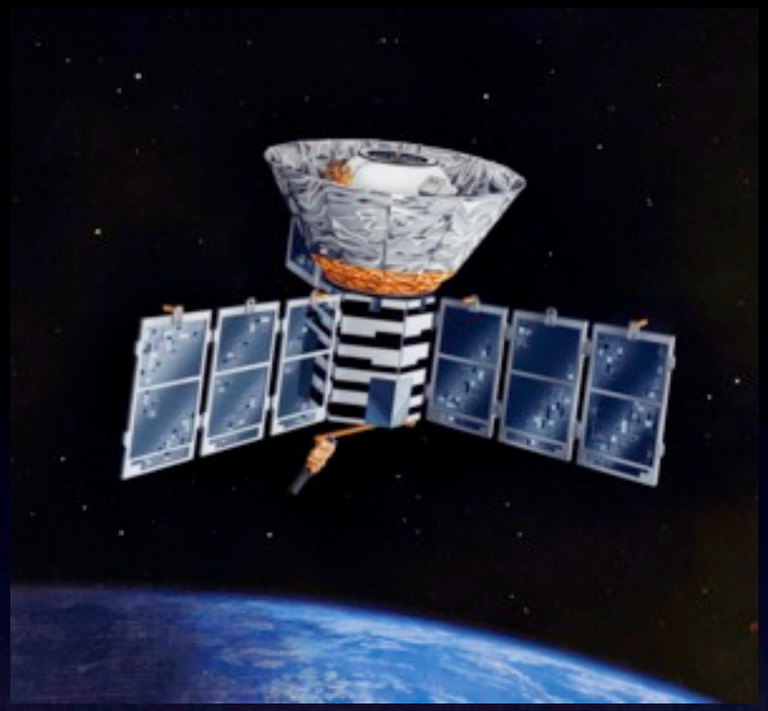
Le fond diffus cosmologique

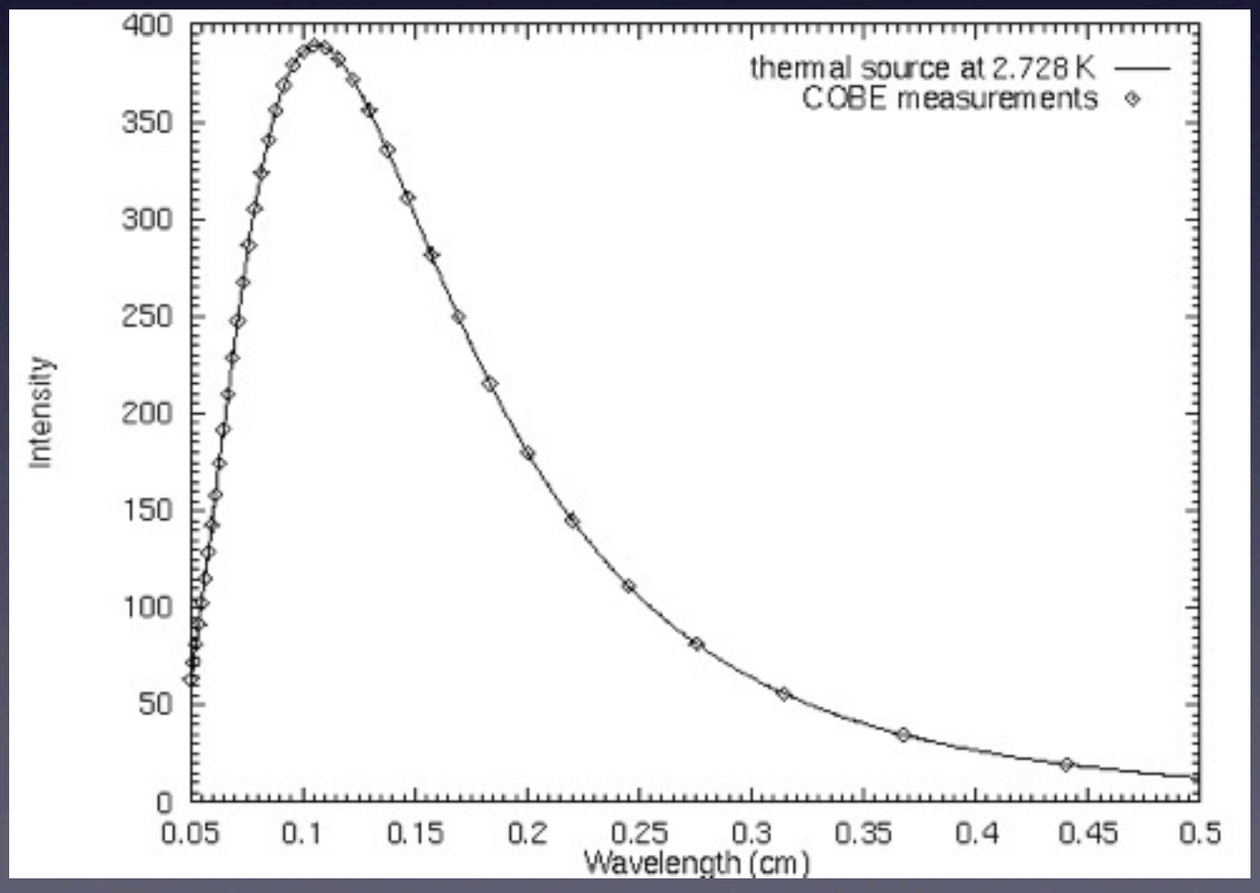
Penzias et Wilson (1965)

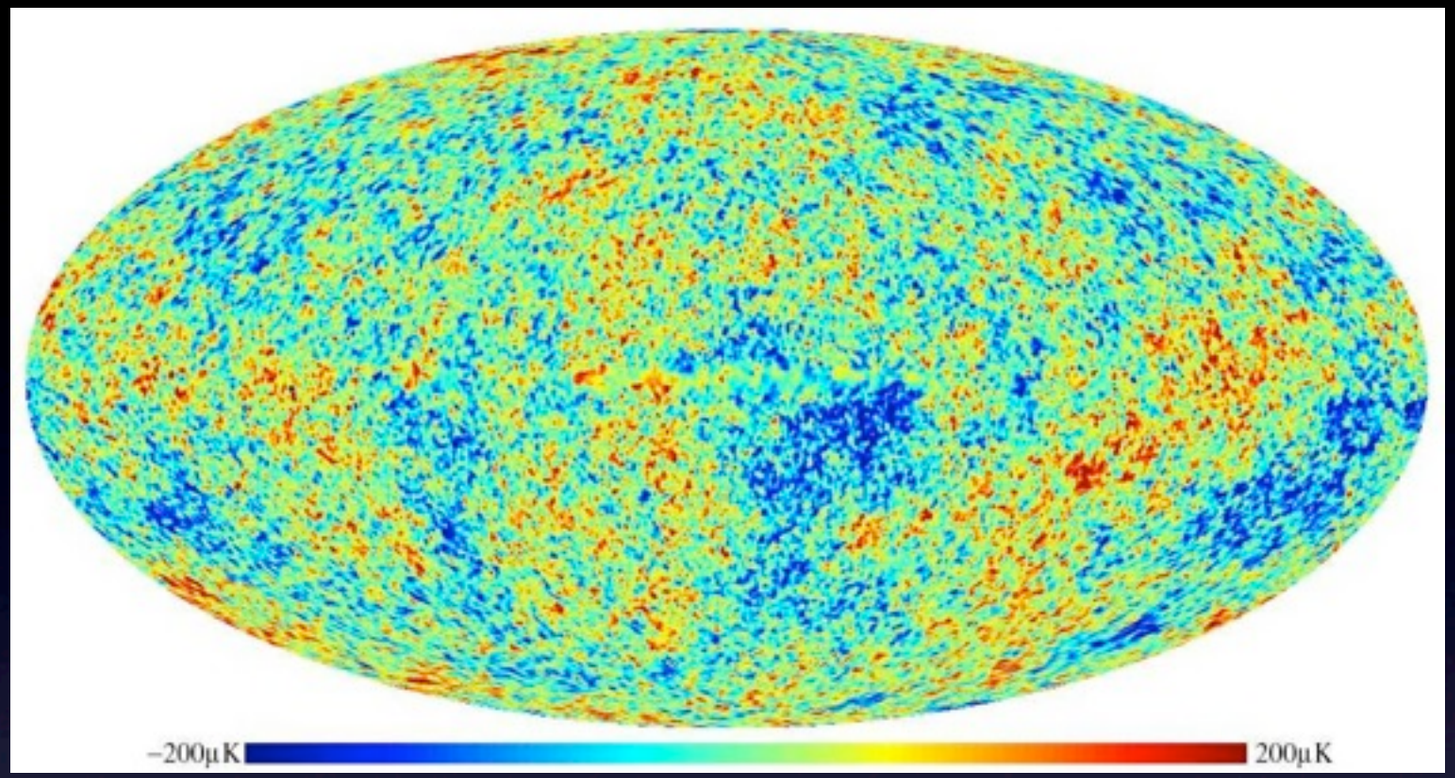


COBE (1992)

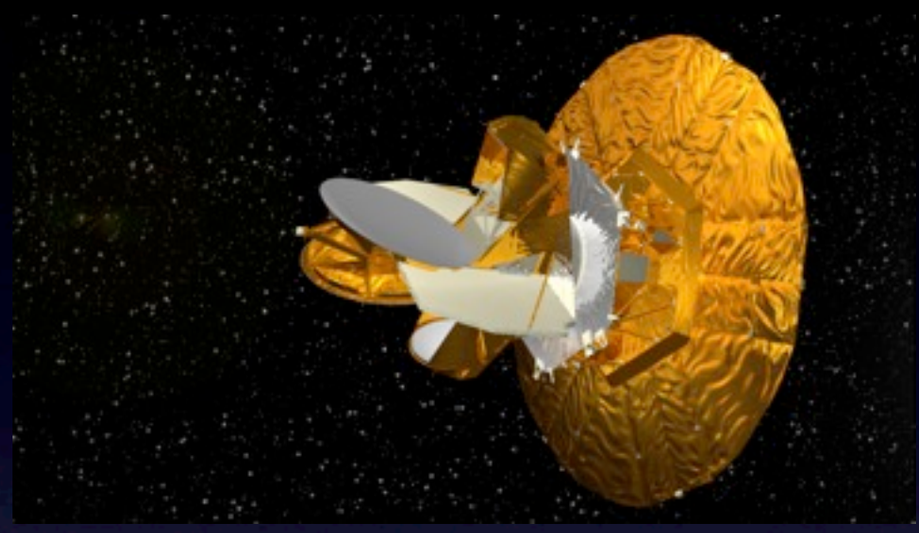




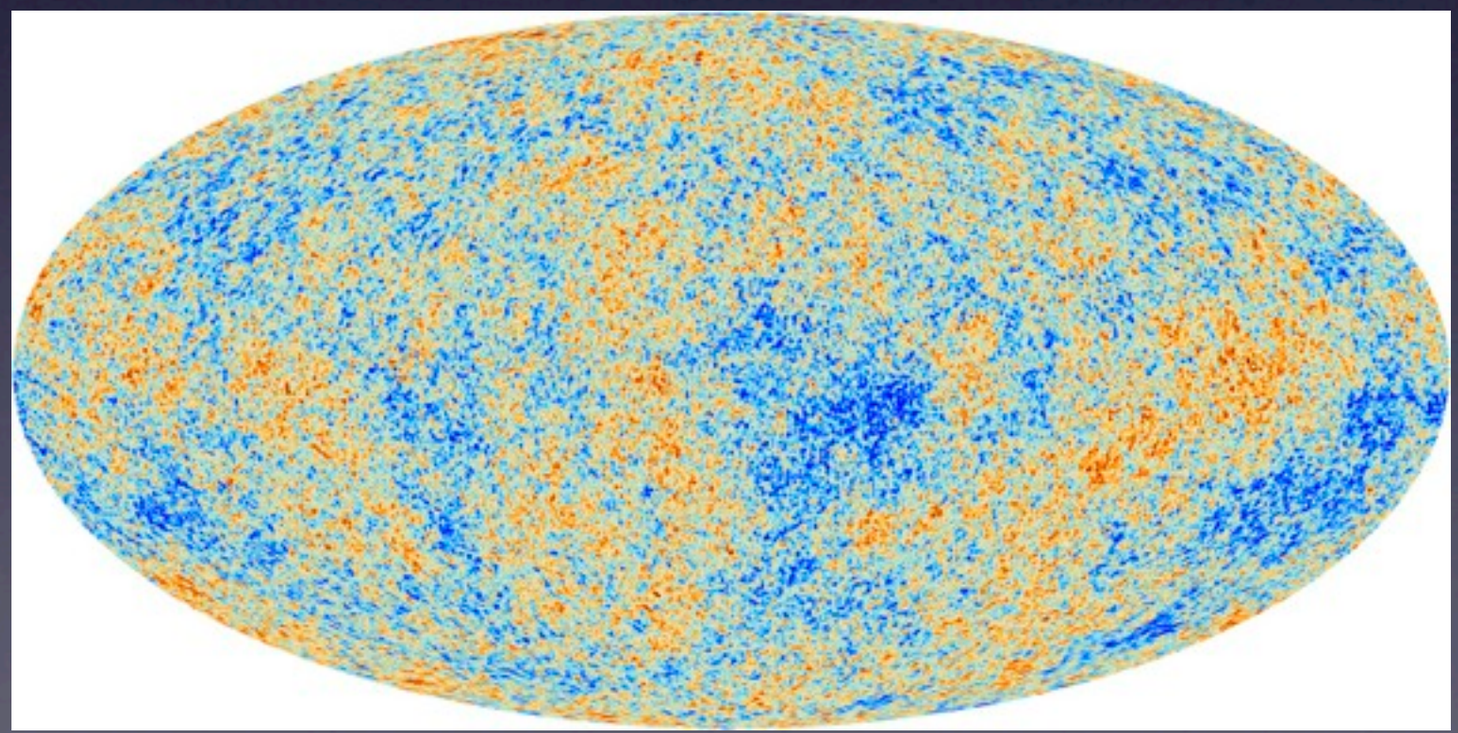

thermal source at 2.728 K
COBE measurements
Intensity
Wavelength (cm)
400
350
300
250
200
150
100
50
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5



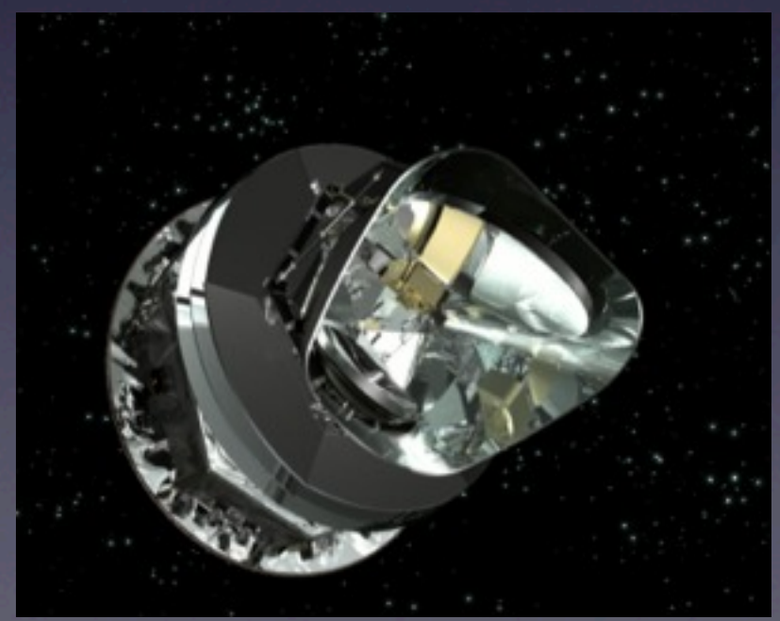
WMAP (2003)



$$\frac{\Delta T}{T} \approx 10^{-4}$$



Planck (2013)



History of the Universe

Inflation Generates Two Types of Waves

Gravitational Waves

Density Waves

Waves Imprint Characteristic Polarization Signals

Free Electrons Scatter Light

Earliest Time Visible with Light

Radius of the Visible Universe

Quantum Fluctuations

Big Bang

Inflation

Protons Formed

Nuclear Fusion Begins

Nuclear Fusion Ends

Cosmic Microwave Background

Neutral Hydrogen Forms

Modem Universe

0

10^{-32} s

1 µs

0.01 s

3 min

380,000 yrs

13.8 Billion yrs

Age of the Universe

Nucléosynthèse

History of the Universe

Inflation Generates Two Types of Waves

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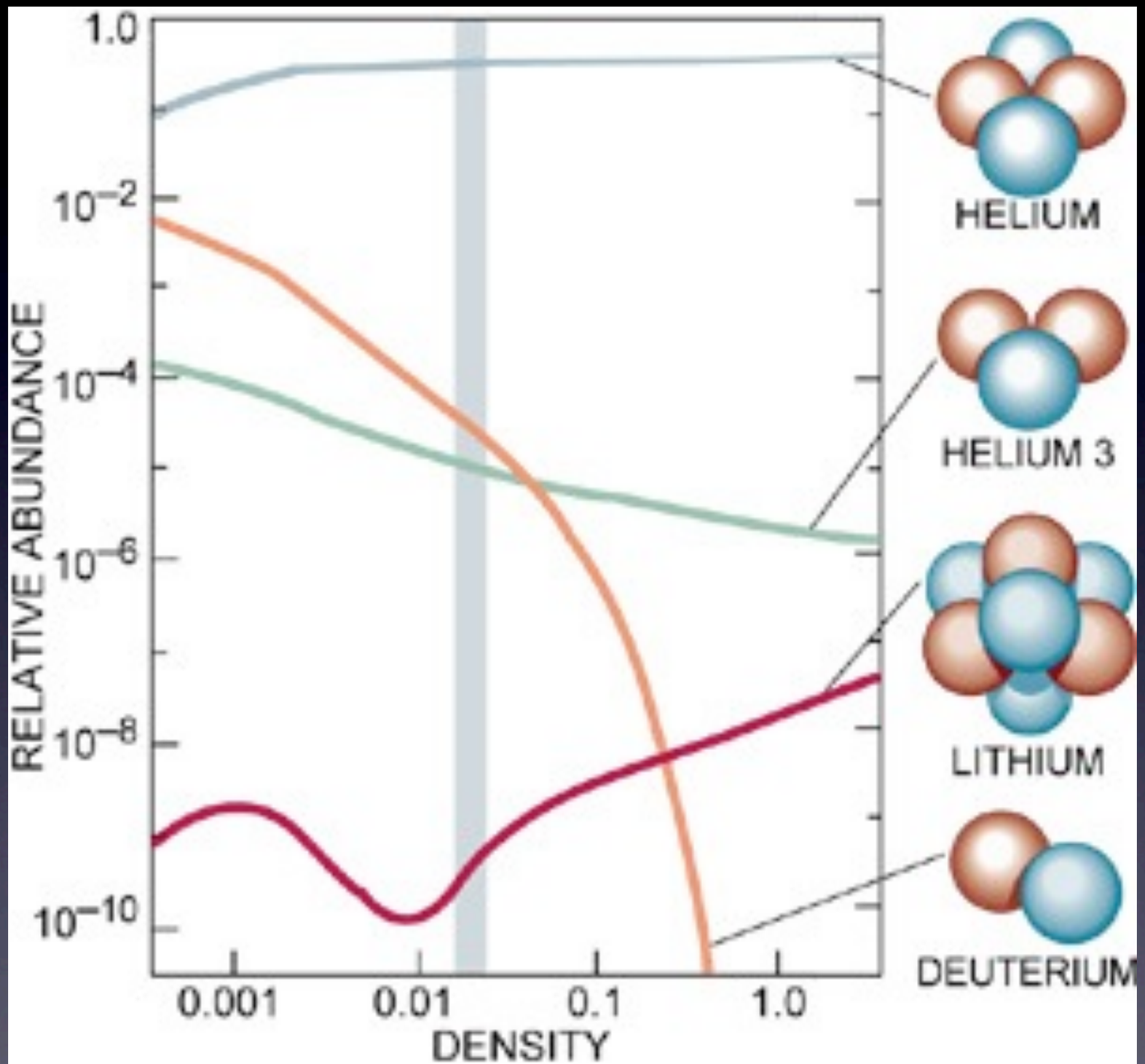
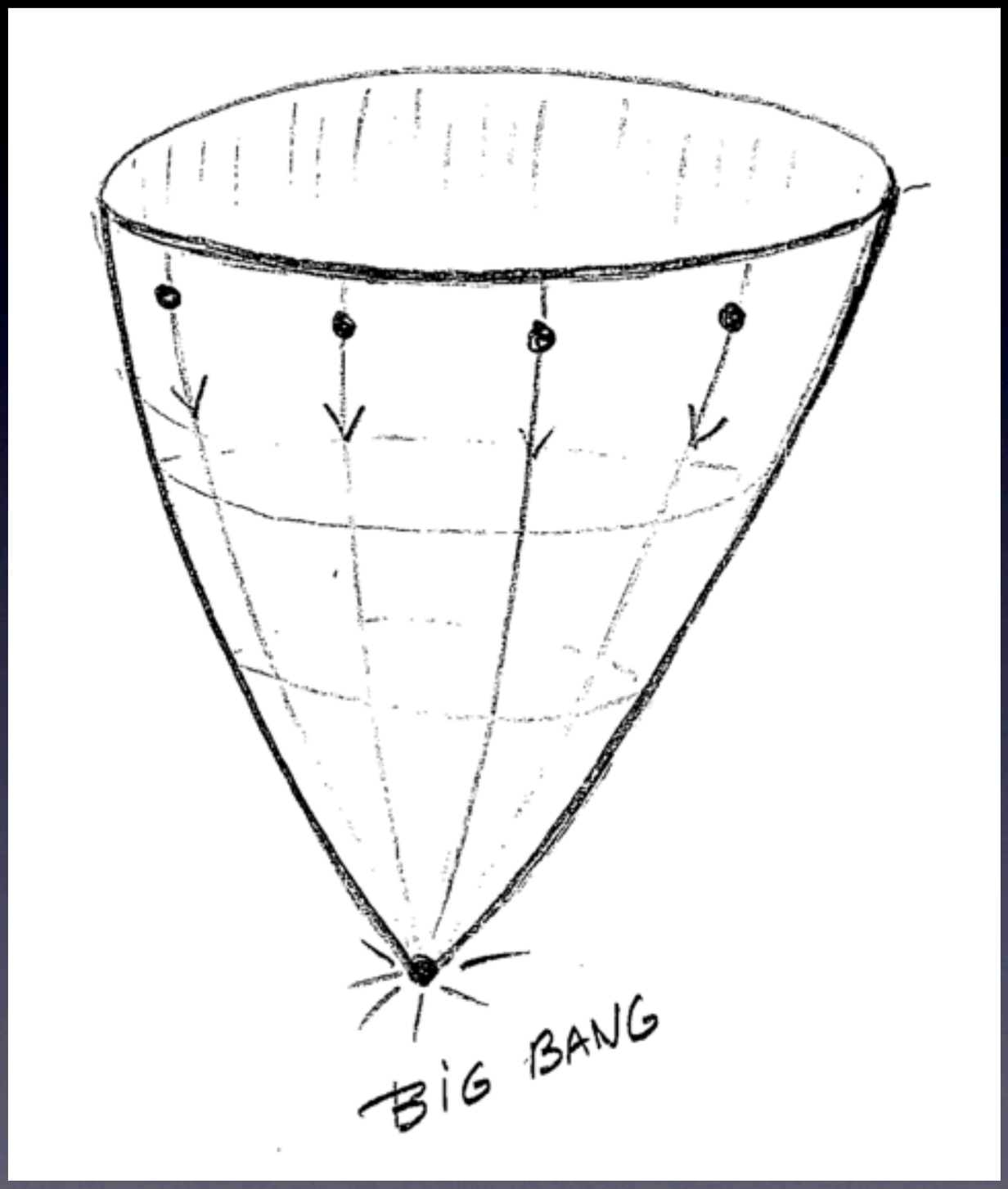
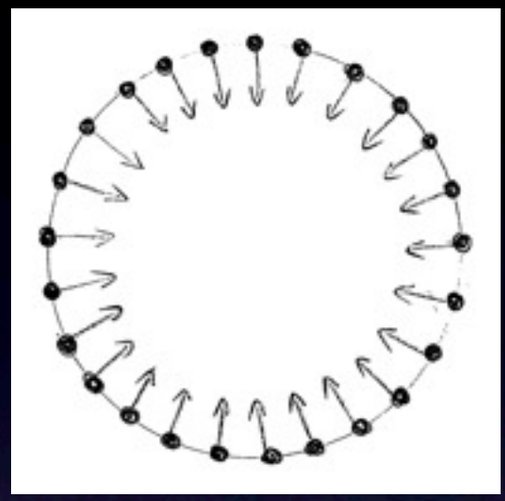
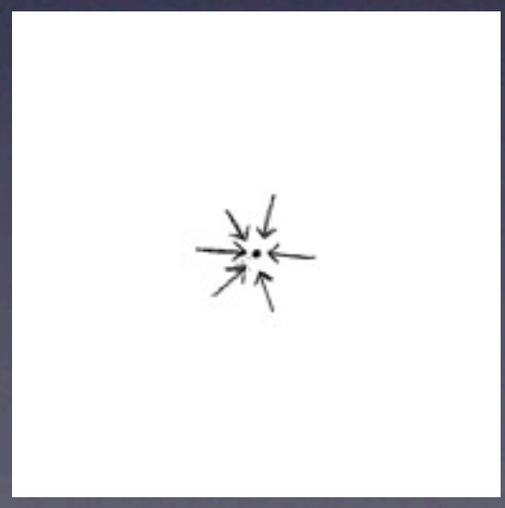

1.0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
RELATIVE ABUNDANCE
0.001
0.01
0.1
1.0
DENSITY
HELIUM
HELIUM 3
LITHIUM
DEUTERIUM

Le big-bang et la naissance du temps

L’effondrement symétrique est singulier

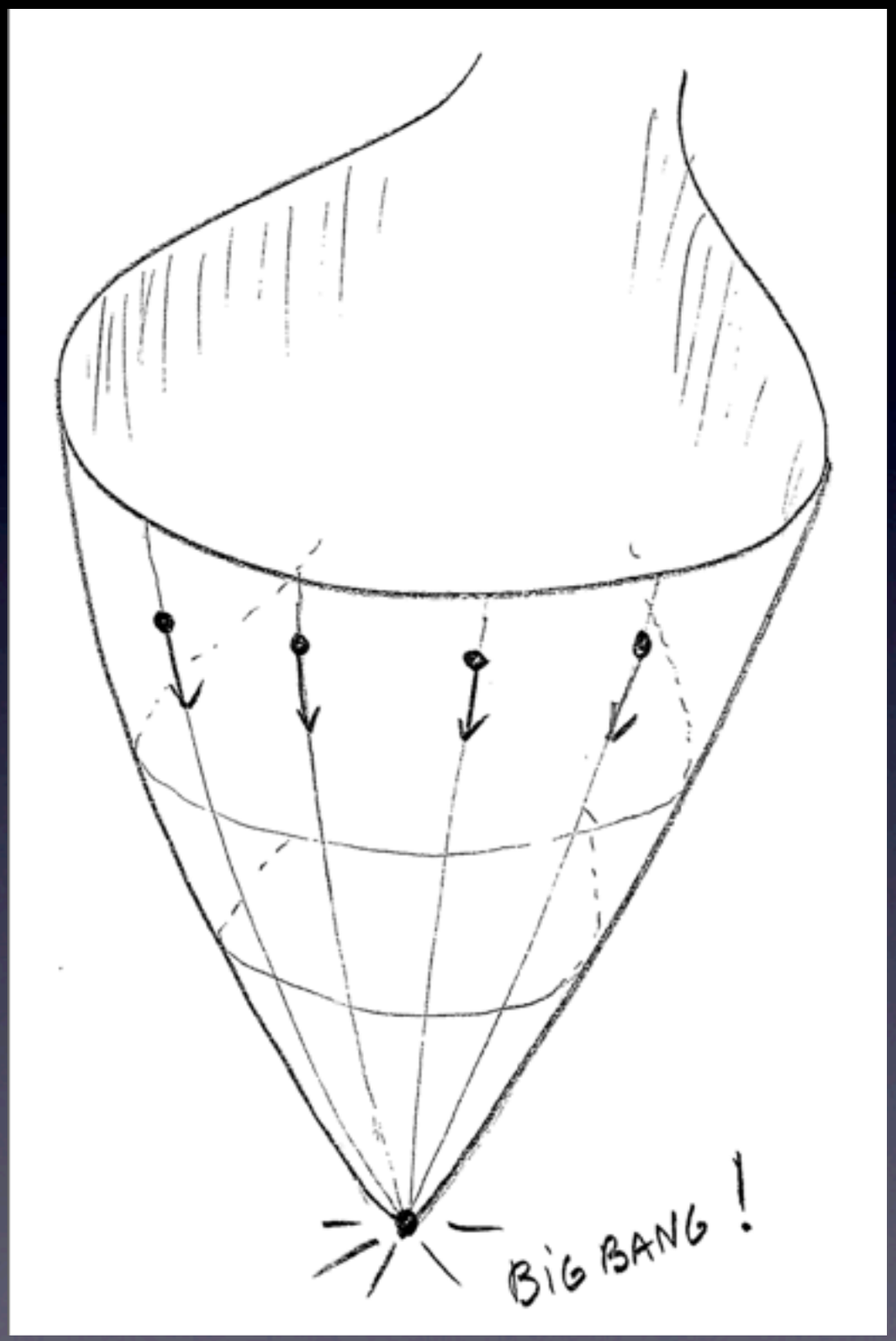


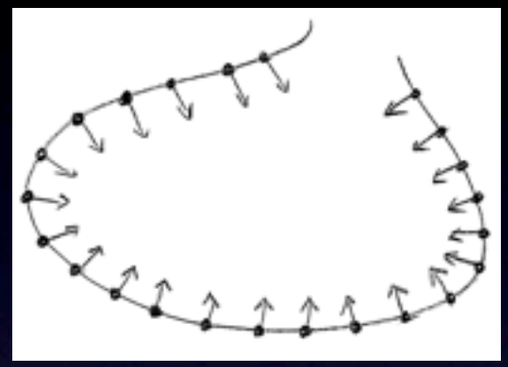


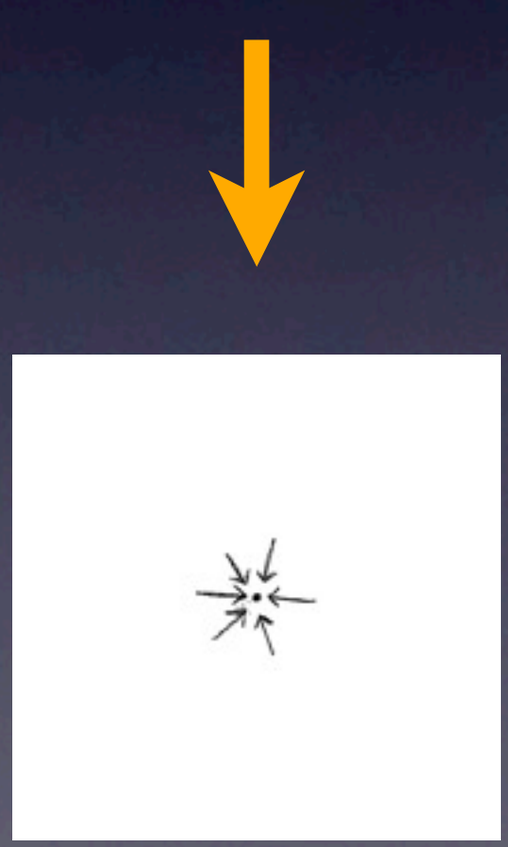


Théorèmes de singularités

Hawking and Penrose (60s-70s)

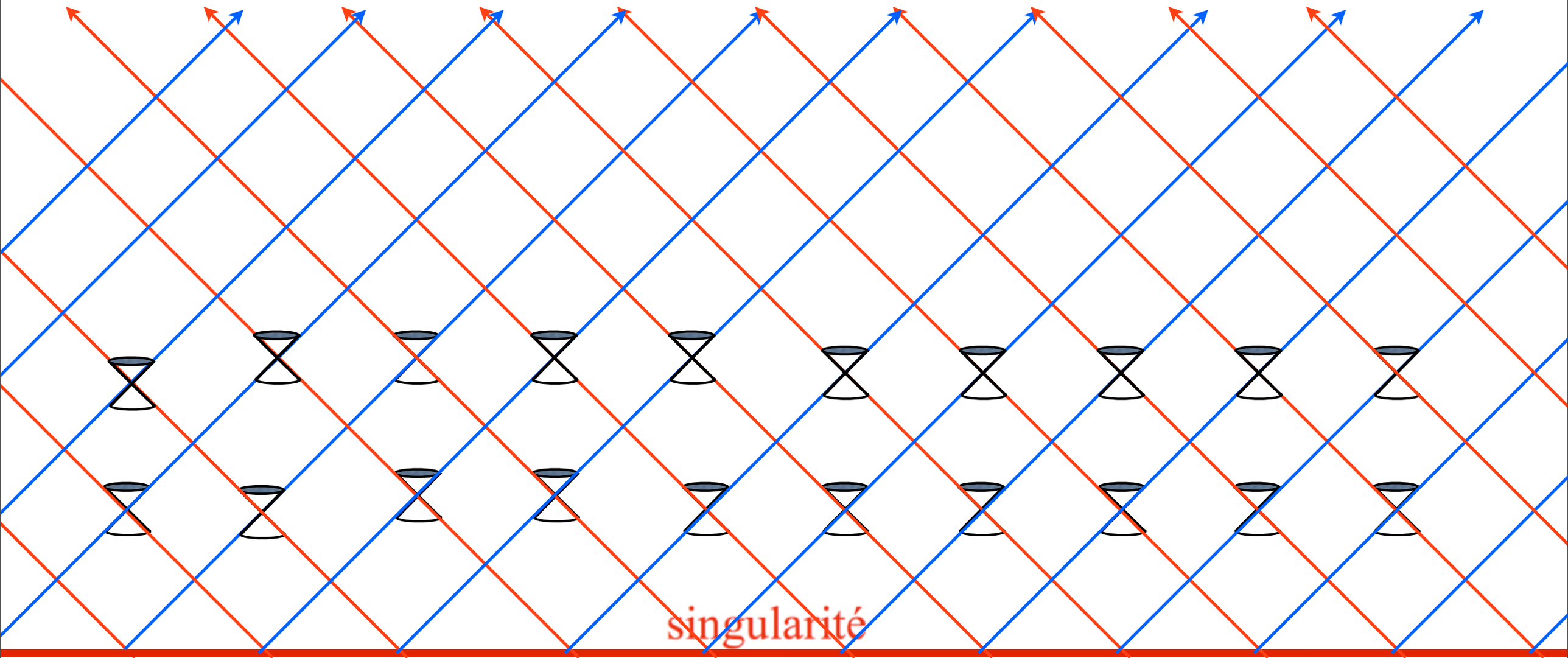




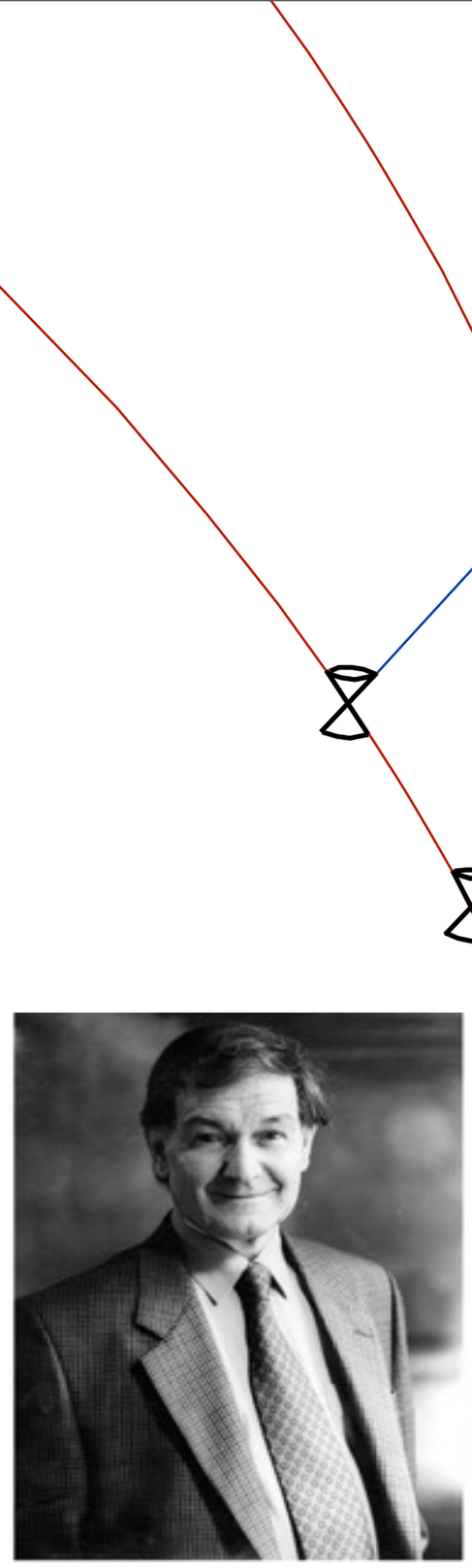


Cosmologie: le temps commence à la singularité

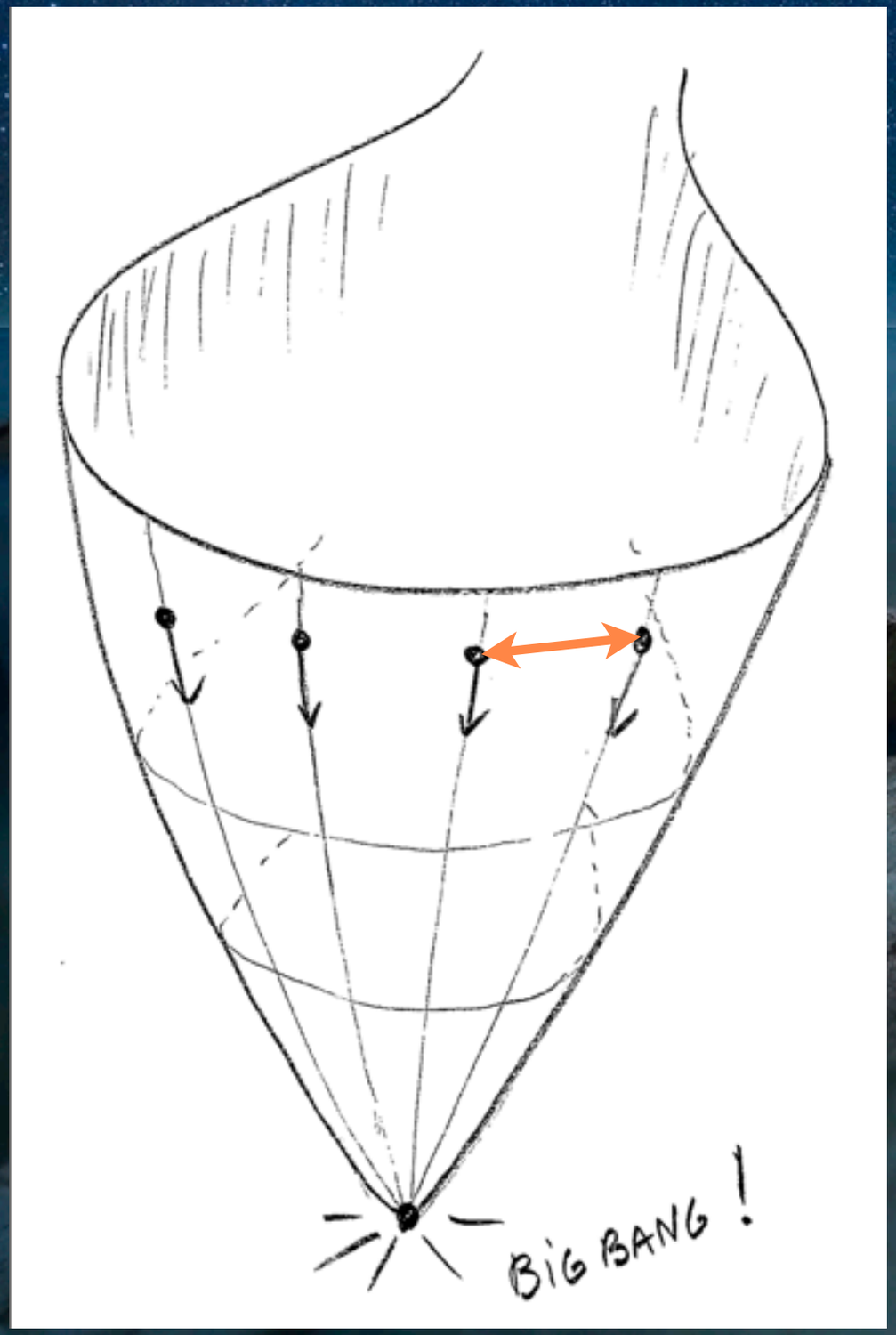
NOUS



Big Bang



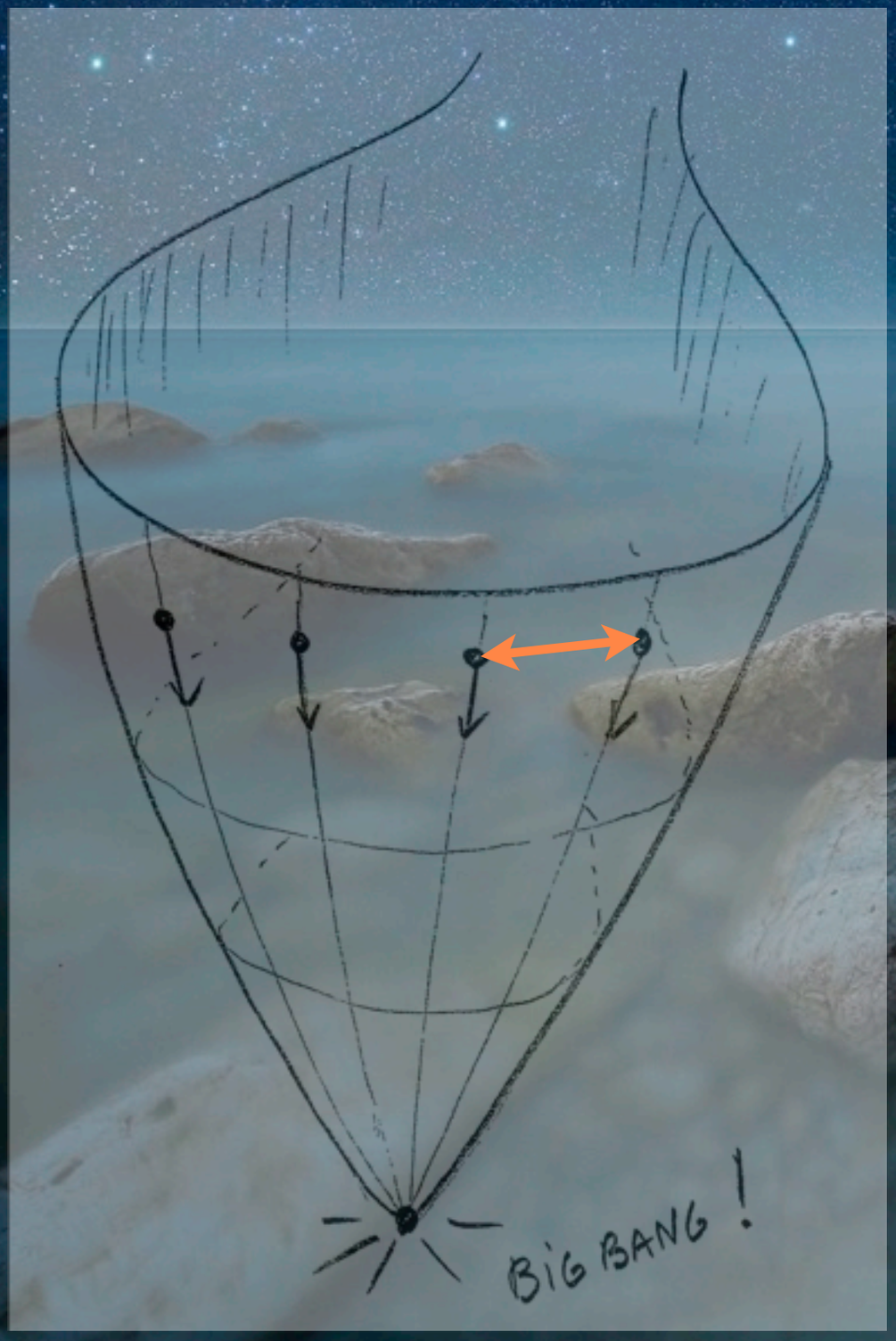
singularité
photon
matière



Distance Terre-Andromeda

$2.5 \times 10^6 ly$

$10^{-8} m$



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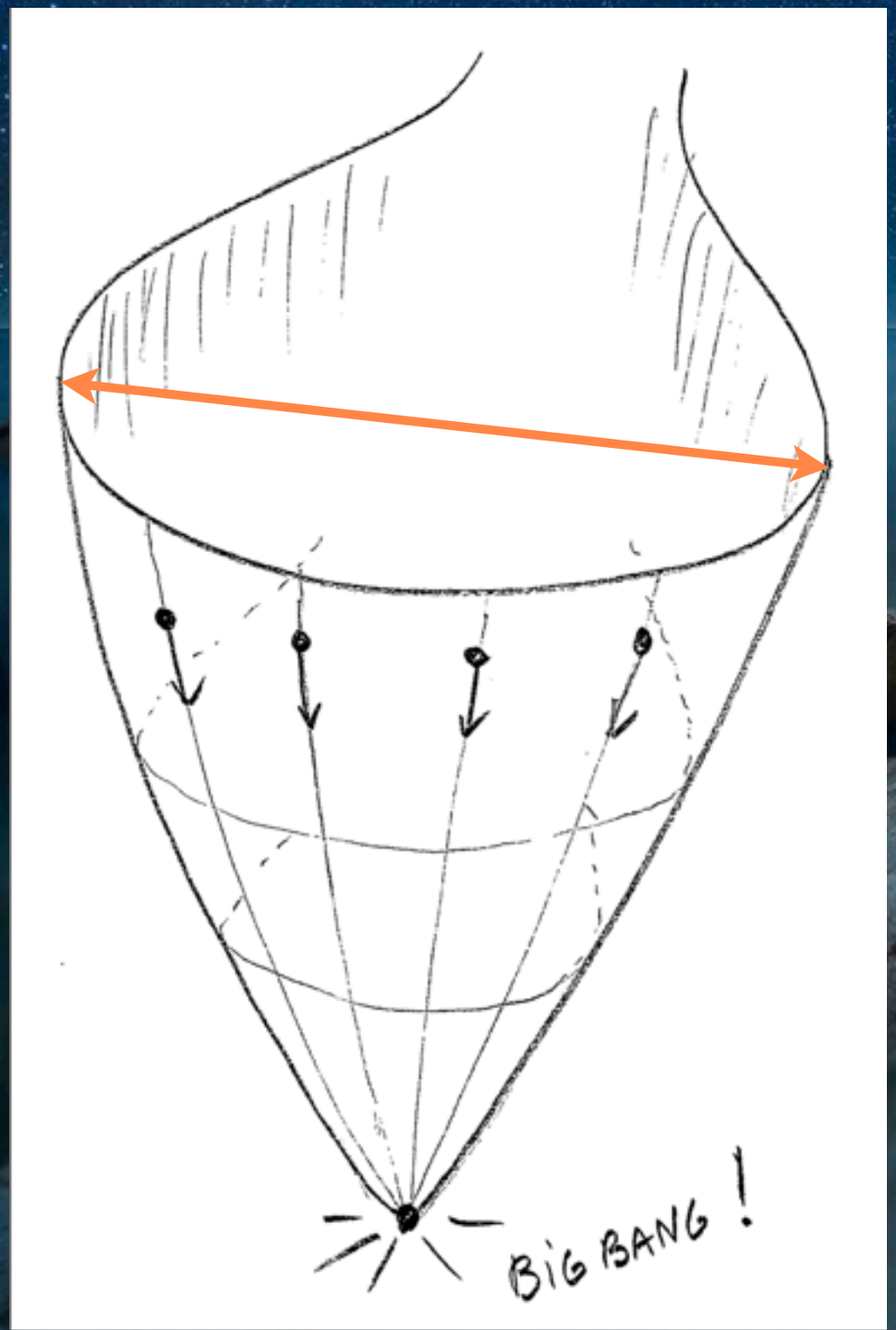
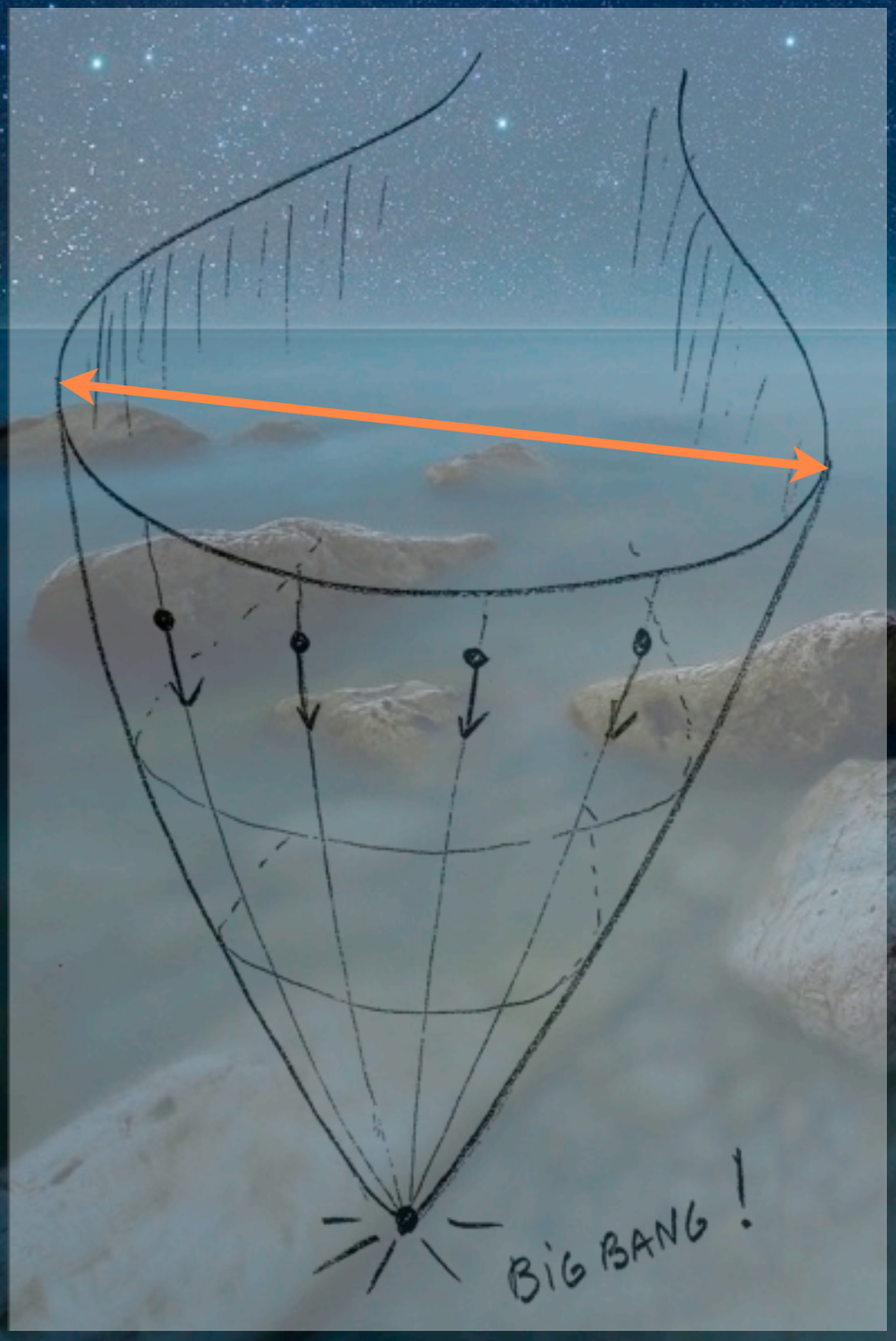


Taille Univers Observable

$14 \times 10^9 ly$

$0,1mm$



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$0,1mm$

Taille Univers Observable

$14 \times 10^9 ly$

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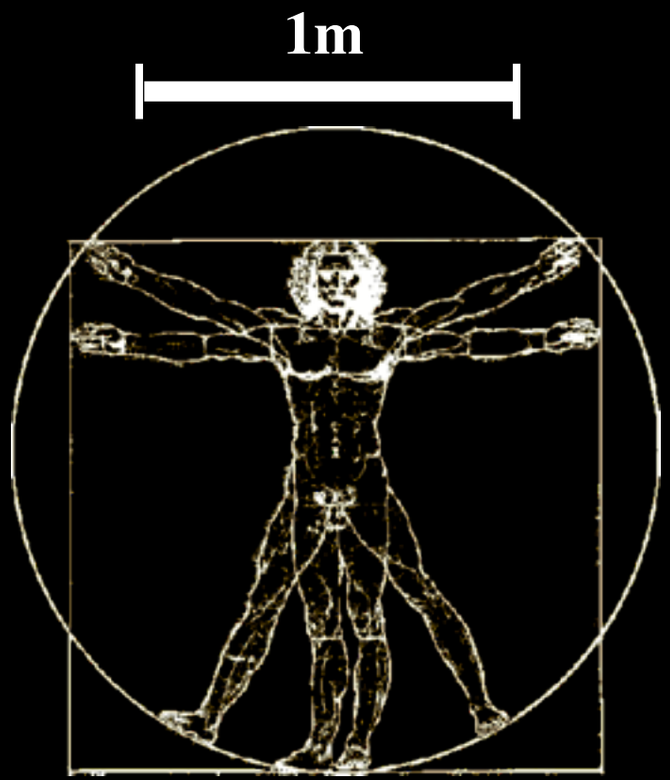
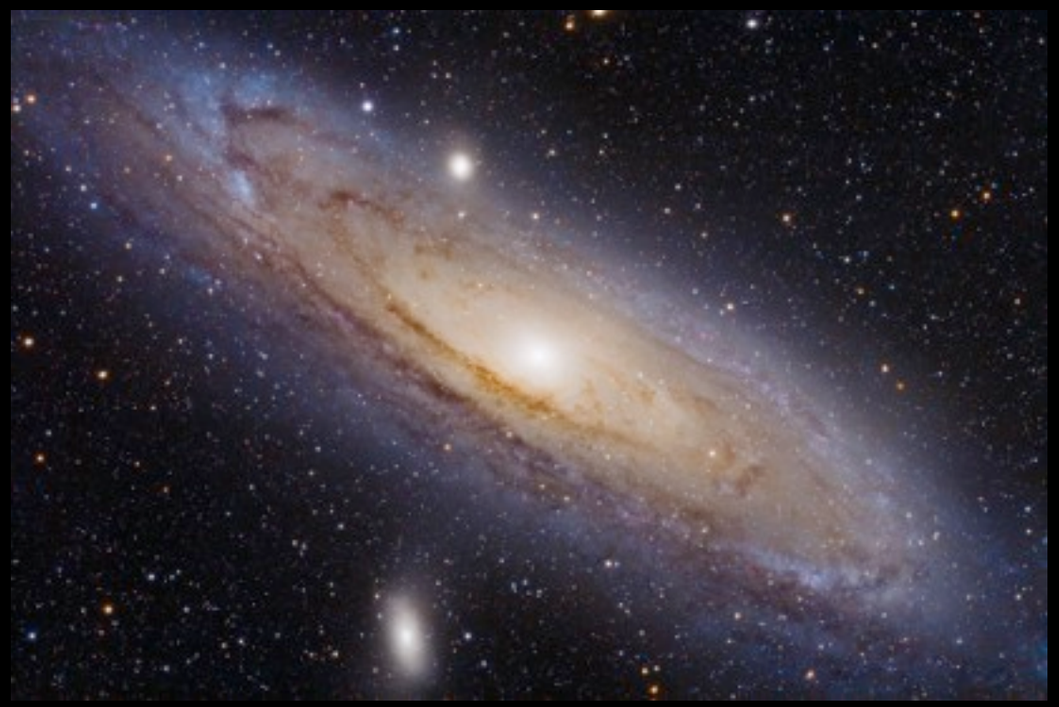
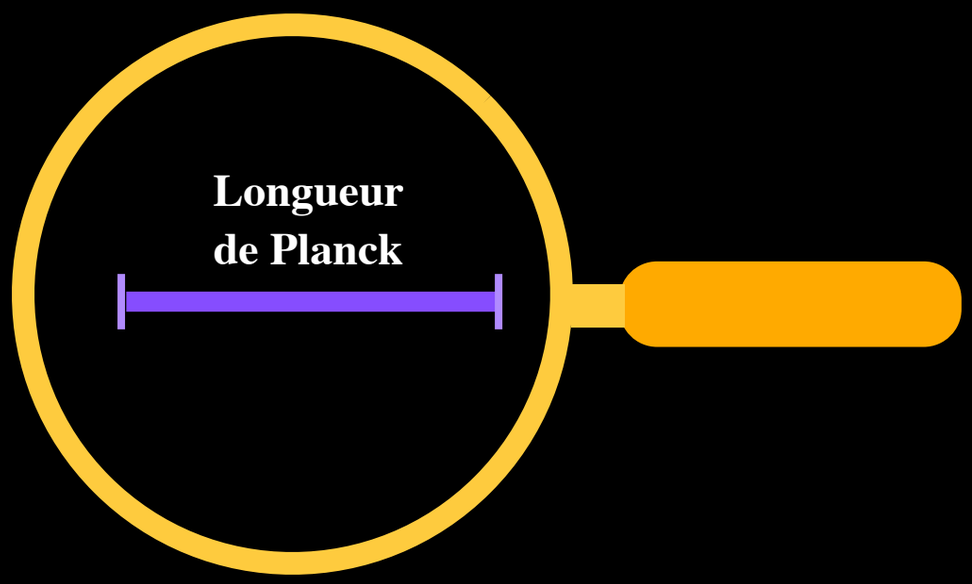
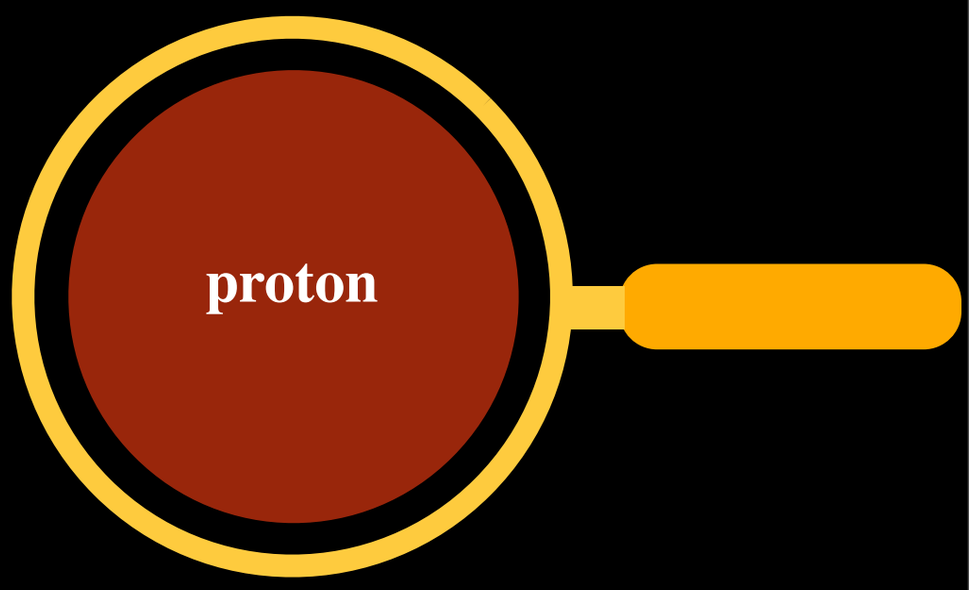
Gravitation Quantique: nouvelle physique à l'échelle de Planck









$2.5 \times 10^6 ly$

Le futur de l'univers

Photo: U. Montan

Saul Perlmutter

Photo: U. Montan

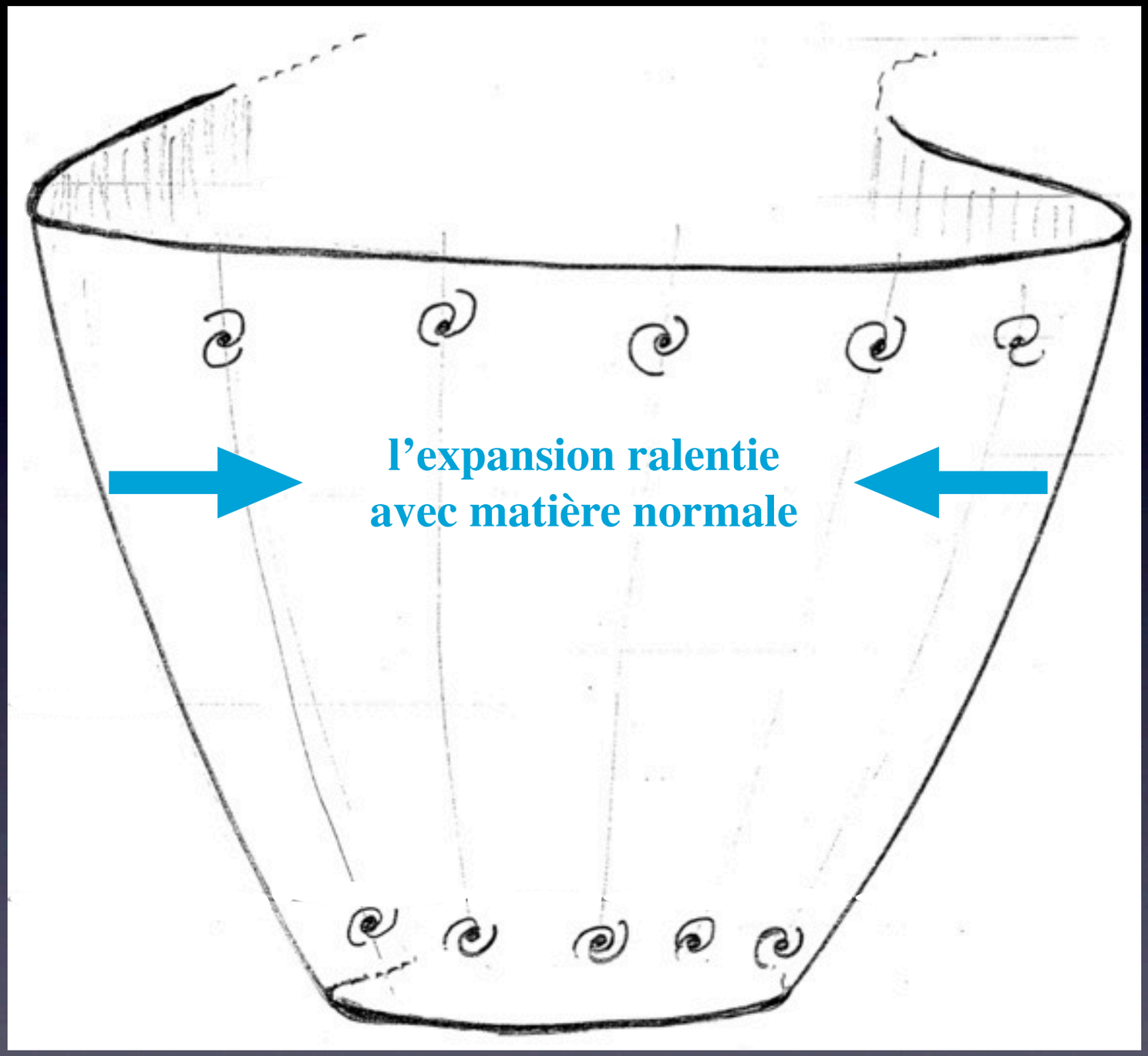
Brian P. Schmidt

Photo: U. Montan

Adam G. Riess

The S0 galaxy NGC 4526 in the Virgo Cluster hosted the well observed type Ia supernova 1994D.

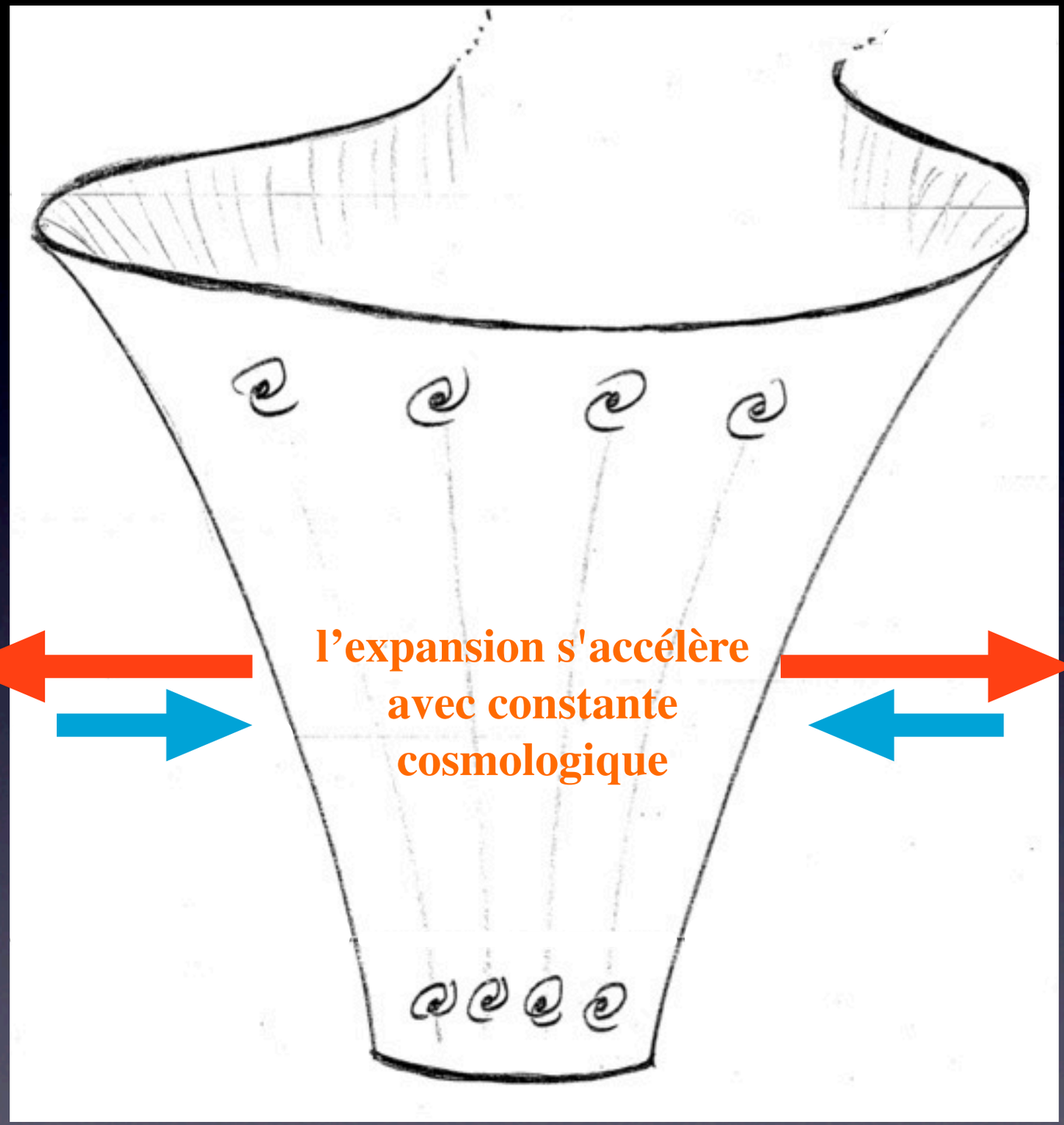
Univers en expansion



Temps

Univers en expansion

Temps



$$R_{ab} - \frac{1}{2} R \; g_{ab} = T_{ab} + \Lambda \; g_{ab}$$

Constante cosmologique: Energie Noir

Photo: U. Montan

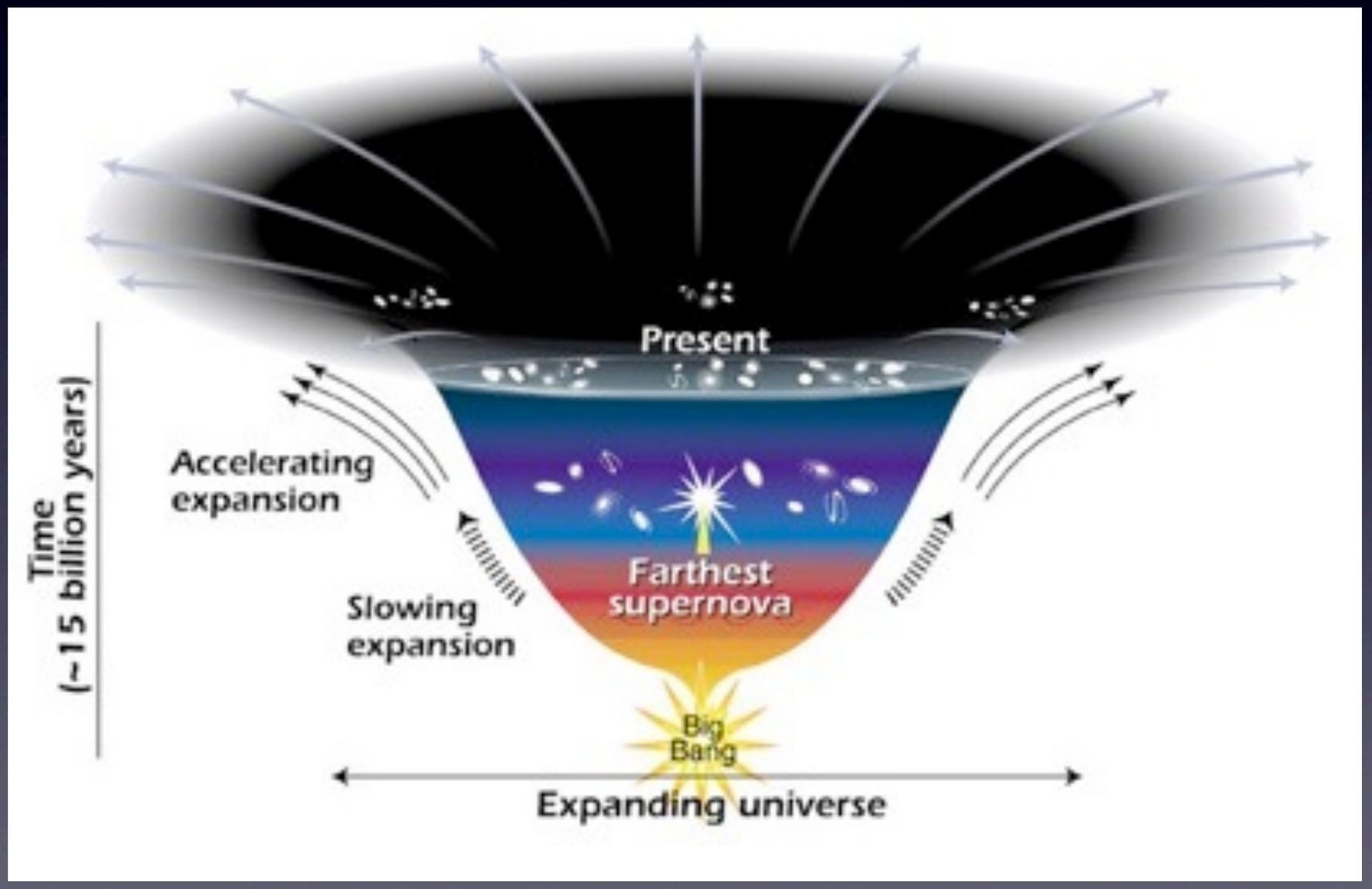
Saul Perlmutter

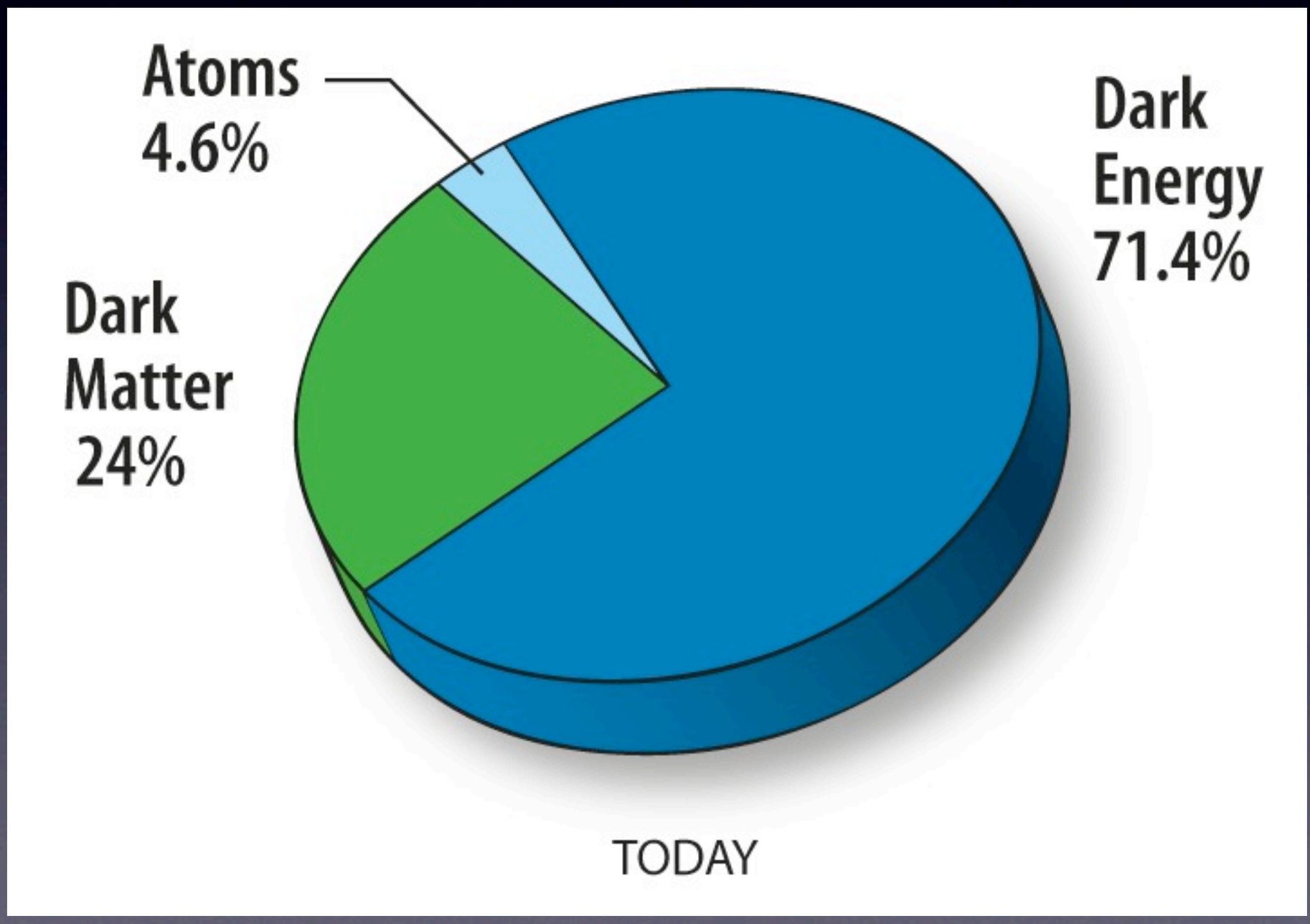
Photo: U. Montan

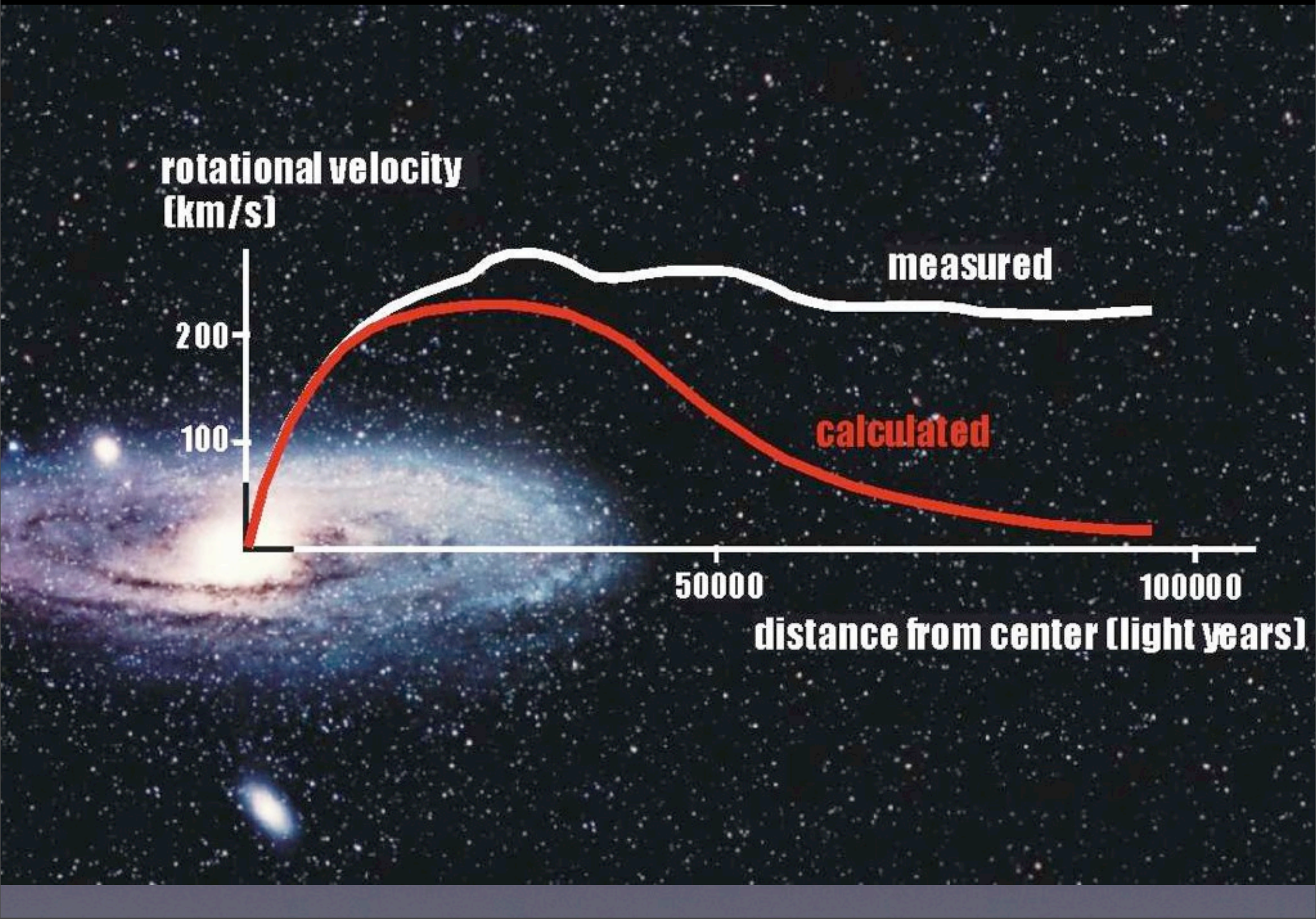
Brian P. Schmidt

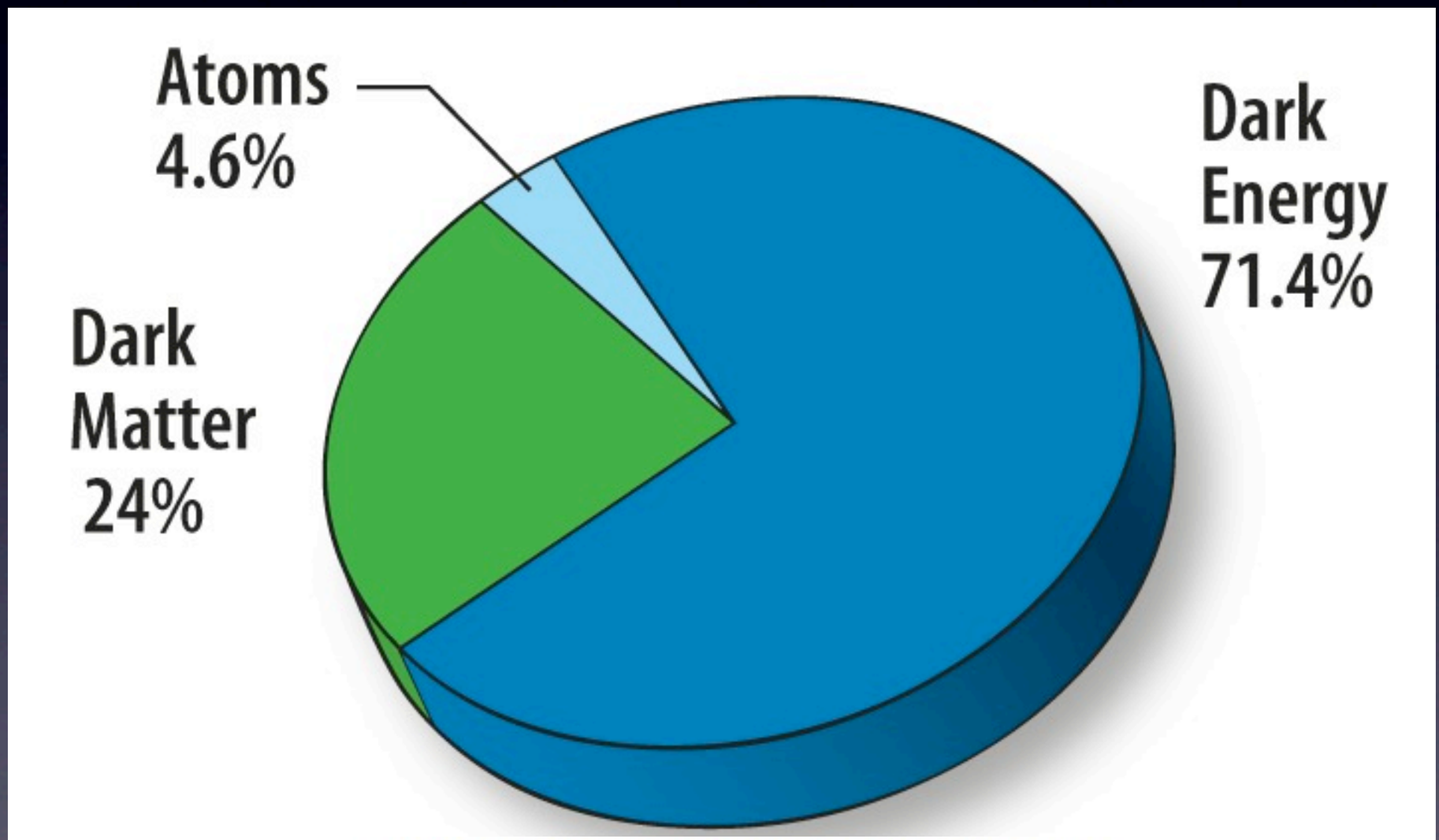
Photo: U. Montan

Adam G. Riess



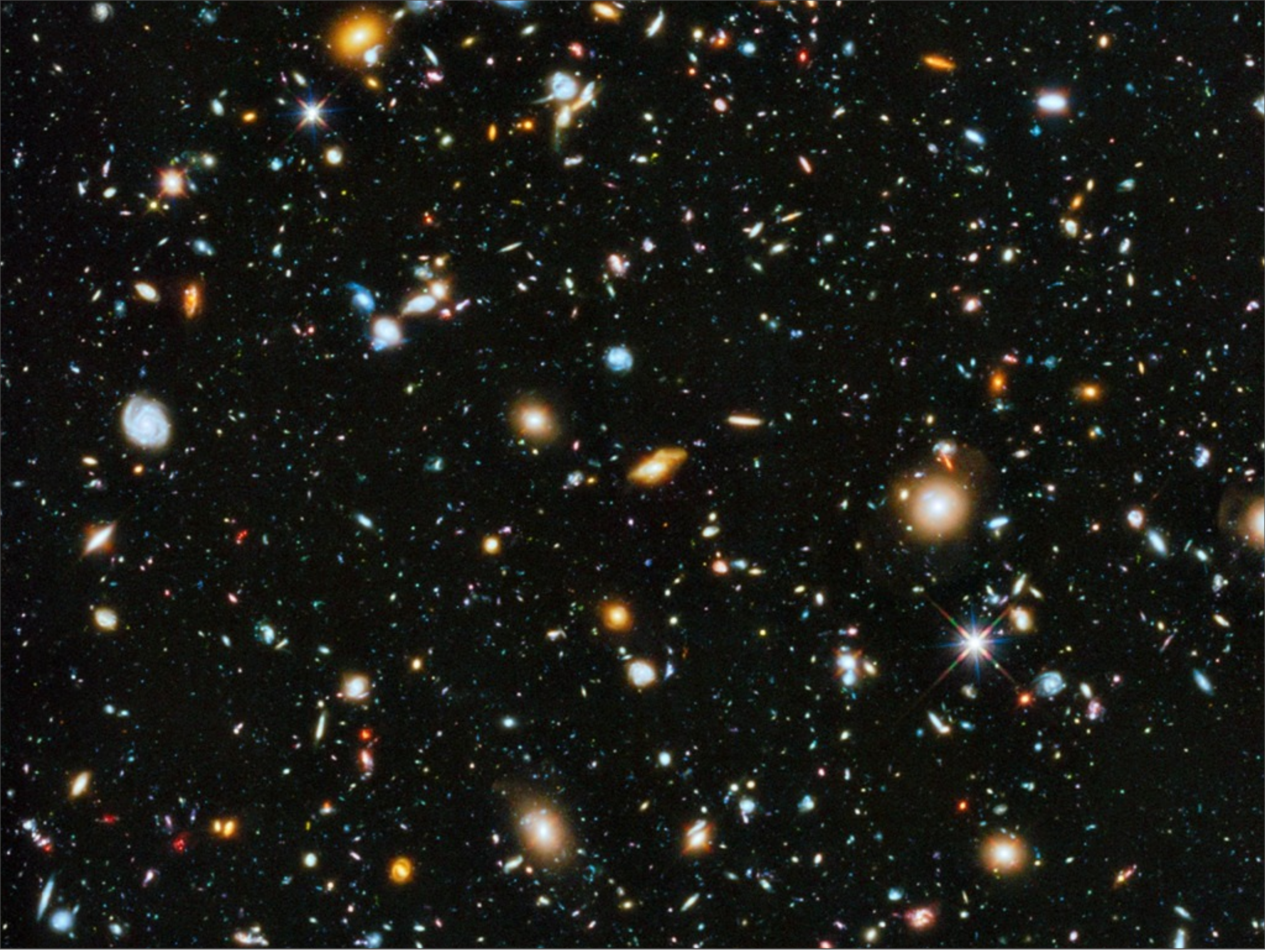

Atoms
4.6%
Dark
Matter
24%
Dark
Energy
71.4%
TODAY


rotational velocity
(km/s)
200
100
measured
calculated
50000
100000
distance from center (light years)



The acceleration is thought to be driven by dark energy, but what that dark energy is remains an enigma - perhaps the greatest in physics today. What is known is that dark energy constitutes about three quarters of the Universe. Therefore the findings of the 2011 Nobel Laureates in Physics have helped to unveil a Universe that to a large extent is unknown to science. And everything is possible again.

Epilogue

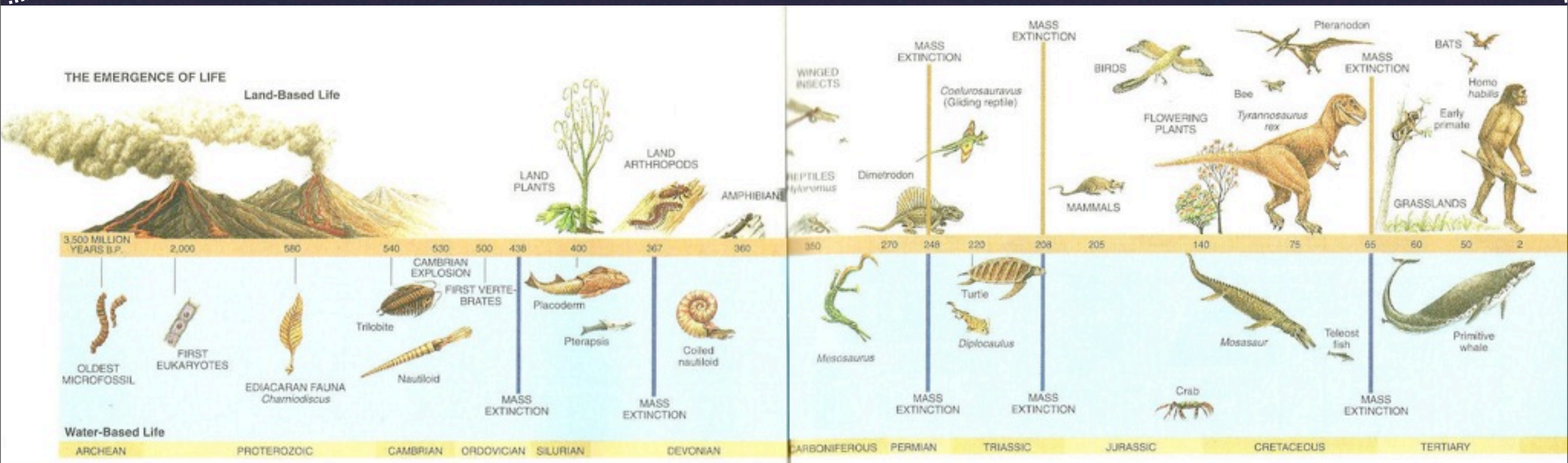


Saturday 13 December 14

Histoire de l'Univers

BIG BANG
-13,7
milliard
d'anné

Histoire de la vie sur terre

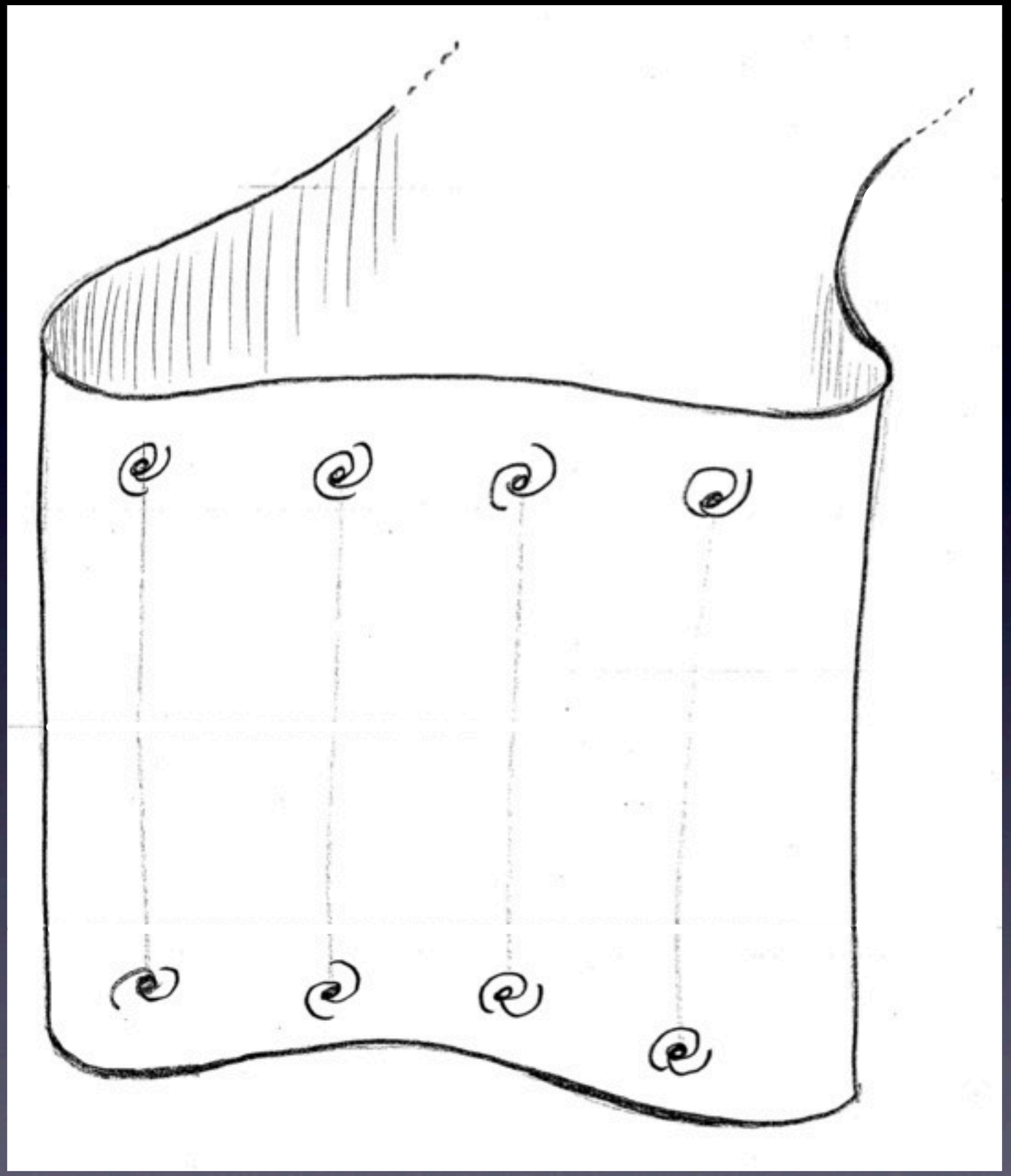


Merci Beaucoup!

“We are the means for the Universe to know itself”

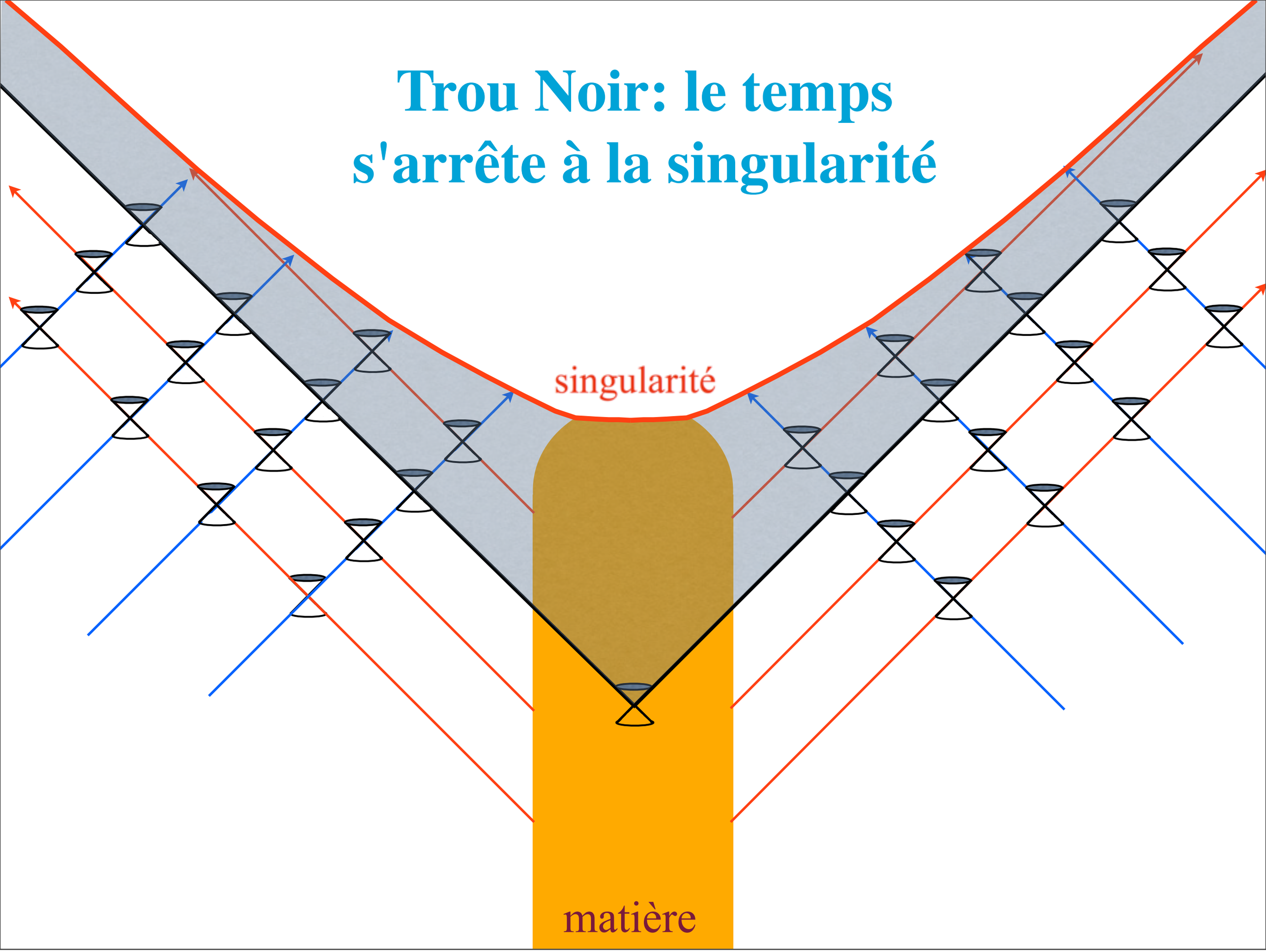
Carl Sagan

Univers en expansion



Temps

Trou Noir: le temps s'arrête à la singularité



Le fond diffus cosmologique

Dès 1948, le facétieux physicien d'origine russe George Gamow note une conséquence inéluctable de ce scénario du big bang. La naissance du cosmos se serait accompagnée de l'émission d'un intense rayonnement. Certes, aujourd'hui, ce brouhaha primordial se serait singulièrement atténué, essoufflé, affaibli. Mais, le "rayonnement fossile" du cosmos, "fond diffus du ciel" ou "premier cri de l'Univers" devrait encore persister.

La prévision reste, hélas, lettre morte. En 1965, deux jeunes radioastronomes du laboratoire de la Bell Telephone, Arno Penzias et Robert Wilson, ignorent ces travaux. Cependant, ils découvrent - par hasard - un fond diffus radio électrique qui envahit toute la voûte céleste. Le signal ne varie ni au fil du jour, ni au cours des saisons. Il est étranger au Soleil et à la Voie lactée. Penzias et Wilson viennent de démasquer le rayonnement fossile. Ils reçoivent le prix Nobel en 1978. C'est l'envolée. On s'aperçoit que le bruit radio suit à la perfection la loi du corps noir, calculée au début du siècle par l'Allemand Max Planck. Le cosmos aurait libéré l'essentiel de son énergie dans son premier âge.

Timeline of the discovery of the CMB

Important dates and persons

1946 George Gamow estimates a temperature of 50K

1946 Robert Dicke predicts a microwave background radiation temperature of "less than 20K" (ref: Helge Kragh), but later revised to 45K (ref: Stephen G. Brush)

1948 Ralph Alpher and Robert Herman re-estimate Gamow's estimate at 5K.

1949 Alpher and Herman re-re-estimate Gamow's estimate at 28K.

1960s Robert Dicke re-estimates an MBR (microwave background radiation) temperature of 40K (ref: Helge Kragh)

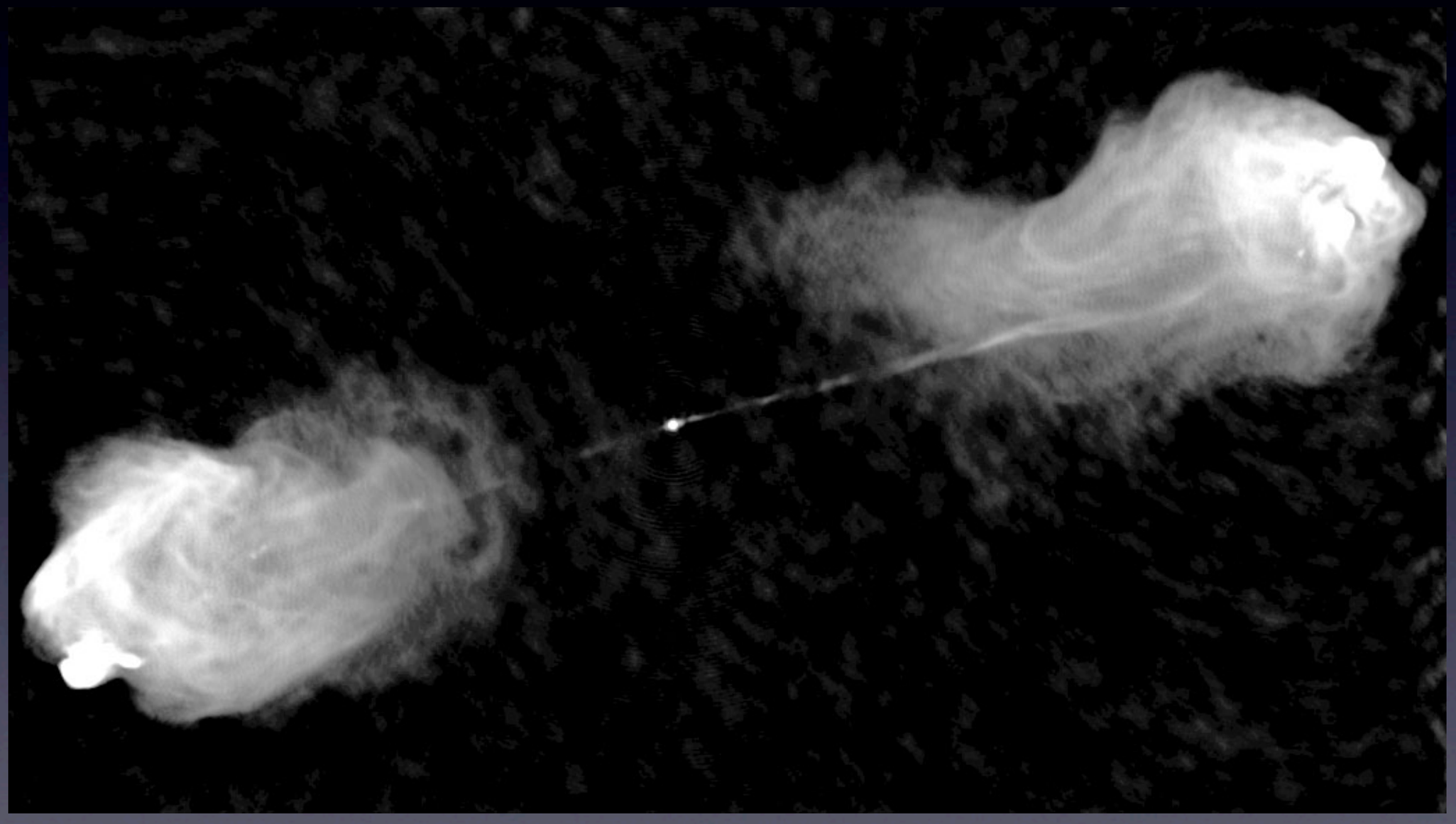
1964 A. G. Doroshkevich and Igor Novikov publish a brief paper, where they name the MBR phenomenon as detectable.

1960s Arno Penzias and Robert Woodrow Wilson measure the temperature to be approximately 3 K.

Saturday 13 December 14

Evidence Observationnelle:

Production de phénomènes très énergétiques dans les jeunes galaxies (ici Cygnus A).

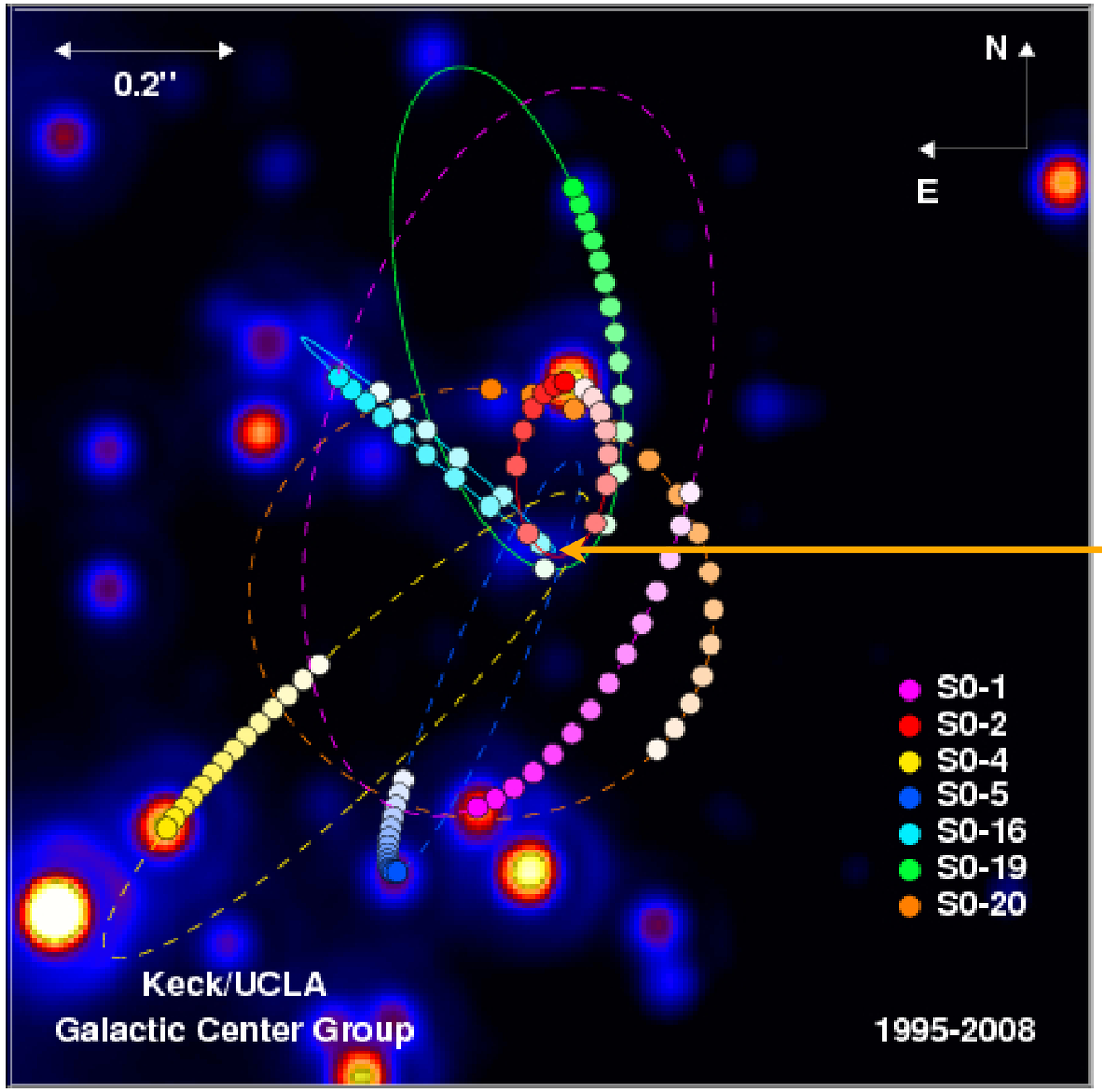


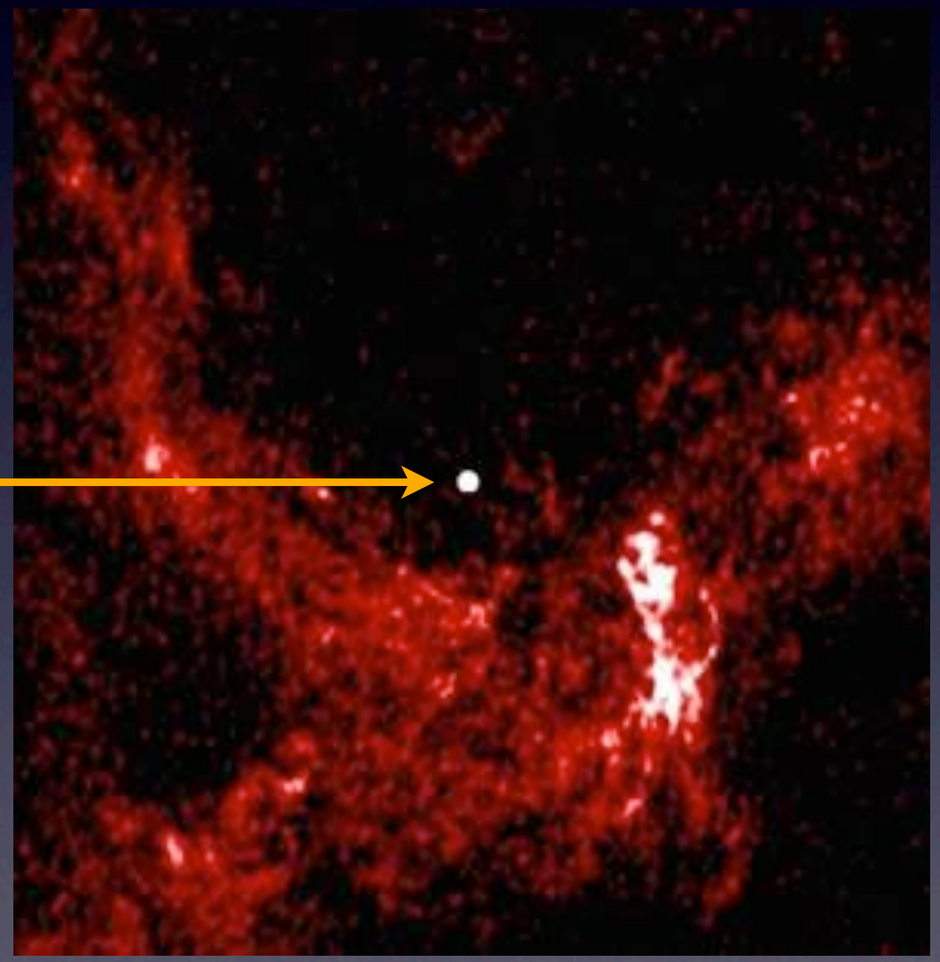
$$\Delta E = 10^7 M_\odot c^2$$

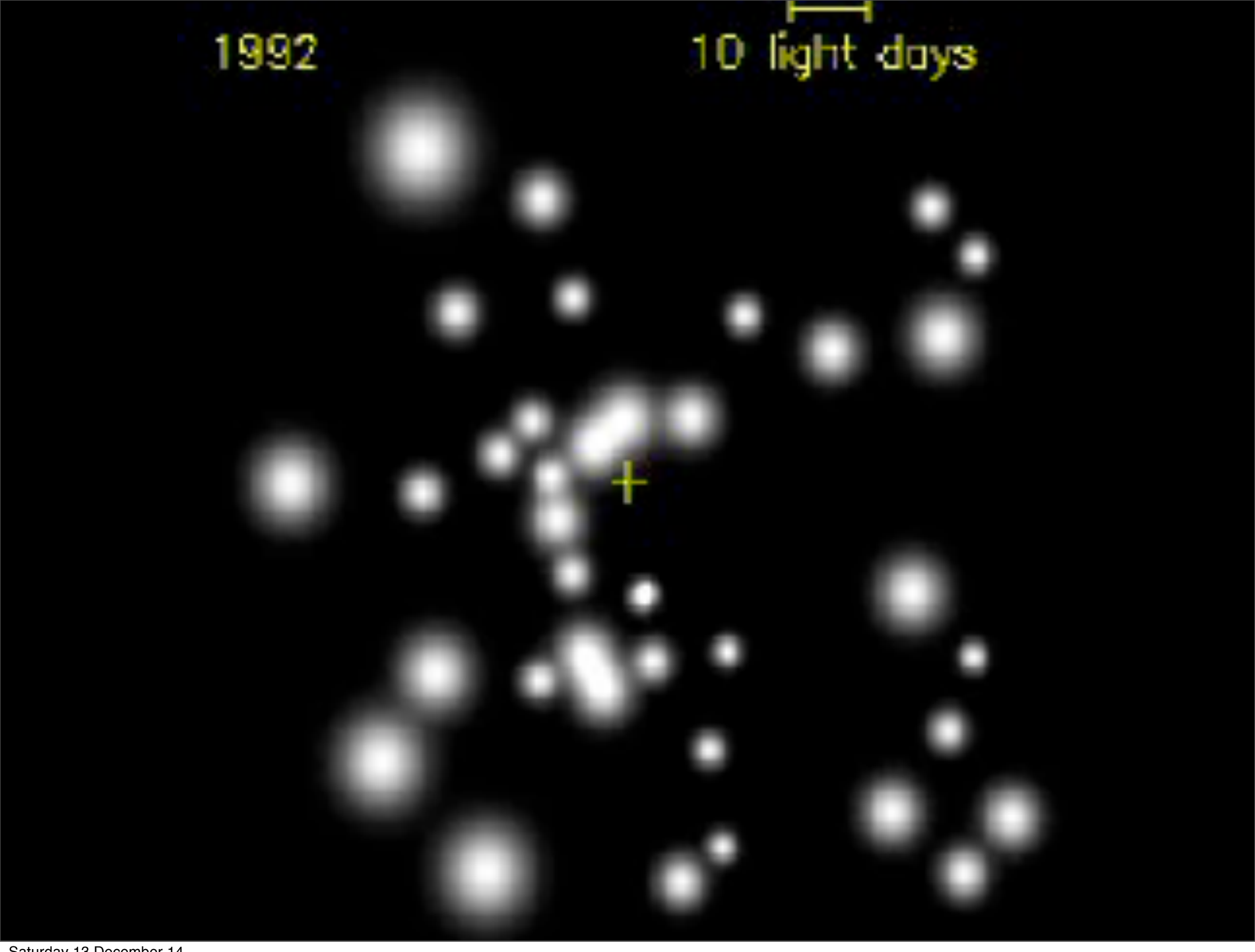
Trou noir binaire dans 3C 75

Evidence Observationnelle:

Observation directe des ses manifestations gravitationnelles.






1992
10 light days

Merci Beaucoup!