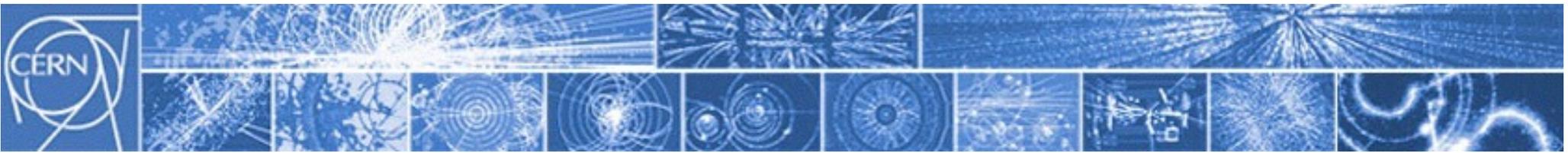
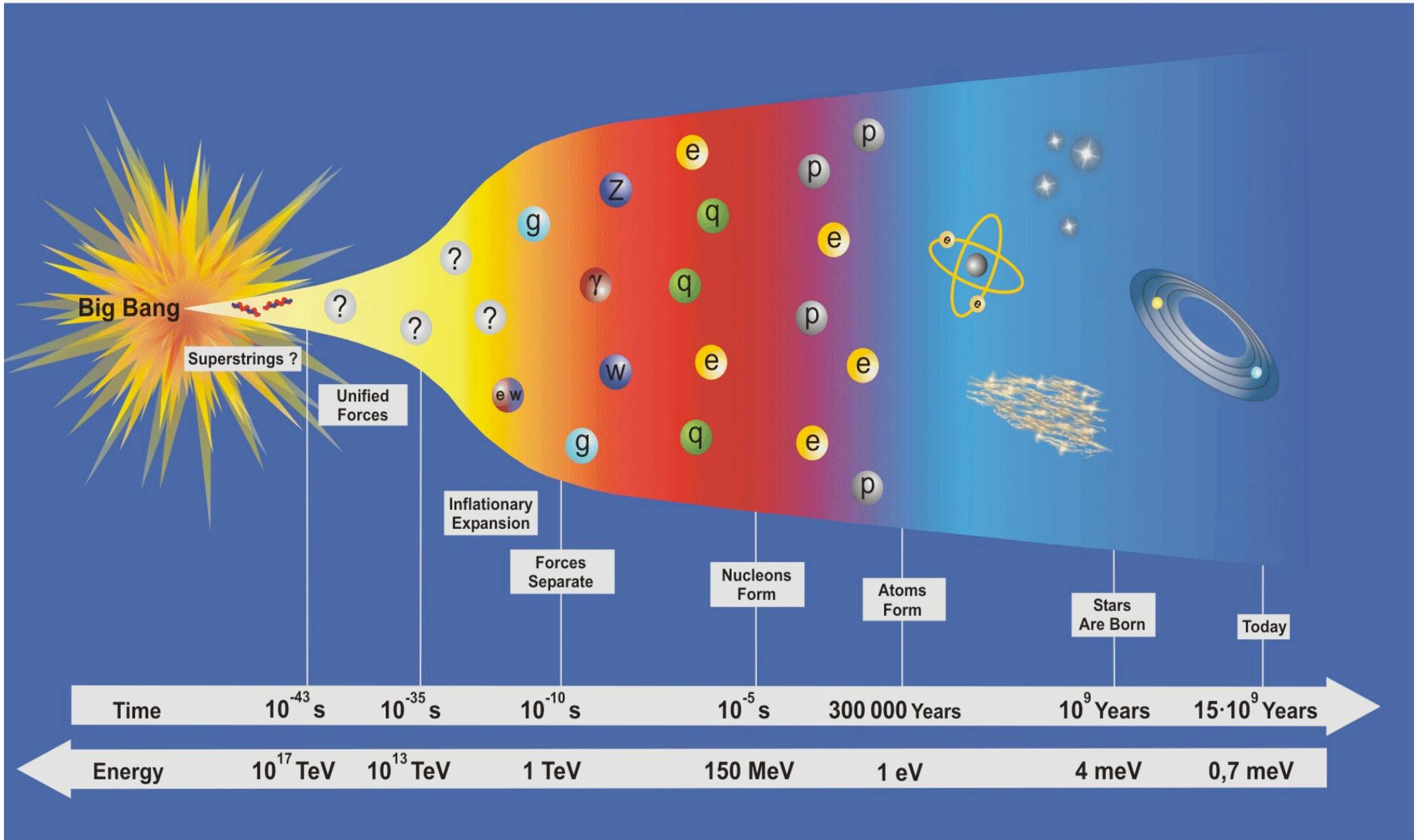
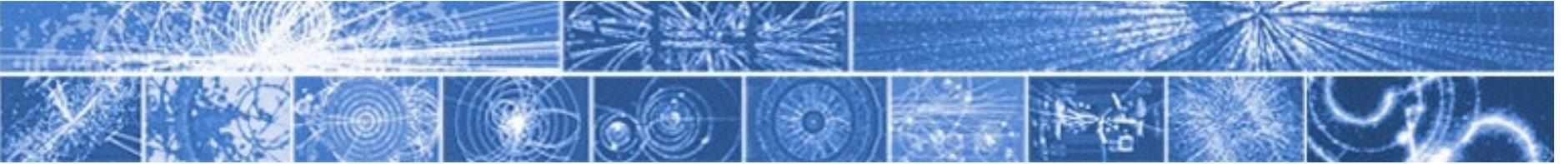


Breve storia dell'Universo

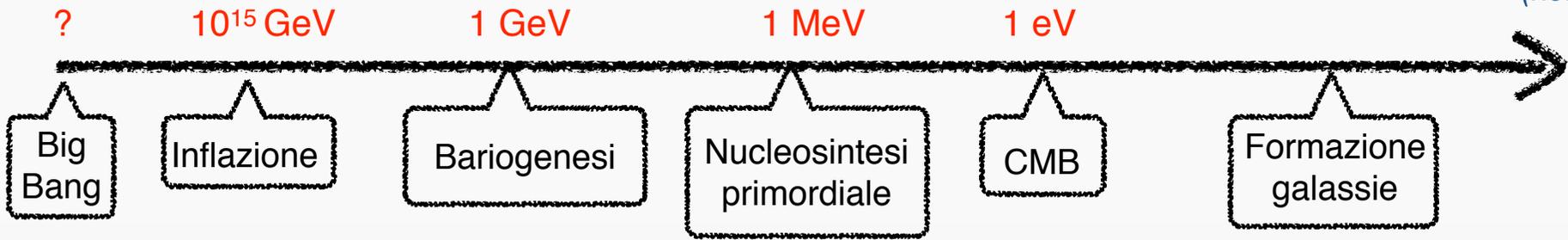


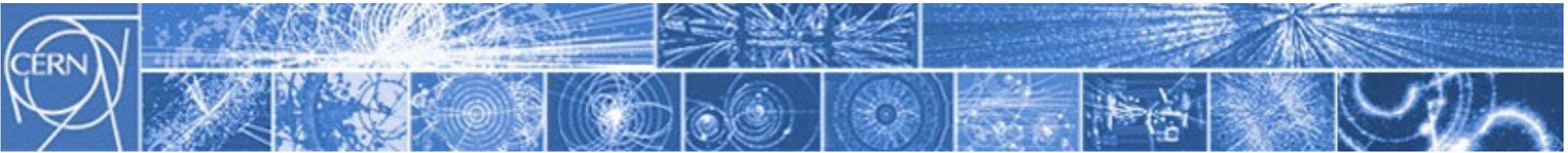
Ripercorrere all'indietro la storia dell'Universo



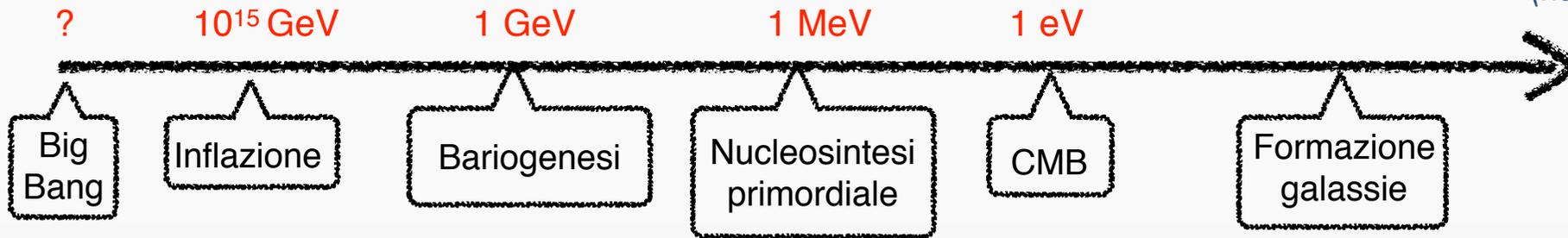


(non in scala!)



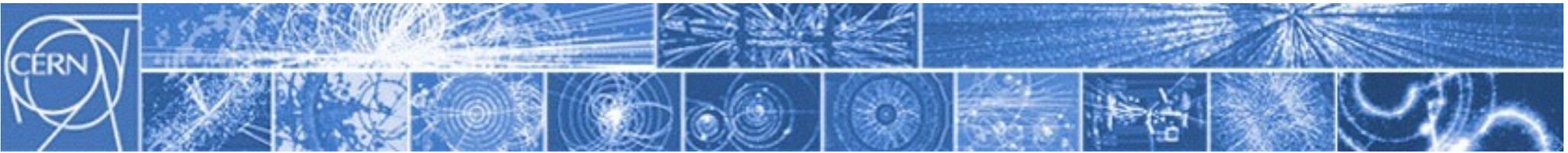


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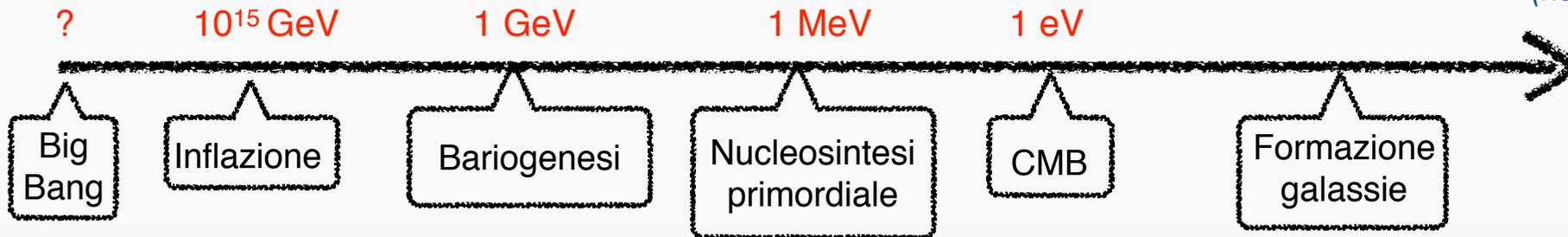


Concetto base:

l'Universo si espande e si raffredda



(non in scala!)

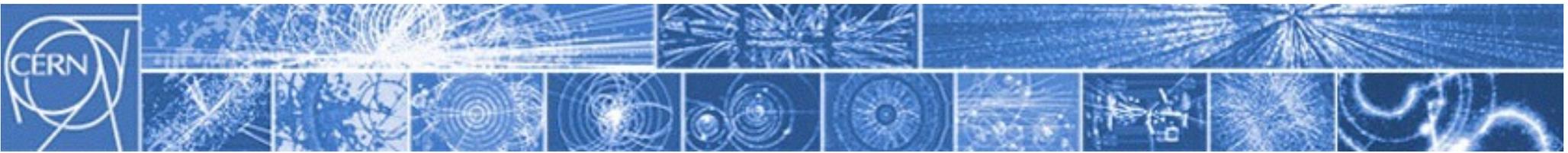


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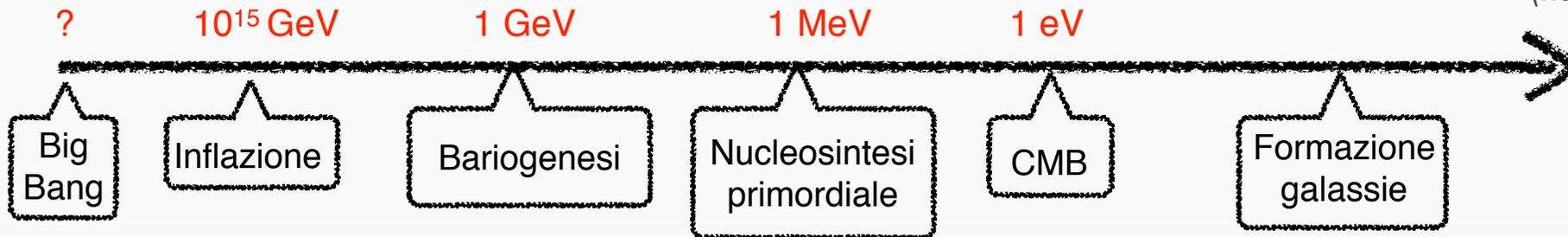
l'Universo si espande e si raffredda

aumenta di volume
come un panettone che lievita

(FAQ: *in* che cosa si espande?)



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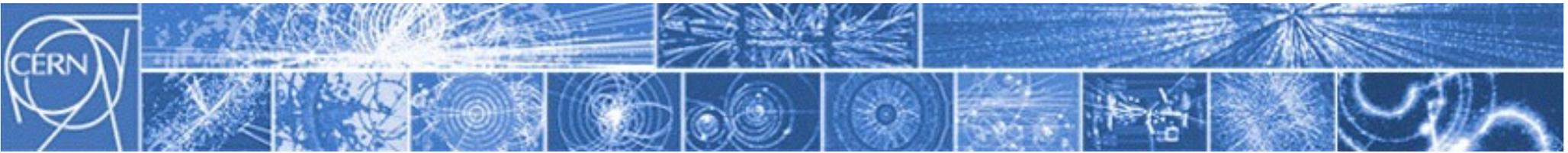
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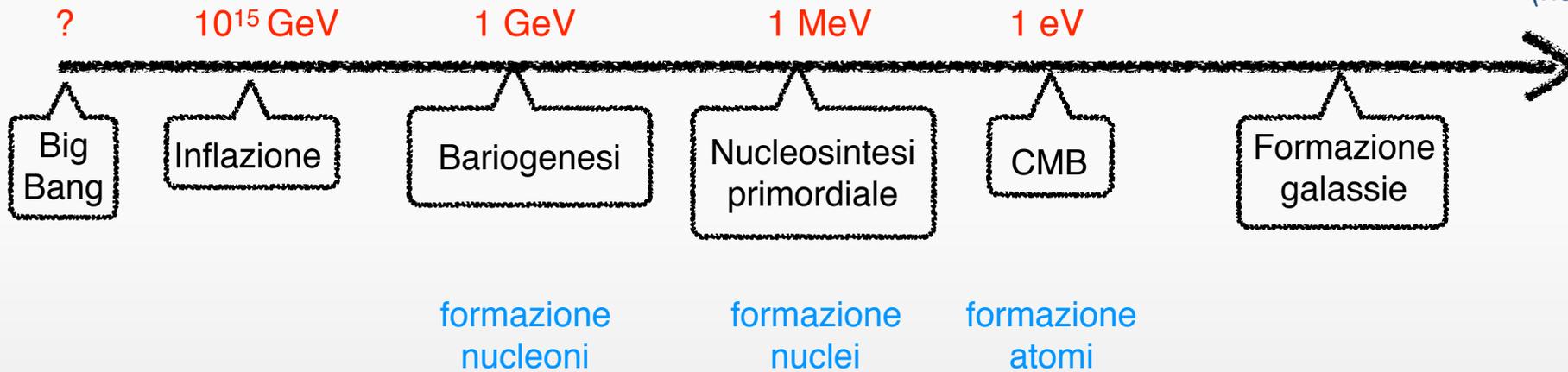
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a **alte T**, la materia si **dissocia**
nei costituenti fondamentali

a **basse T**, la materia si **agglomera**
in strutture sempre più complesse



(non in scala!)



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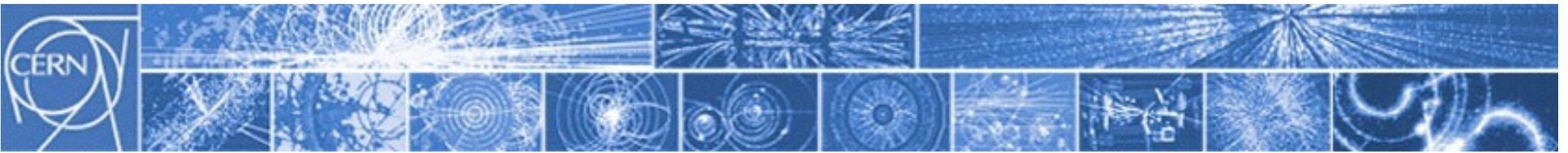
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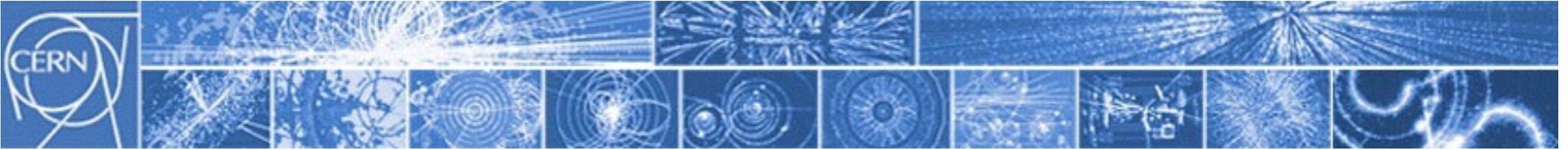
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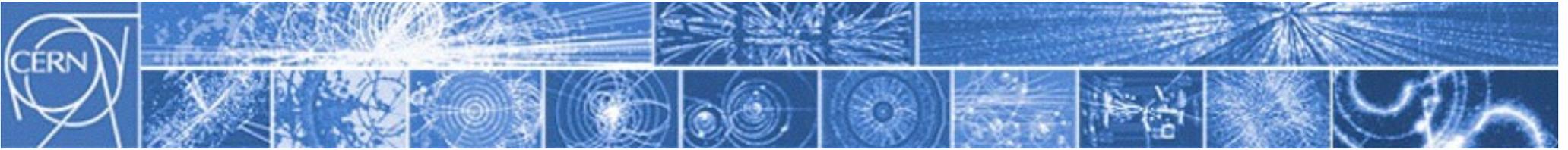
Relatività generale e basi di cosmologia (in 2 slides / 2 minuti)



Relatività generale e basi di cosmologia (in 2 slides / 2 minuti)

Equazioni di Einstein

$$G_{\mu\nu} = 8\pi G T_{\mu\nu}$$



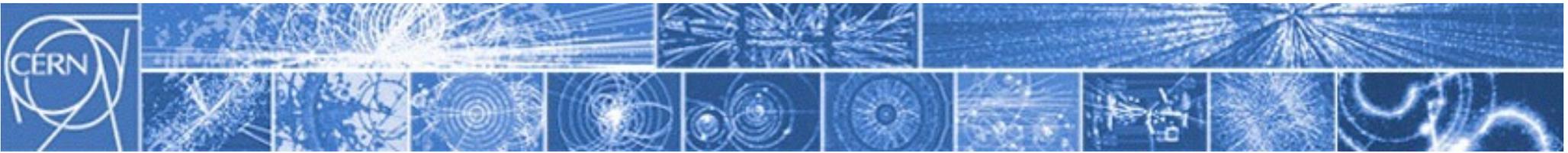
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*geometria dello
spazio-tempo*

*contenuto di
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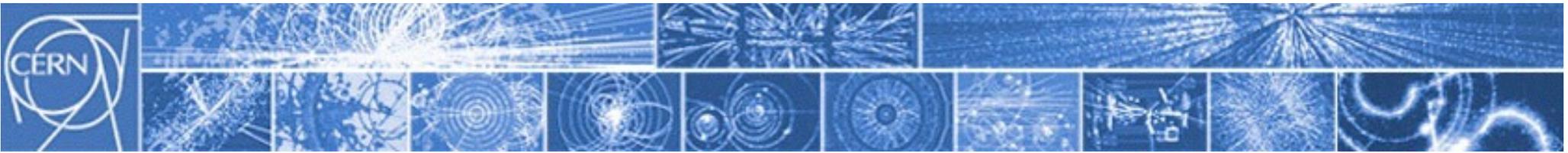
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$R_{\mu\nu}$ funzione di $g_{\mu\nu}$

$g_{\mu\nu}$: la metrica

$a(t)$: il fattore di scala
(la grandezza)
dell'Universo



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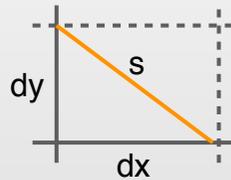
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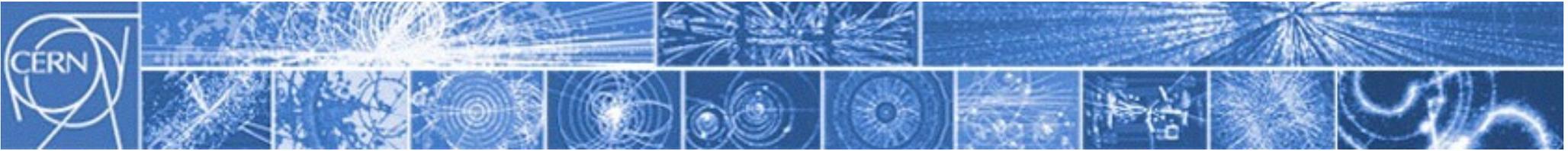
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$$s^2 = dx^2 + dy^2$$

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Relatività generale e basi di cosmologia (in 2 slides / 2 minuti)

Equazioni di Einstein

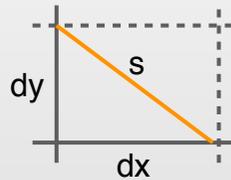
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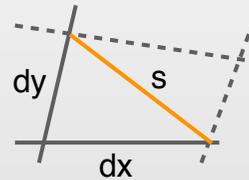
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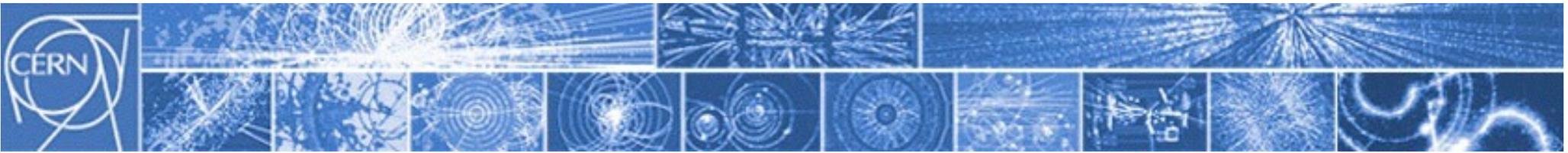
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Relatività generale e basi di cosmologia (in 2 slides / 2 minuti)

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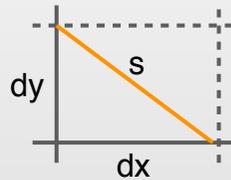
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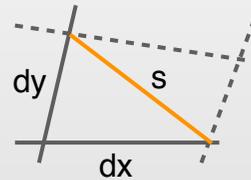
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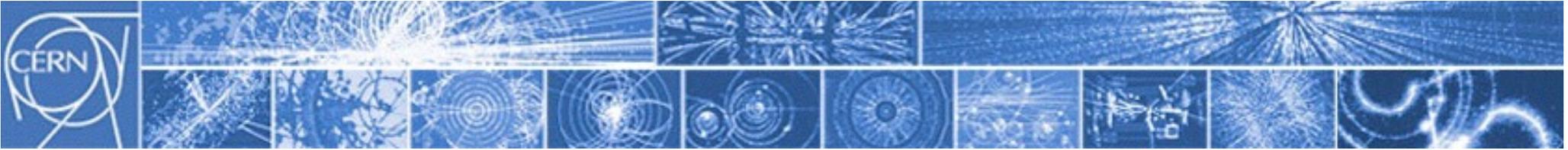
contenuto di
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Parametro di Hubble

$$H = \frac{\dot{a}}{a}$$

Redshift

$$z = \frac{\lambda_0}{\lambda_1} \propto \frac{T_1}{T_0}$$



Relatività generale e basi di cosmologia (in 2 slides / 2 minuti)

Equazioni di Einstein

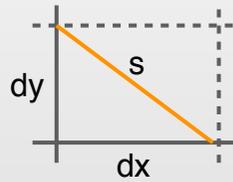
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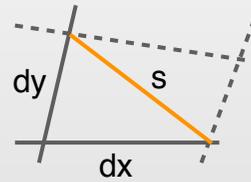
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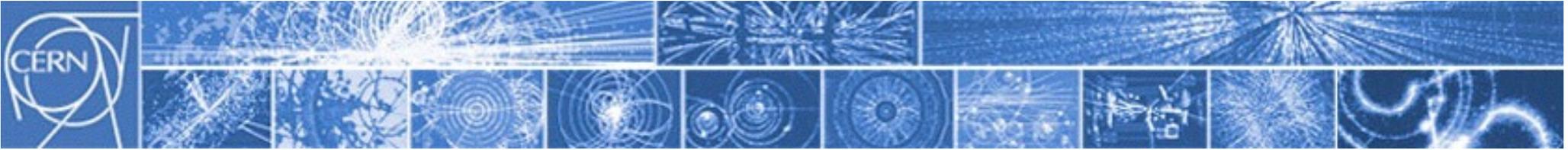
$$T_{\mu\nu} = \begin{pmatrix} \rho & & & \\ & -P & & \\ & & -P & \\ & & & -P \end{pmatrix} \quad G = \frac{1}{M_{Pl}^2}$$

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Relatività generale e basi di cosmologia (in 2 slides / 2 minuti)

Equazioni di Einstein

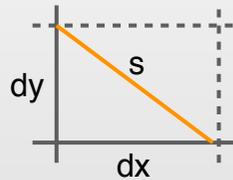
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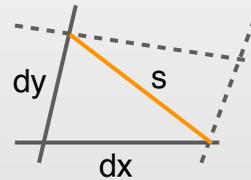
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Equazione di stato $P = w\rho$

'matter' $P = 0$ $\rho \propto 1/a^3$

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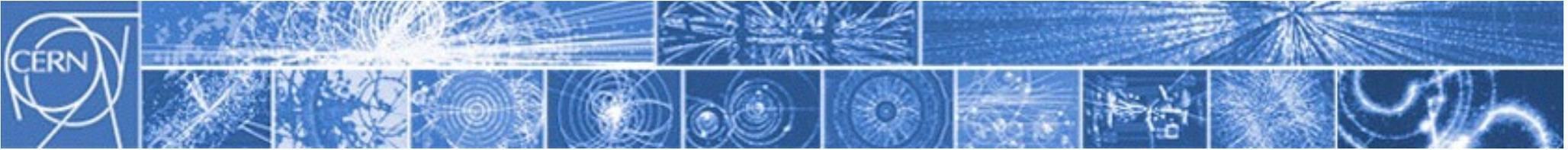
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Relatività generale e basi di cosmologia (in 2 slides / 2 minuti)

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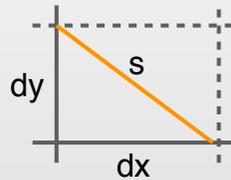
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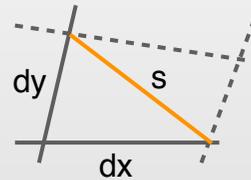
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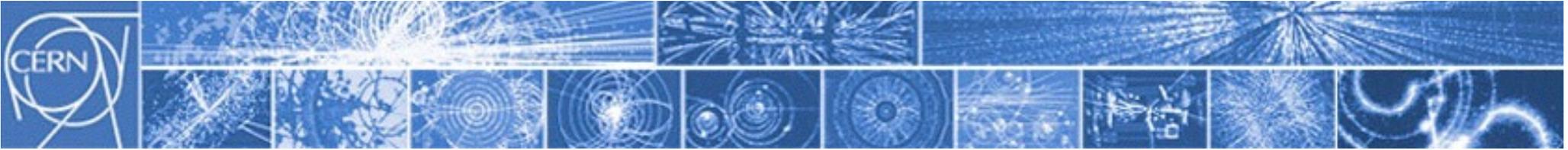
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Relatività generale e basi di cosmologia (in 2 slides / 2 minuti)

Equazioni di Einstein

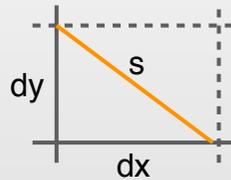
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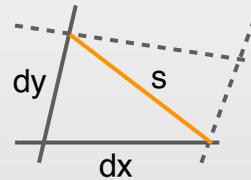
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geometria dello spazio-tempo



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omogeneità isotropia

Parametro di Hubble

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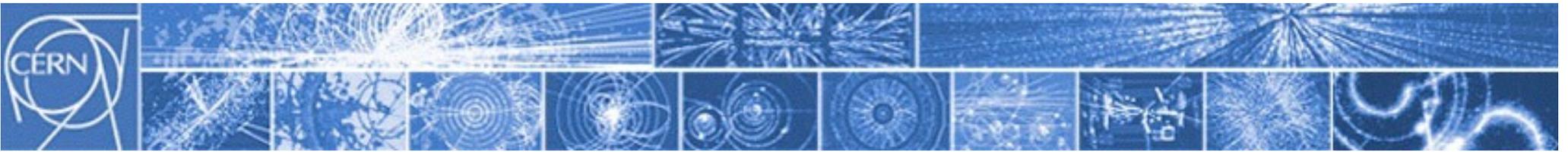
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Equazioni di Friedmann-Robertson-Walker

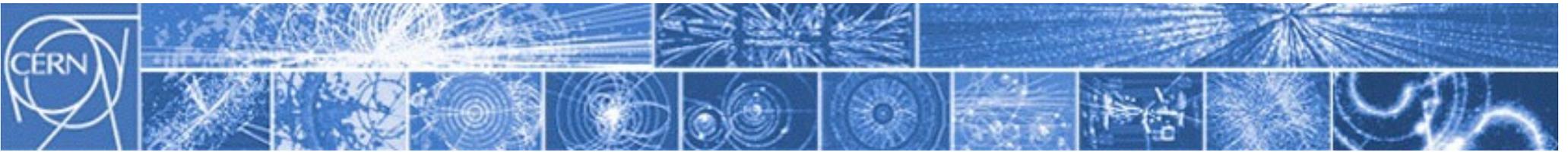
$$\left(\frac{\dot{a}}{a}\right)^2 + \frac{k}{a^2} = \frac{8\pi G}{3} \rho \quad \text{FRW I}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3} (\rho + 3P) \quad \text{FRW II}$$



Relatività generale e basi di cosmologia (in 2 slides / 2 minuti)

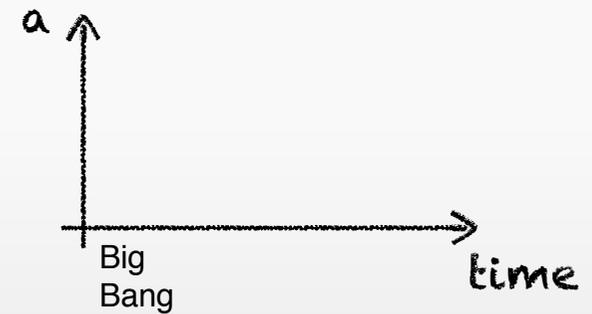
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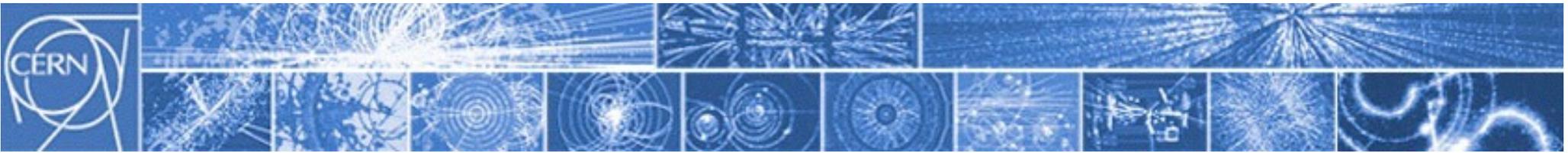


Relatività generale e basi di cosmologia (in 2 slides / 2 minuti)

$$\left(\frac{\dot{a}}{a}\right)^2 + \frac{k}{a^2} = \frac{8\pi G}{3}\rho$$

con alcuni (non semplici) passaggi
posso risolvere per $a(t)$:



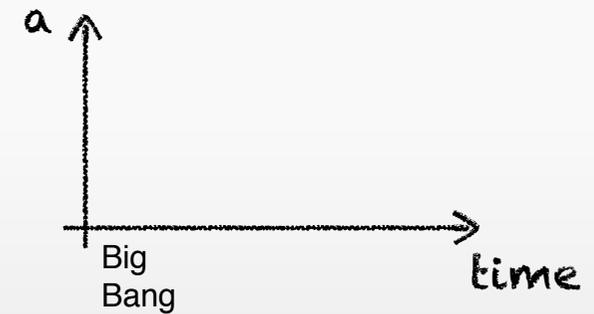


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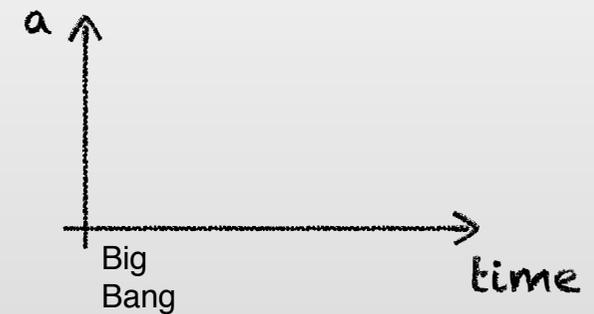
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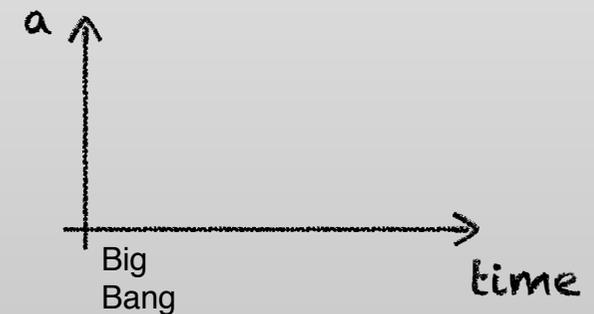
$$k < 0$$

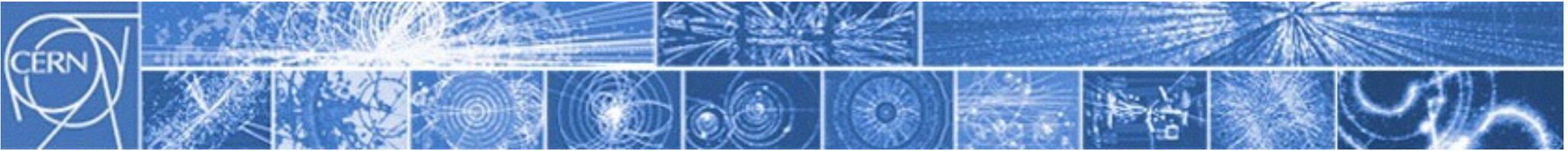


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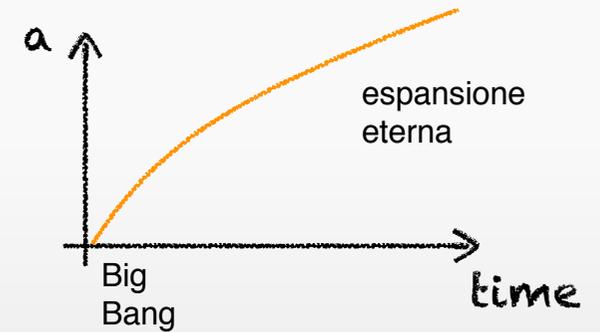


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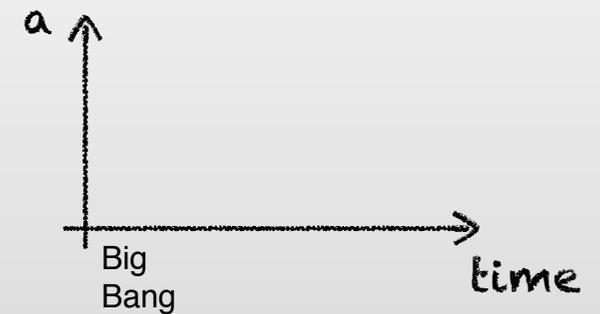
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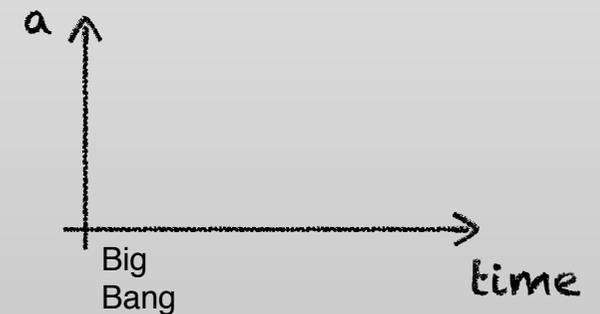
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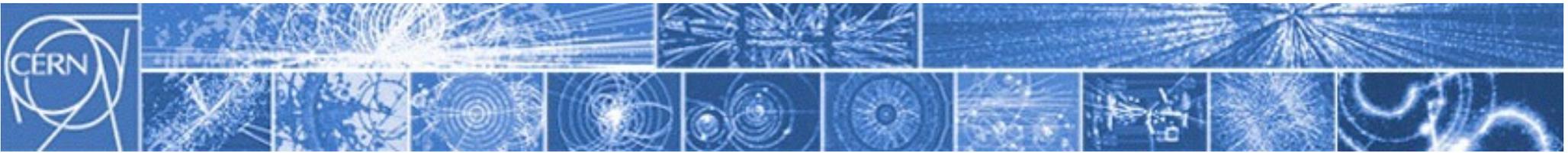


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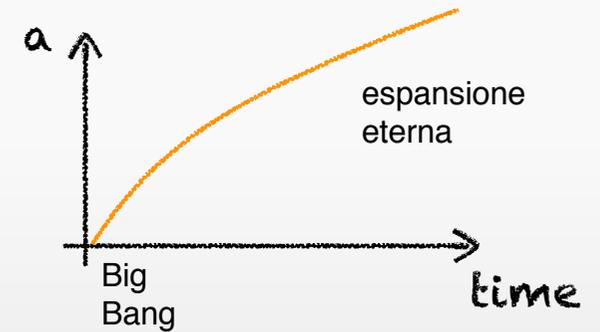


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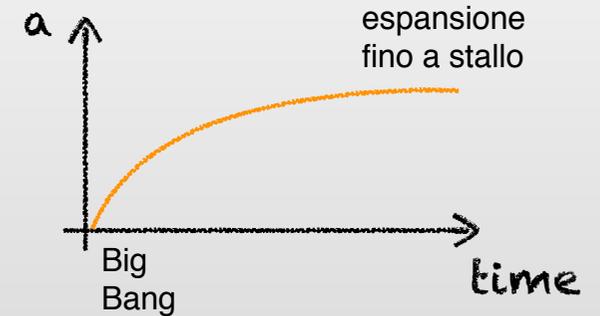
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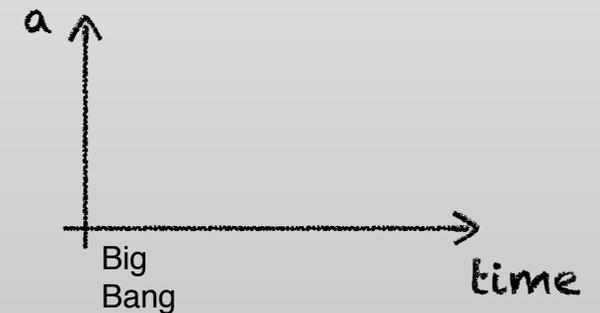
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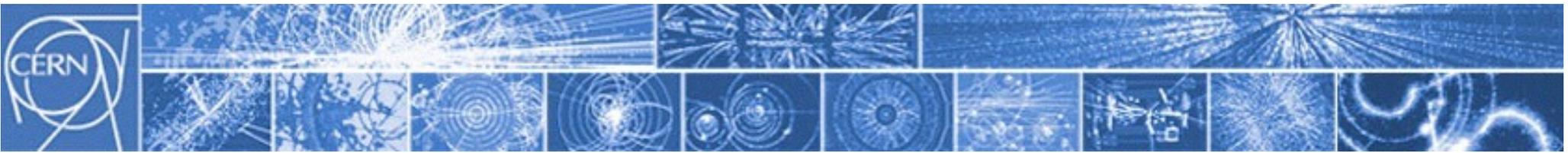


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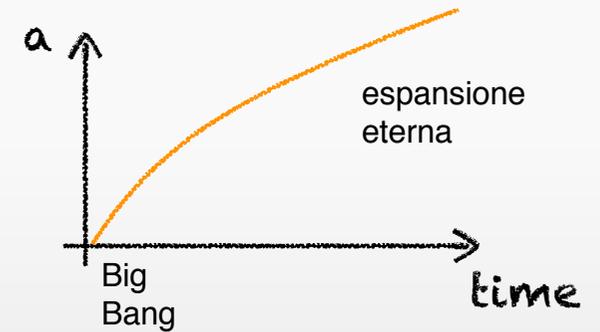


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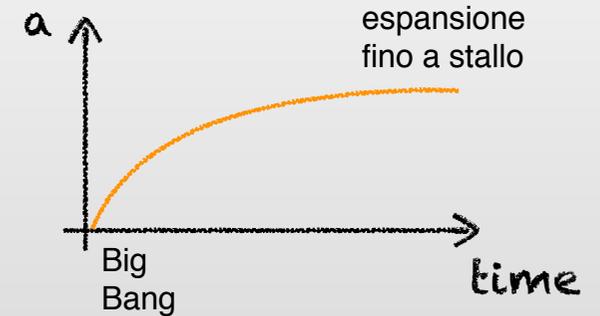
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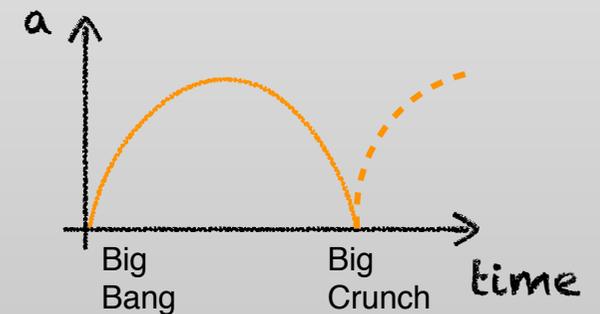
$k < 0$

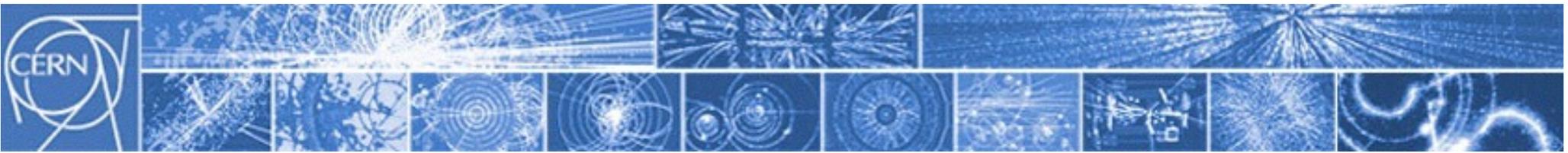


$k = 0$



$k > 0$





Relatività generale e basi di cosmologia (in 2 slides / 2 minuti)

$$\left(\frac{\dot{a}}{a}\right)^2 + \frac{k}{a^2} = \frac{8\pi G}{3}\rho$$

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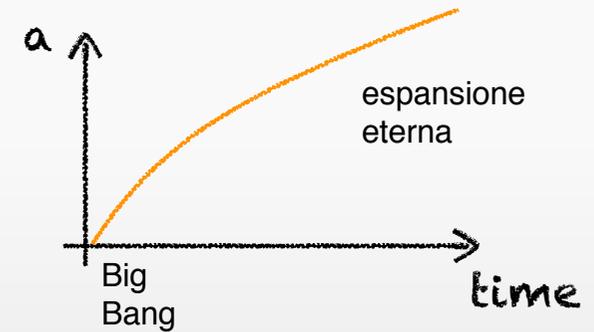
$$\frac{k}{H^2 a^2} = \Omega - 1$$

dove $\Omega = \frac{\rho}{\rho_{\text{crit}}}$

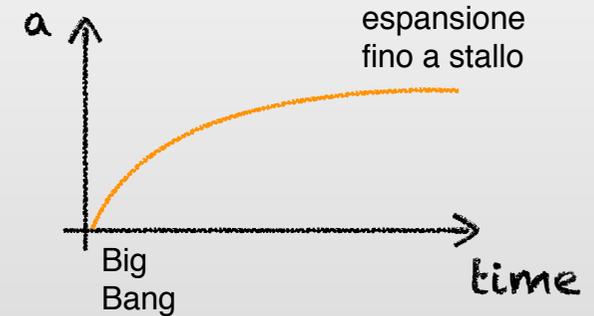
$$\rho_{\text{crit}} = \frac{3H^2}{8\pi G}$$

un valore ben preciso,
e.g. $0.96 \cdot 10^{-29} \text{ gr/cm}^3$ today

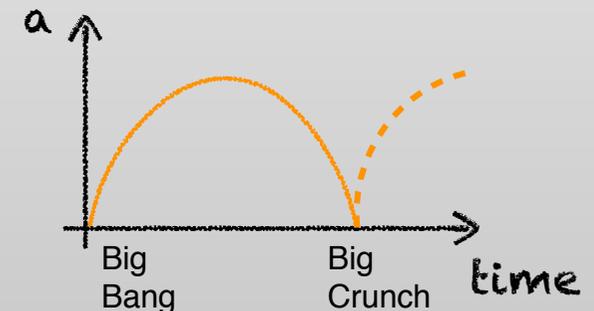
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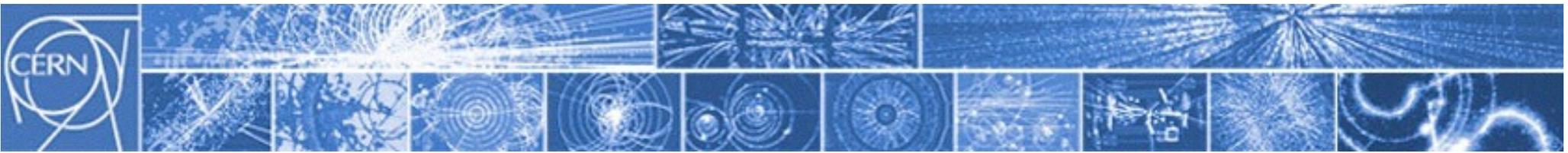


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Relatività generale e basi di cosmologia (in 2 slides / 2 minuti)

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quindi

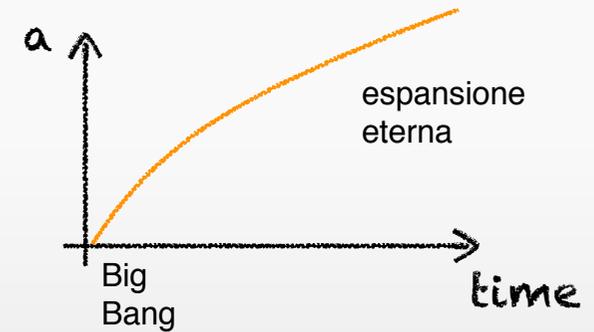
$$\rho < \rho_{\text{crit}} \Rightarrow \Omega < 1 \Rightarrow k < 0$$

$$\rho = \rho_{\text{crit}} \Rightarrow \Omega = 1 \Rightarrow k = 0$$

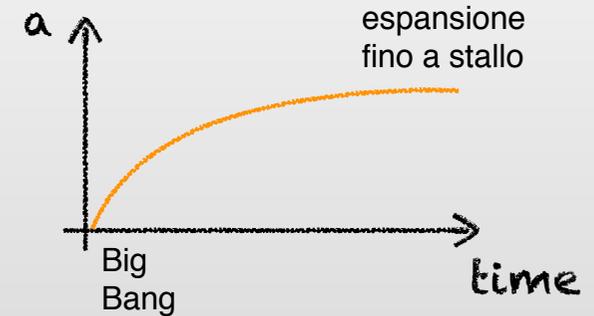
$$\rho > \rho_{\text{crit}} \Rightarrow \Omega > 1 \Rightarrow k > 0$$

pesare l'Universo per determinarne il fato!

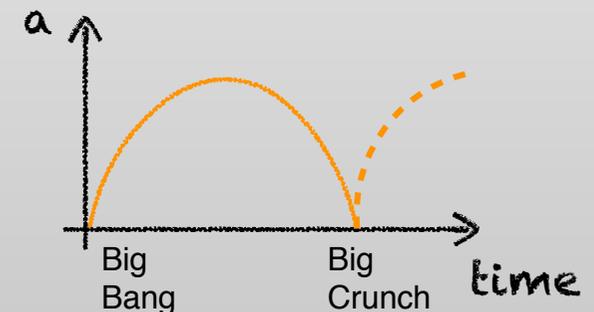
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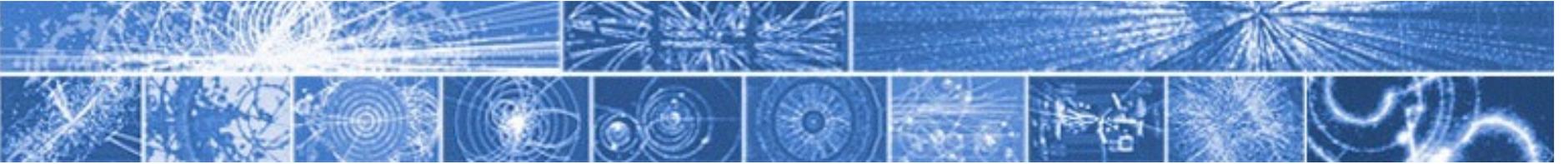


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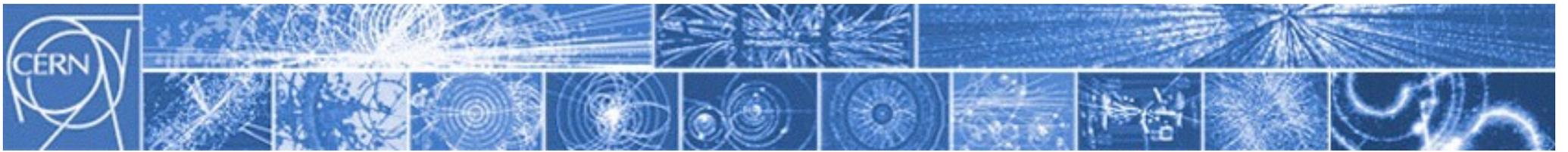


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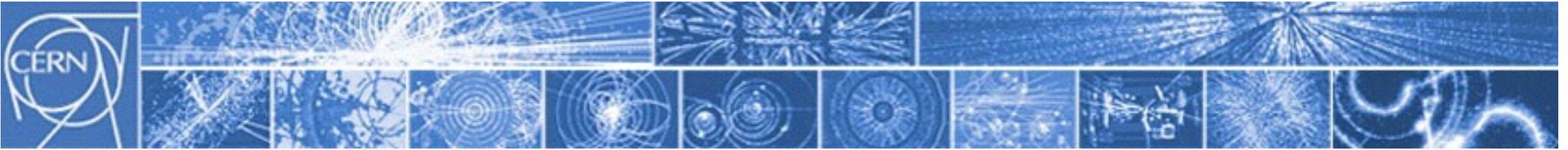




Inflazione



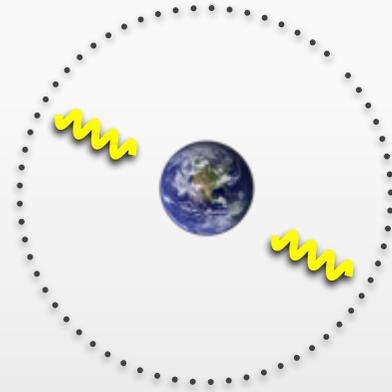
Inflazione

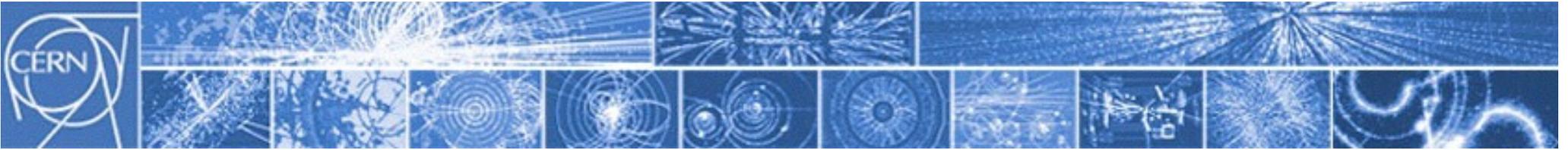


Inflazione

Problema:

come mai l'Universo
è così omogeneo?
regioni causalmente
disconnesse
non hanno motivo
di essere simili

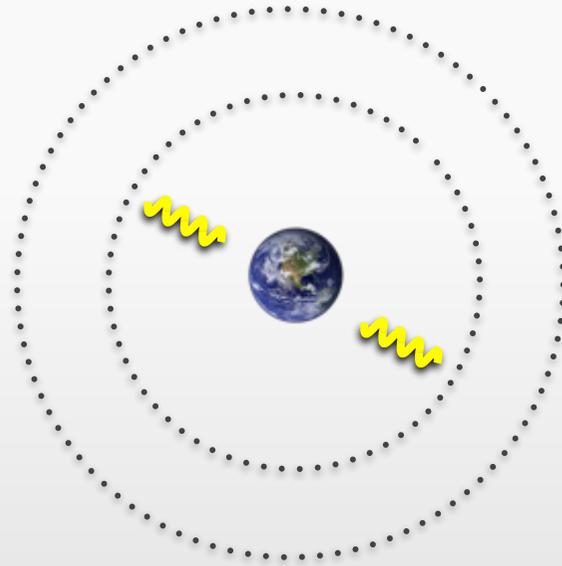


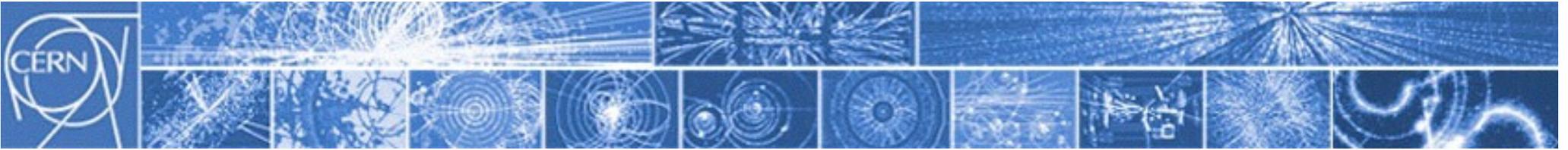


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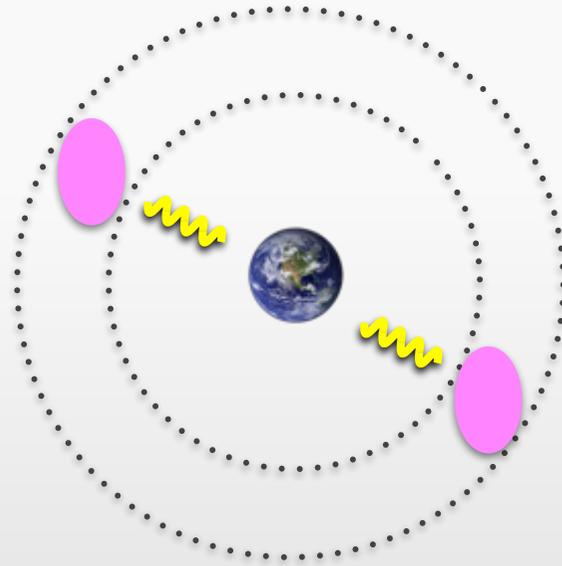


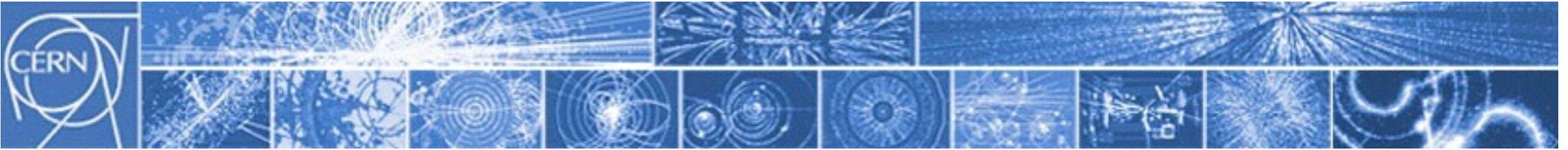


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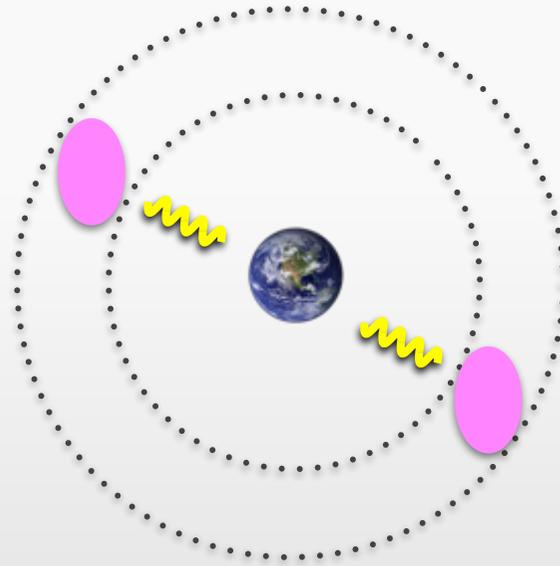




Inflazione

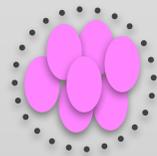
Problema:

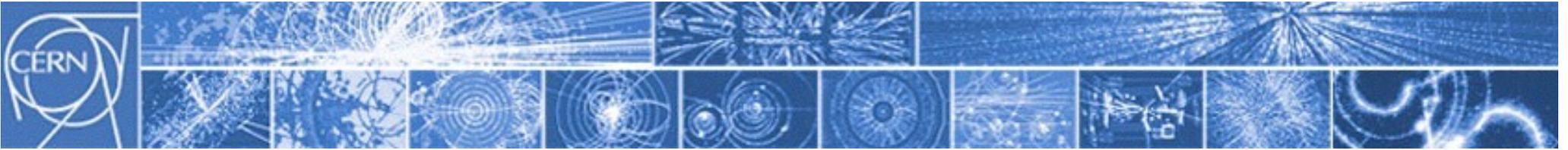
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Soluzione:

erano causalmente
connesse, poi
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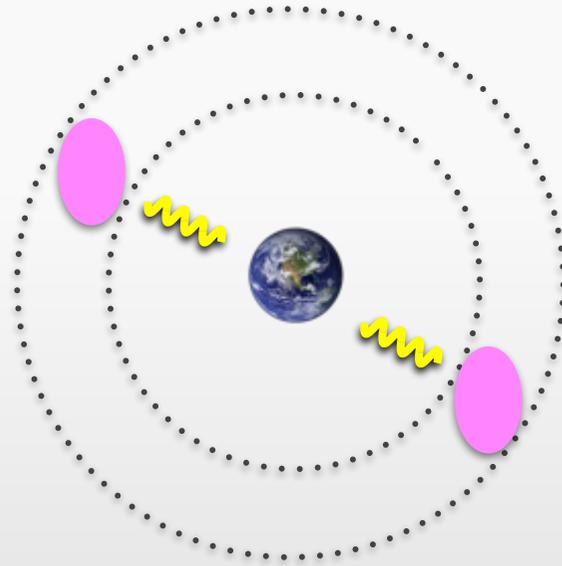




Inflazione

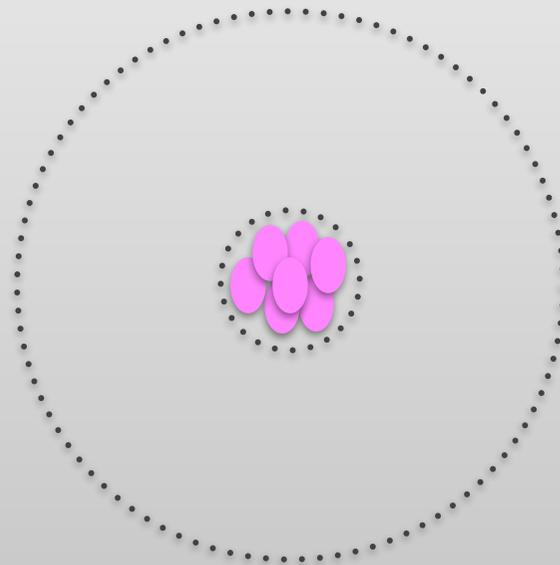
Problema:

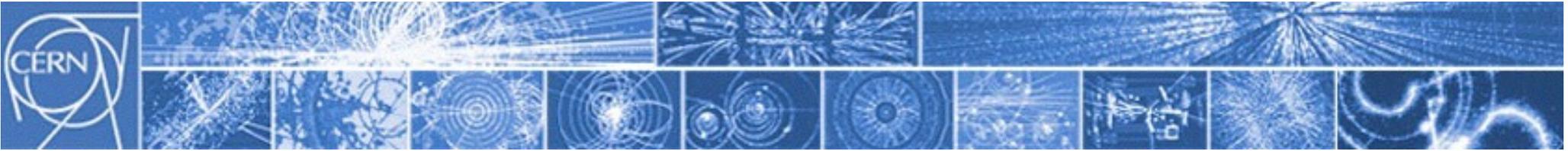
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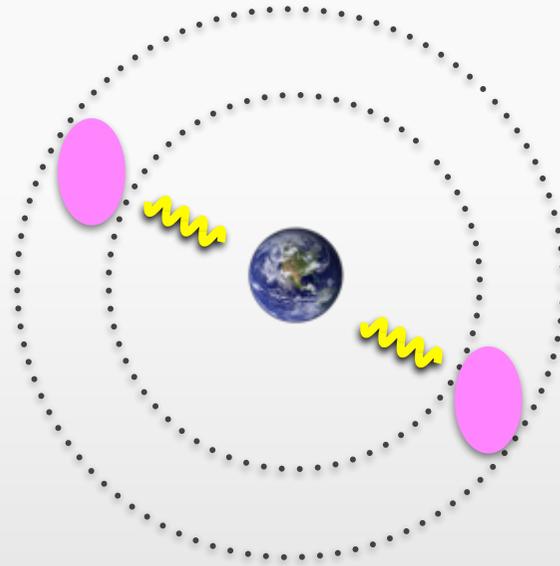




Inflazione

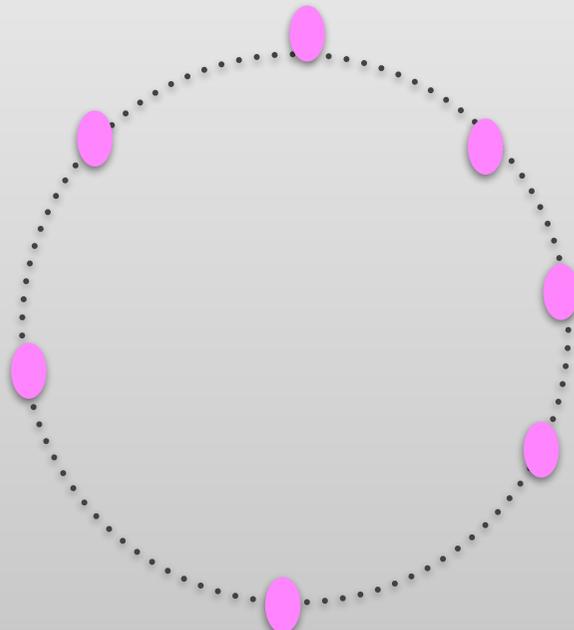
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Soluzione:

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$$\left(\frac{\dot{a}}{a}\right)^2 + \frac{k}{a^2} = \frac{8\pi G}{3}\rho$$

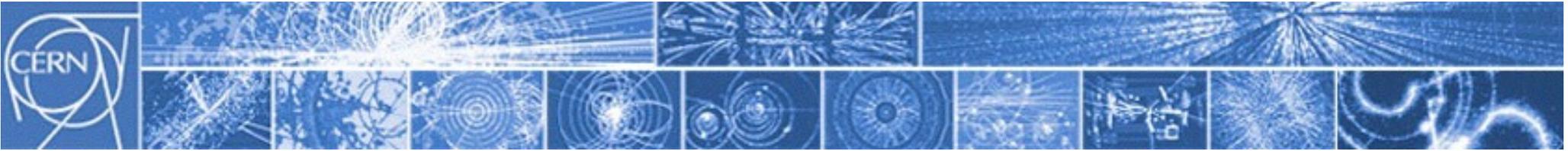
se ho una sostanza tale che $\rho = \text{cost}$

allora soluzione:

$$\dot{a} = \text{cost } a$$



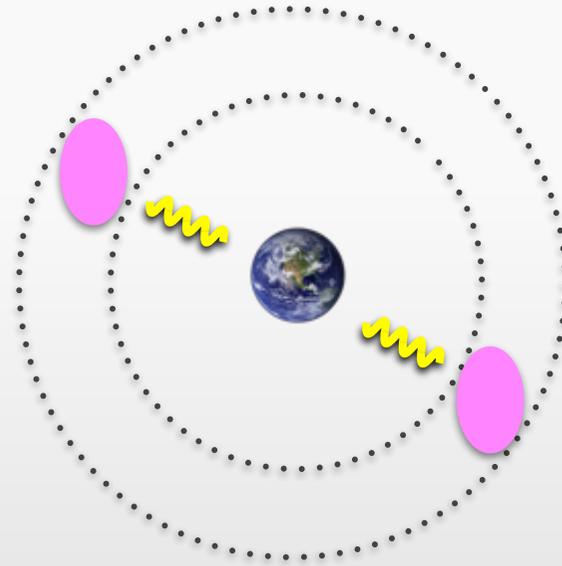
$$a \propto e^t$$



Inflazione

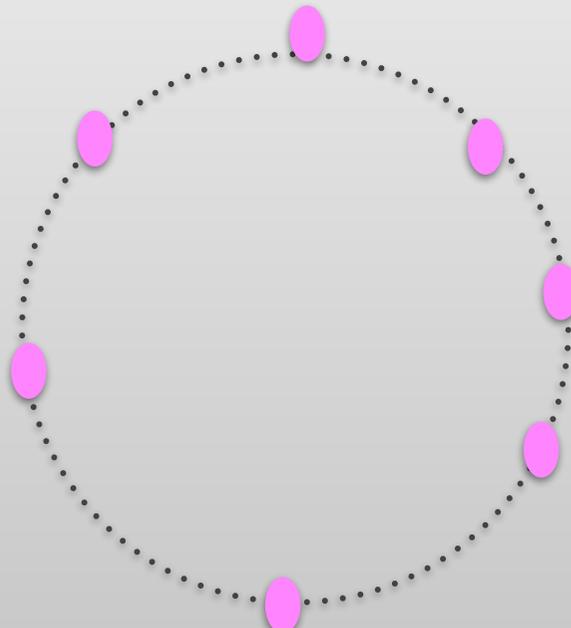
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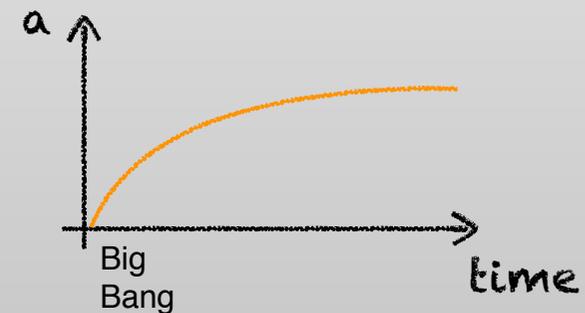
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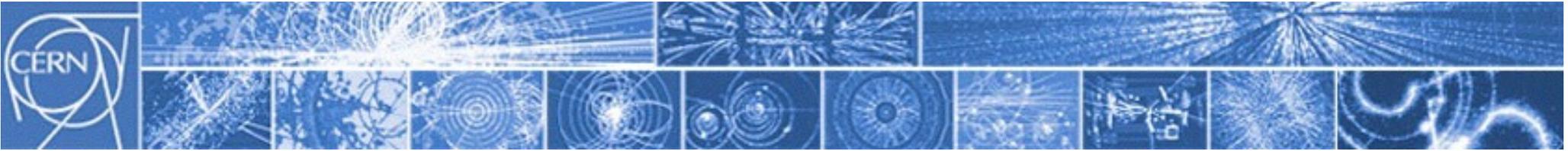
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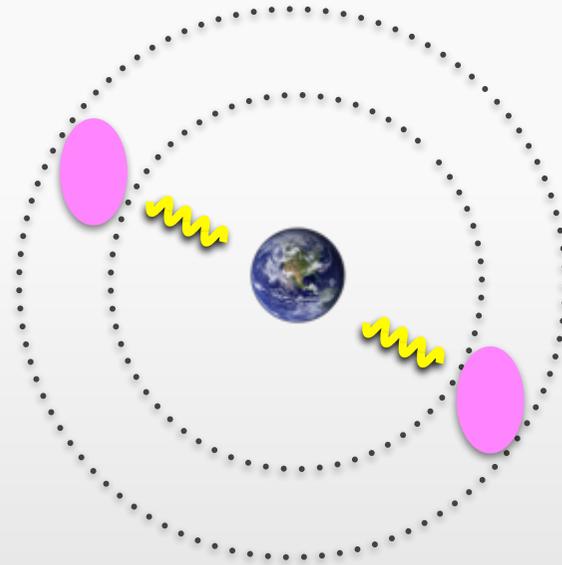




Inflazione

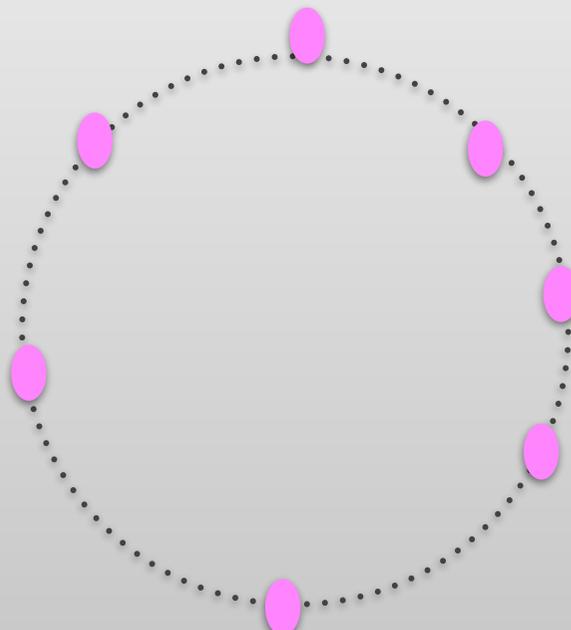
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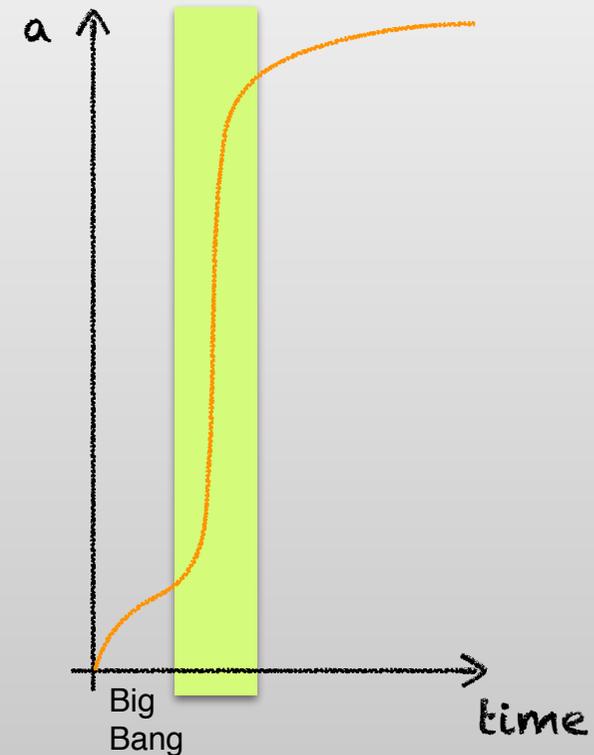
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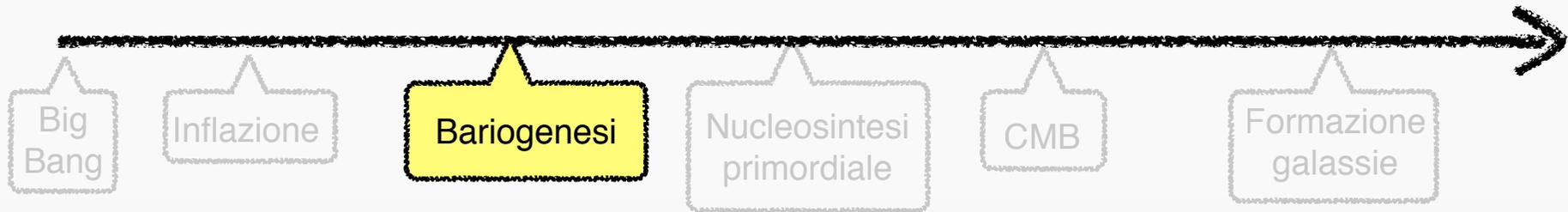
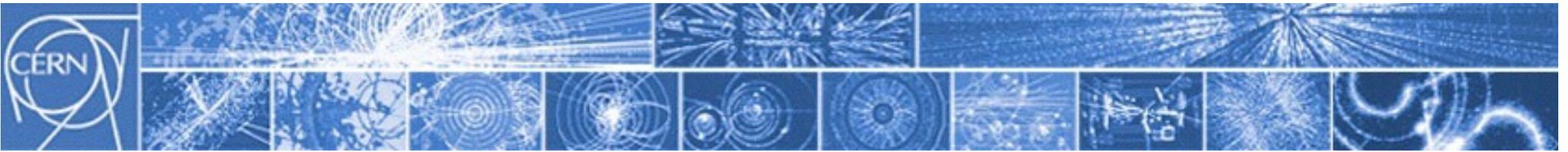
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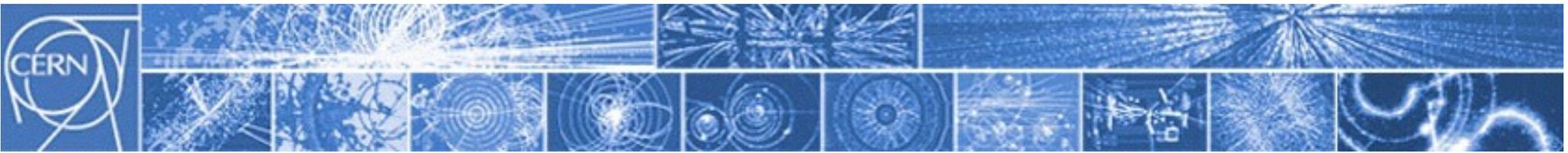


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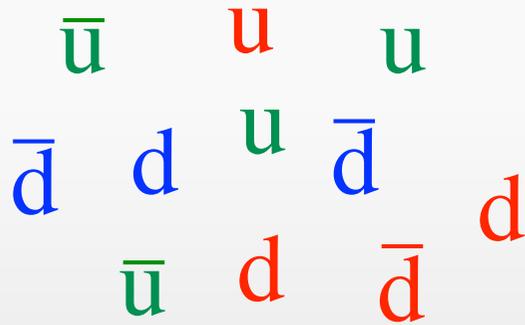


Bariogenesi & asimmetria barionica (*BAU*)



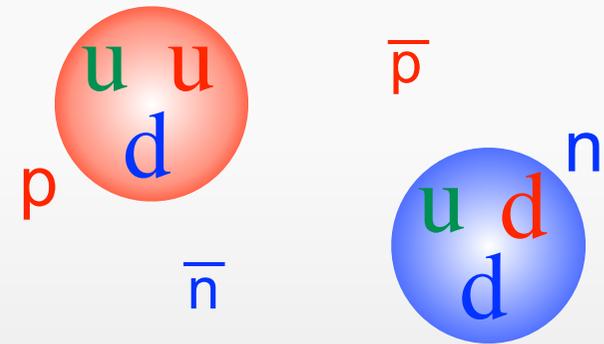
Bariogenesi

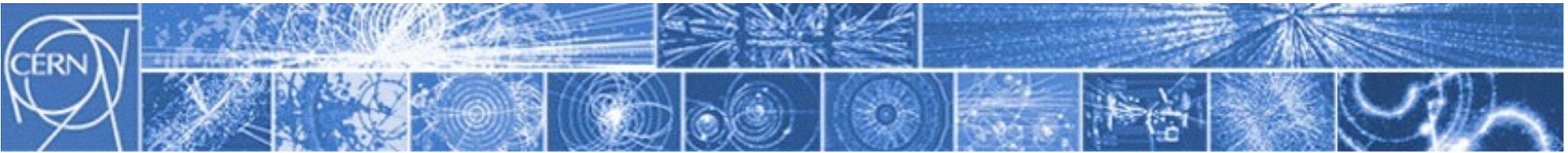
mare di quark (e antiquark) 'liberi'



$T \sim 1 \text{ GeV}$

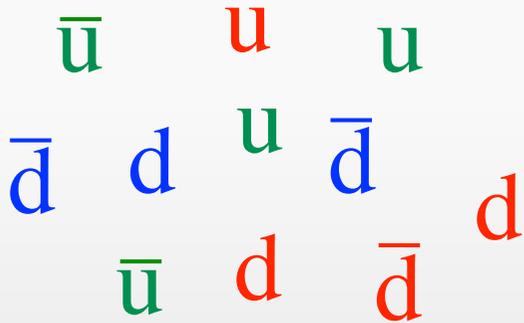
barioni (e antibarioni)





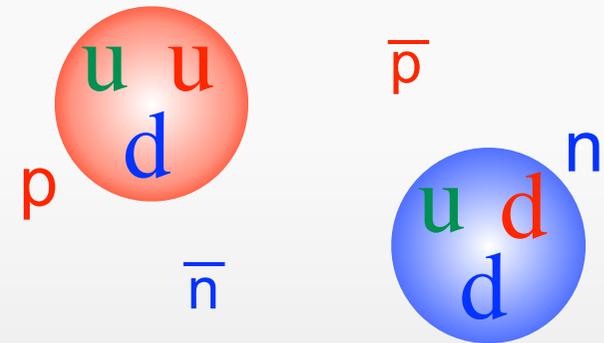
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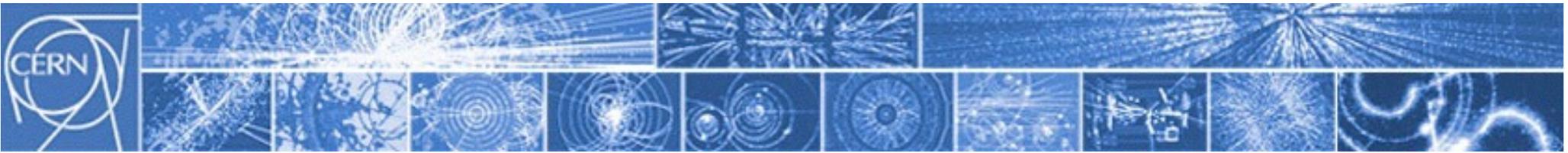
barioni (e antibarioni)



Problema: l'Universo sembra contenere solo materia (barioni)

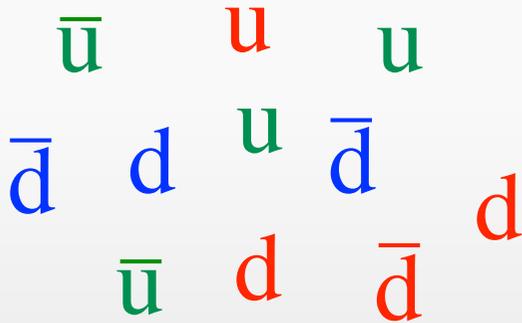
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Bariogenesi

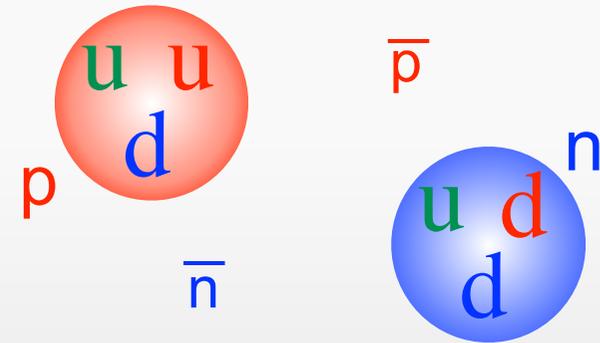
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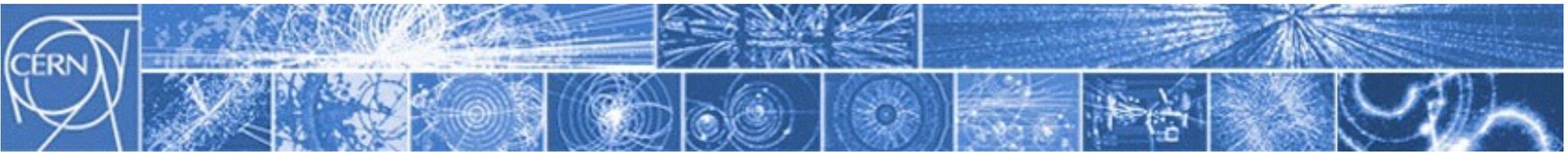


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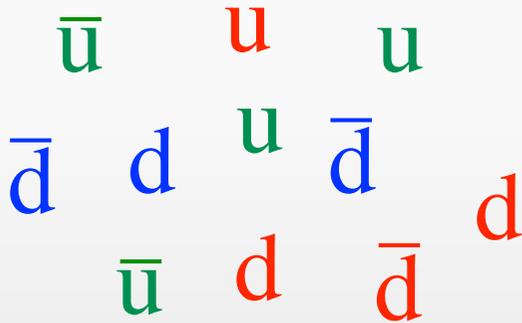
ma ci si aspetterebbe simmetria





Bariogenesi

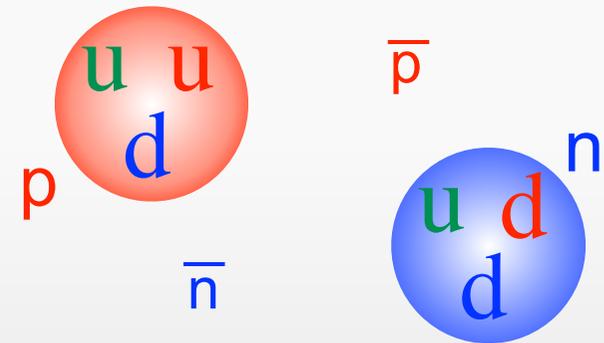
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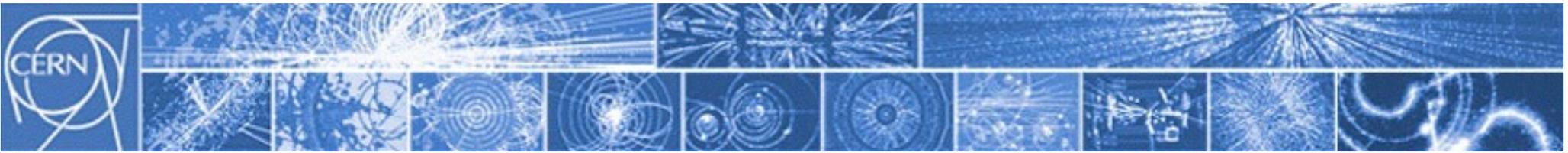


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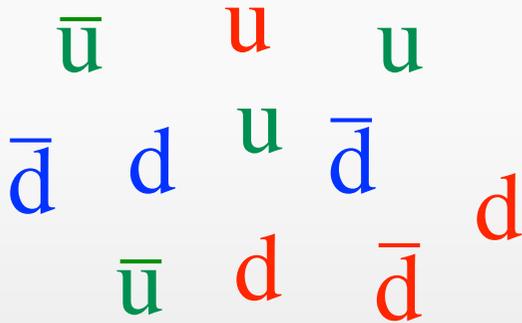
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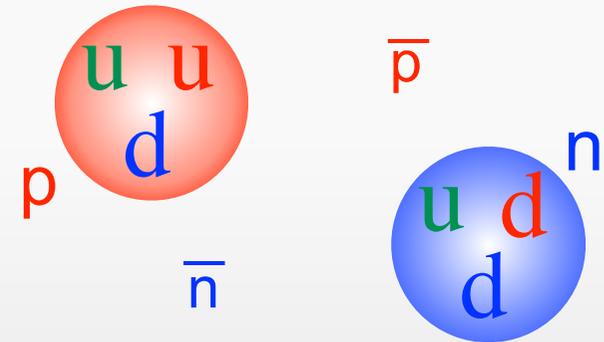
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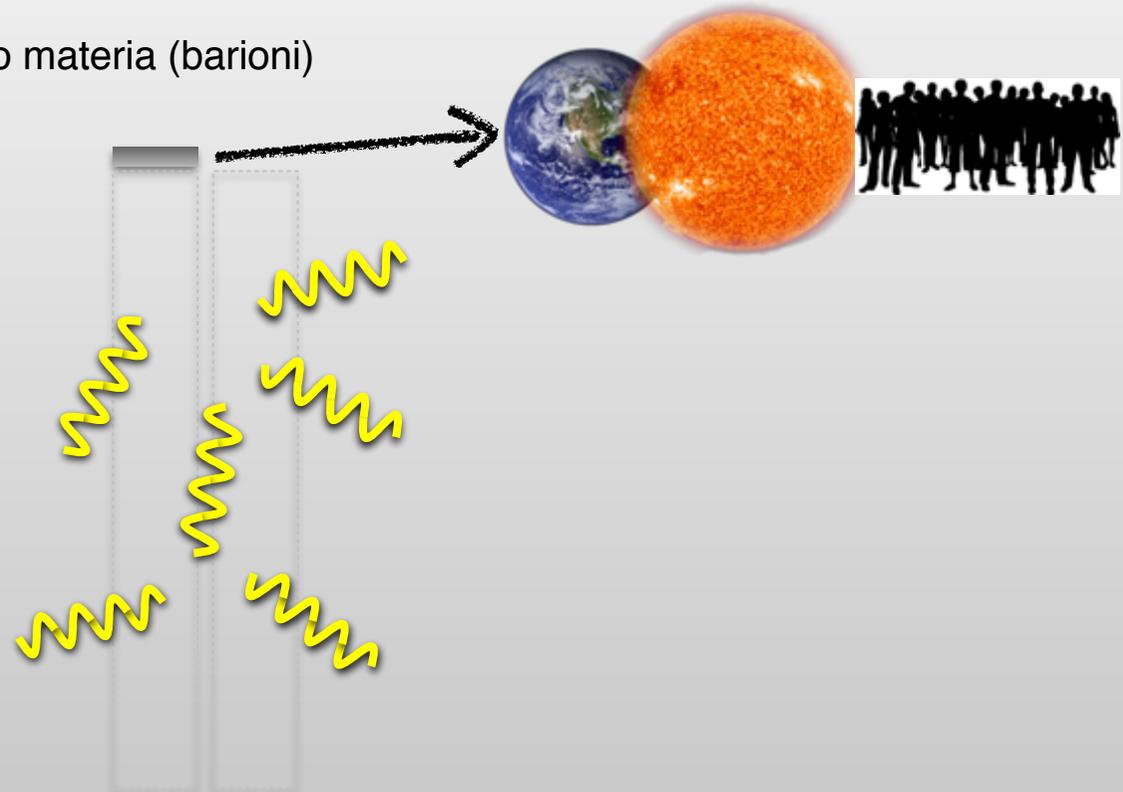
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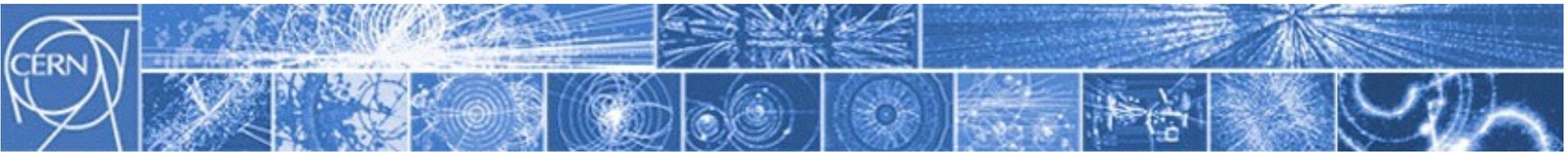


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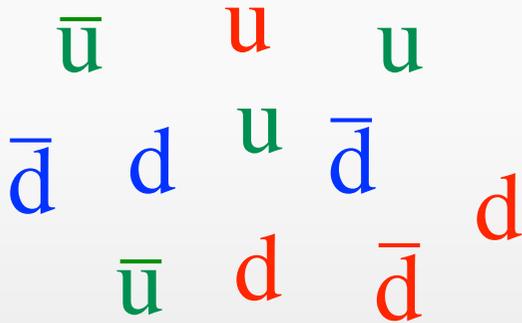
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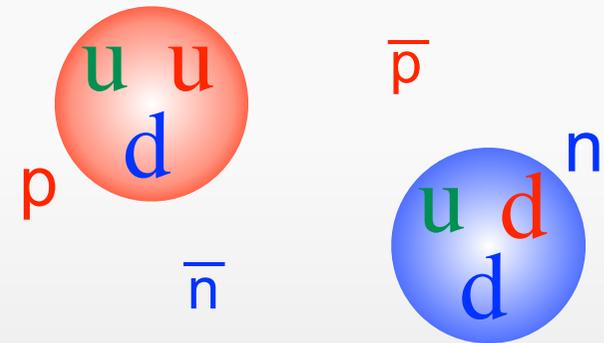
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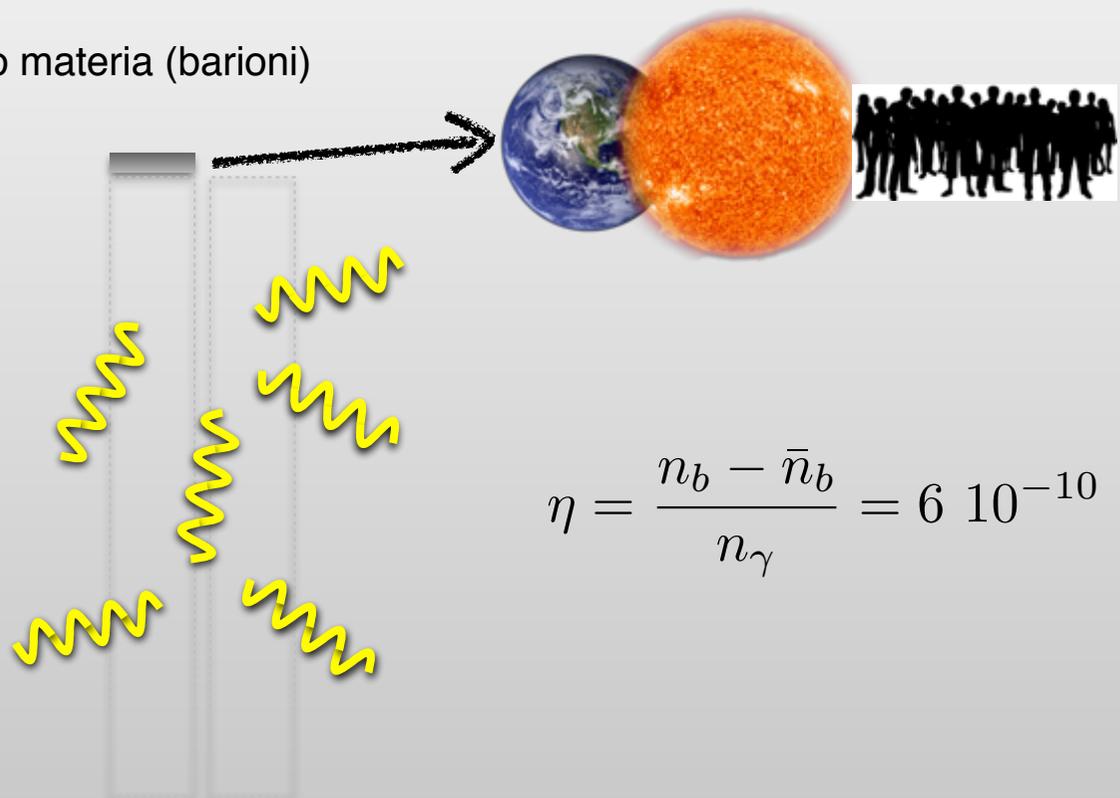
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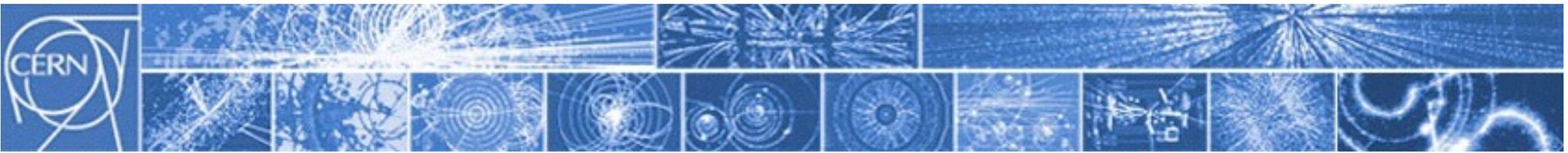
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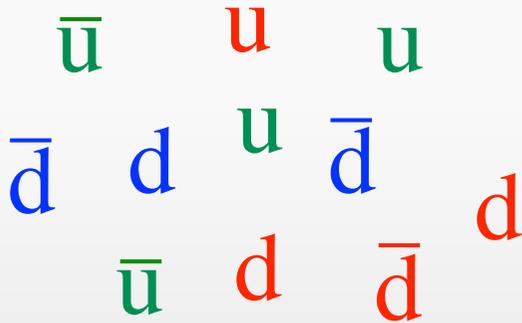


$$\eta = \frac{n_b - \bar{n}_b}{n_\gamma} = 6 \cdot 10^{-10}$$



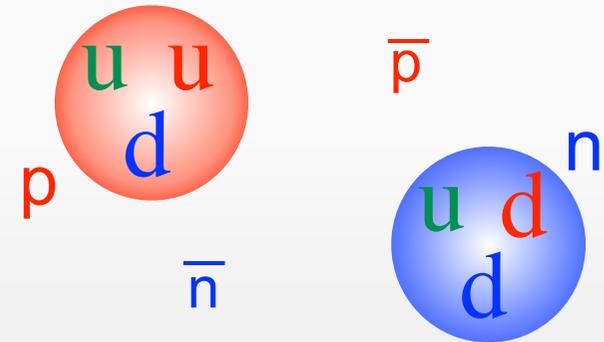
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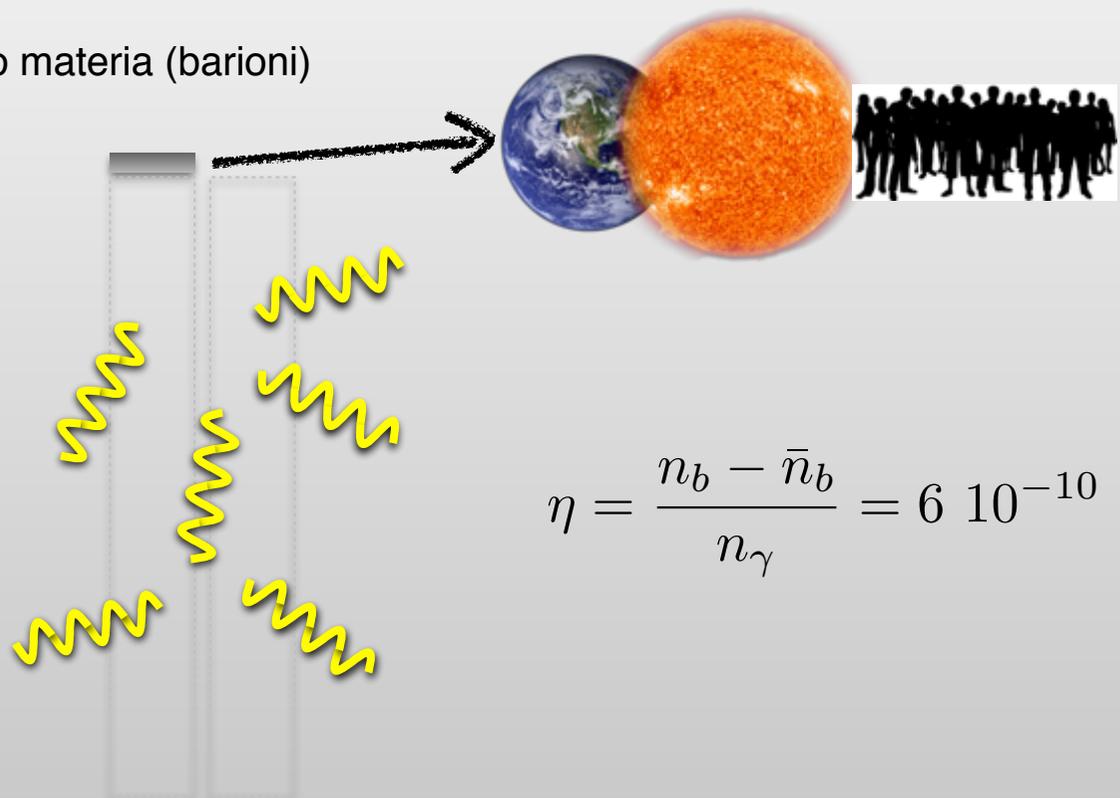


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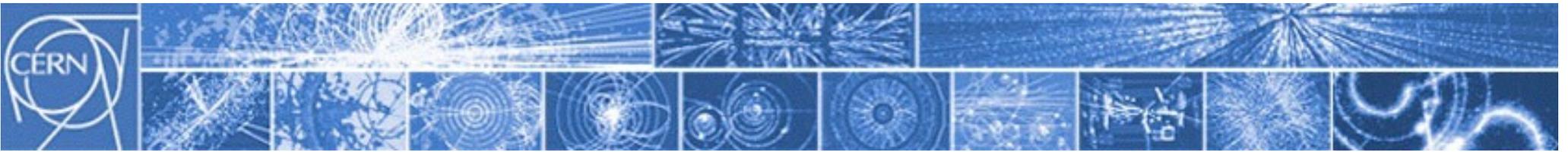
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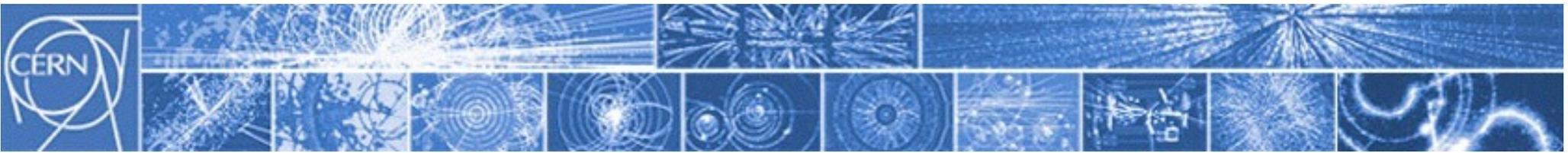
da dove viene l'asimmetria???



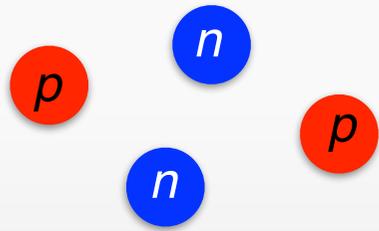
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Nucleosintesi primordiale (*BBN*)



Nucleosintesi primordiale



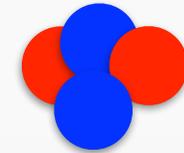
$T \sim 1 \text{ MeV}$



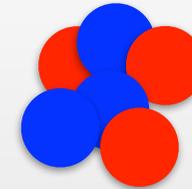
Deuterio

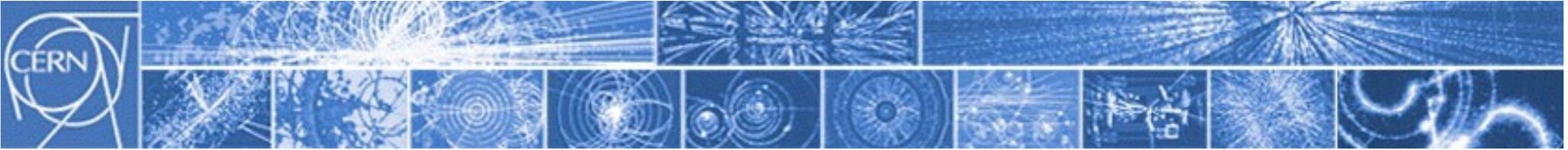


Elio



(Litio)





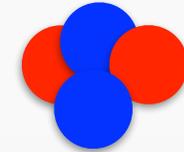
Nucleosintesi primordiale



Deuterio



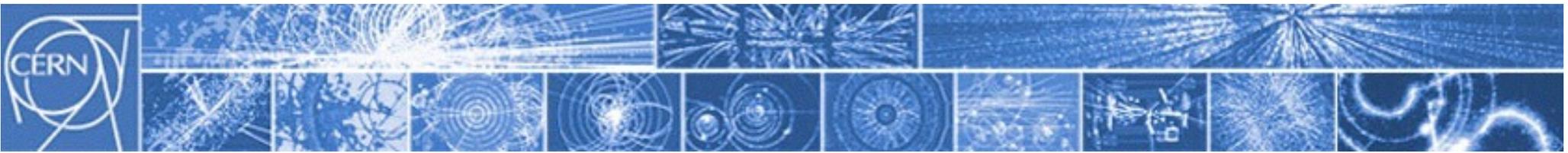
Elio



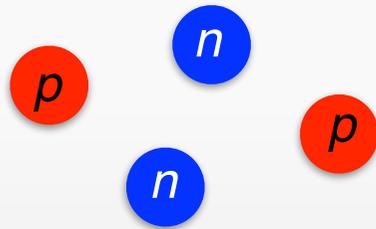
p: 938.3 MeV
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$p e^- \leftrightarrow n \nu$

energia legame D: $\sim 2.2 \text{ MeV}$



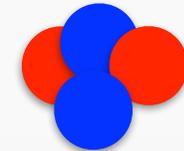
Nucleosintesi primordiale



Deuterio



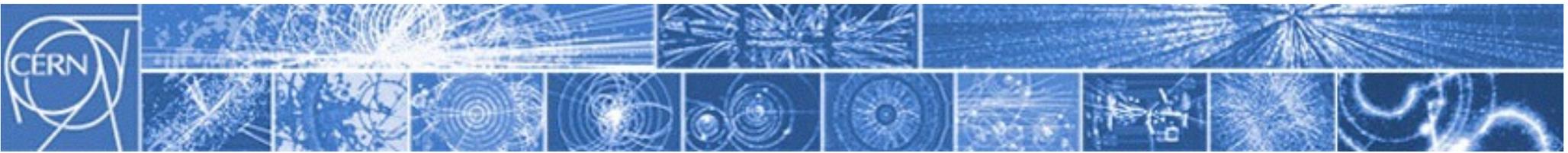
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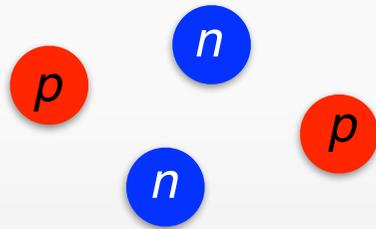
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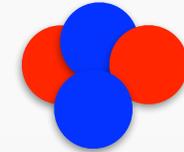
Nucleosintesi primordiale



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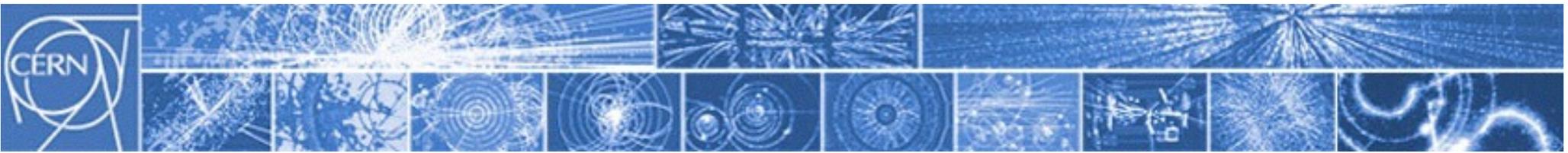
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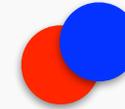
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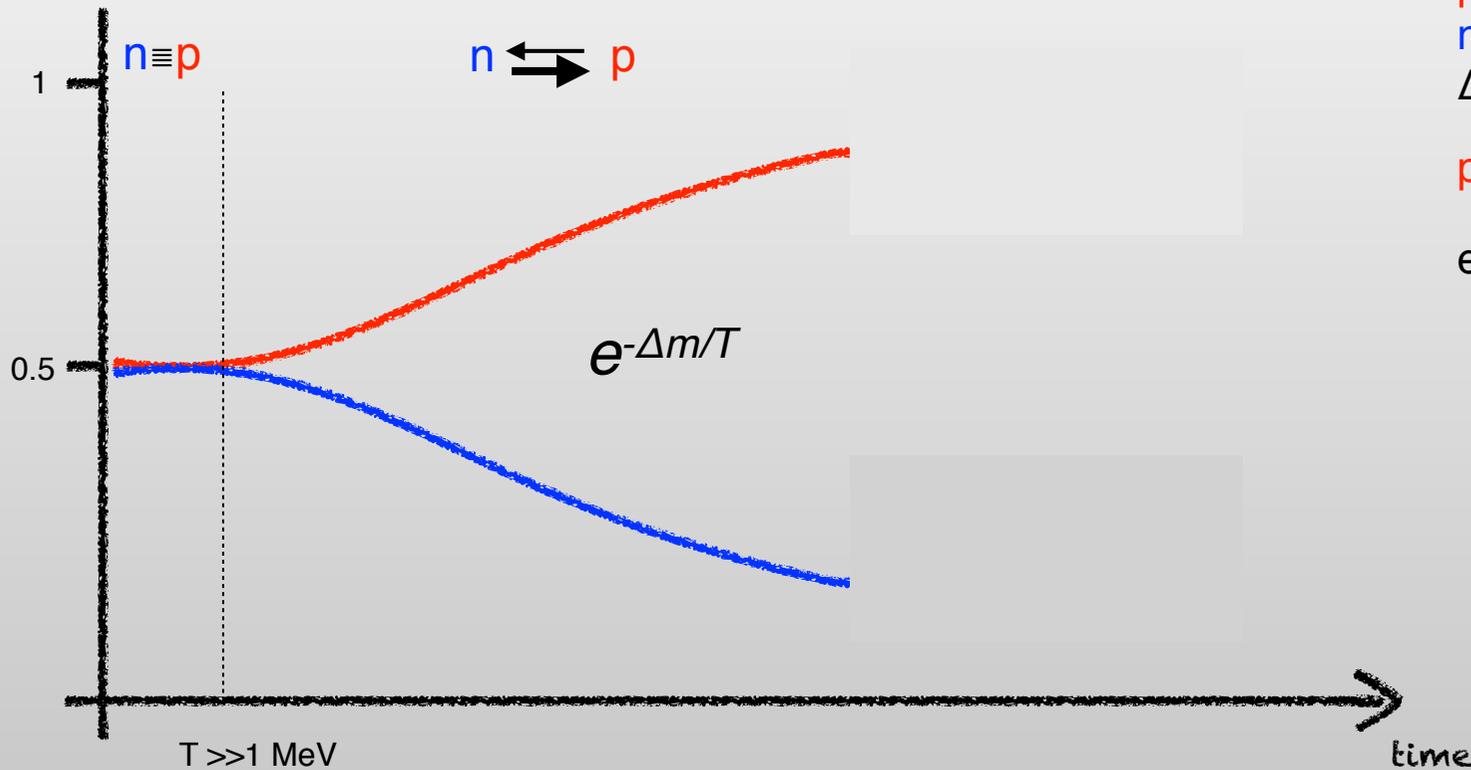
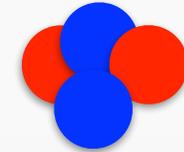
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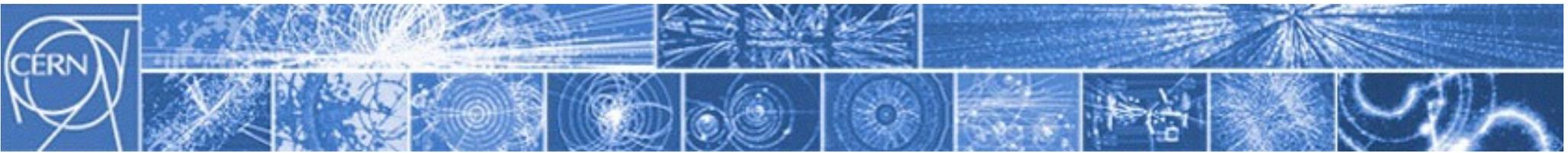
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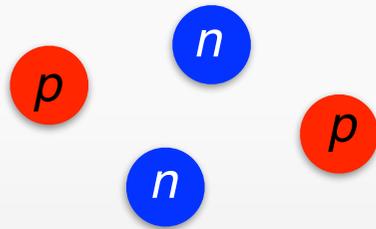
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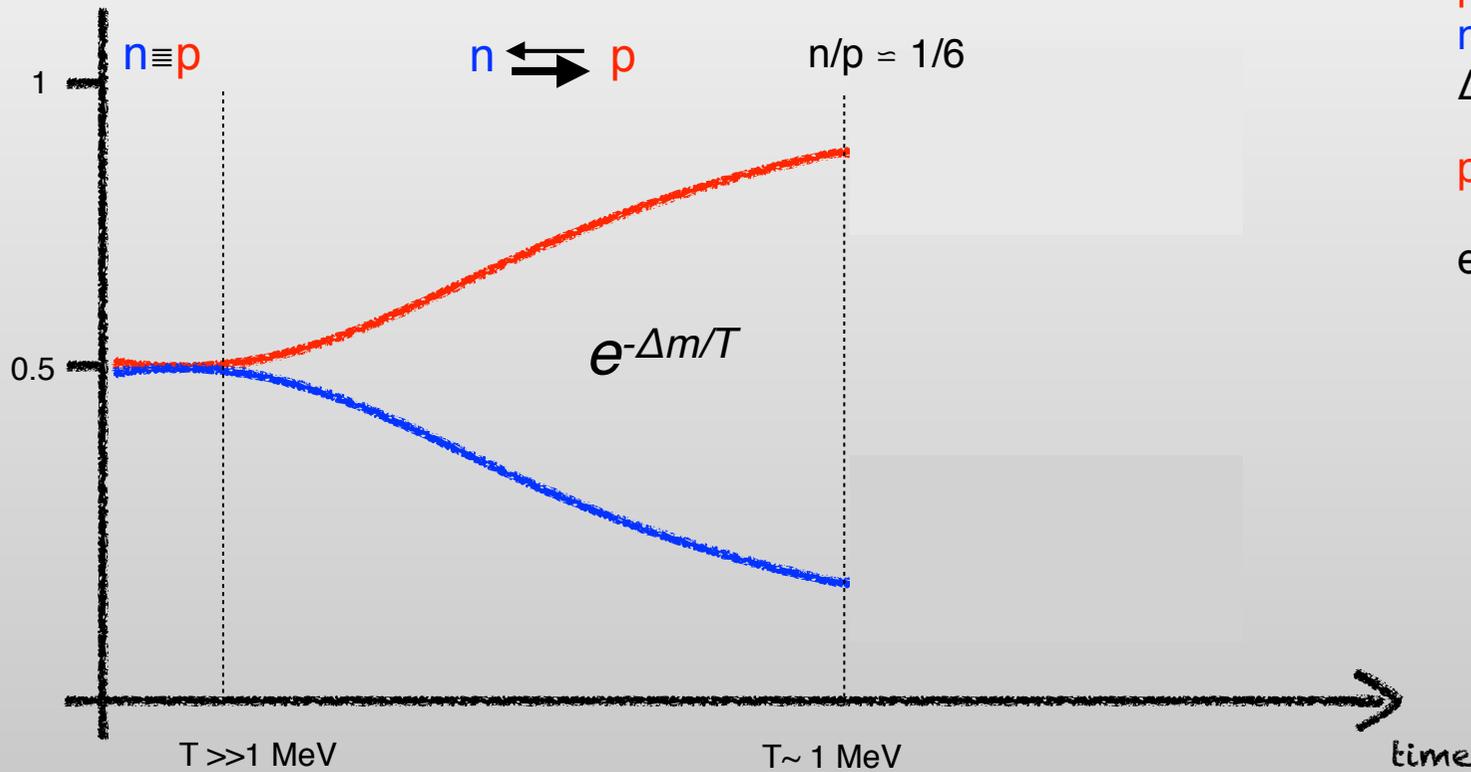
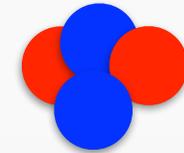
Nucleosintesi primordiale



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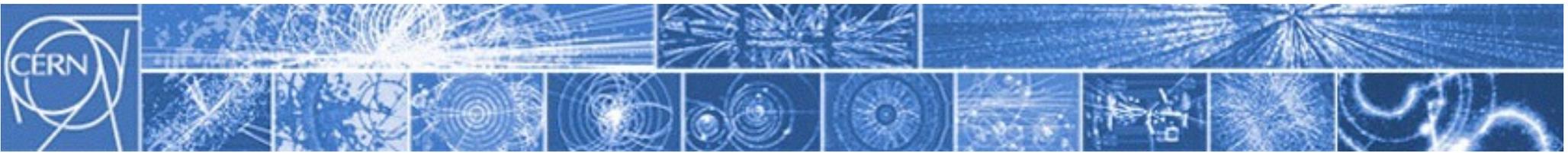
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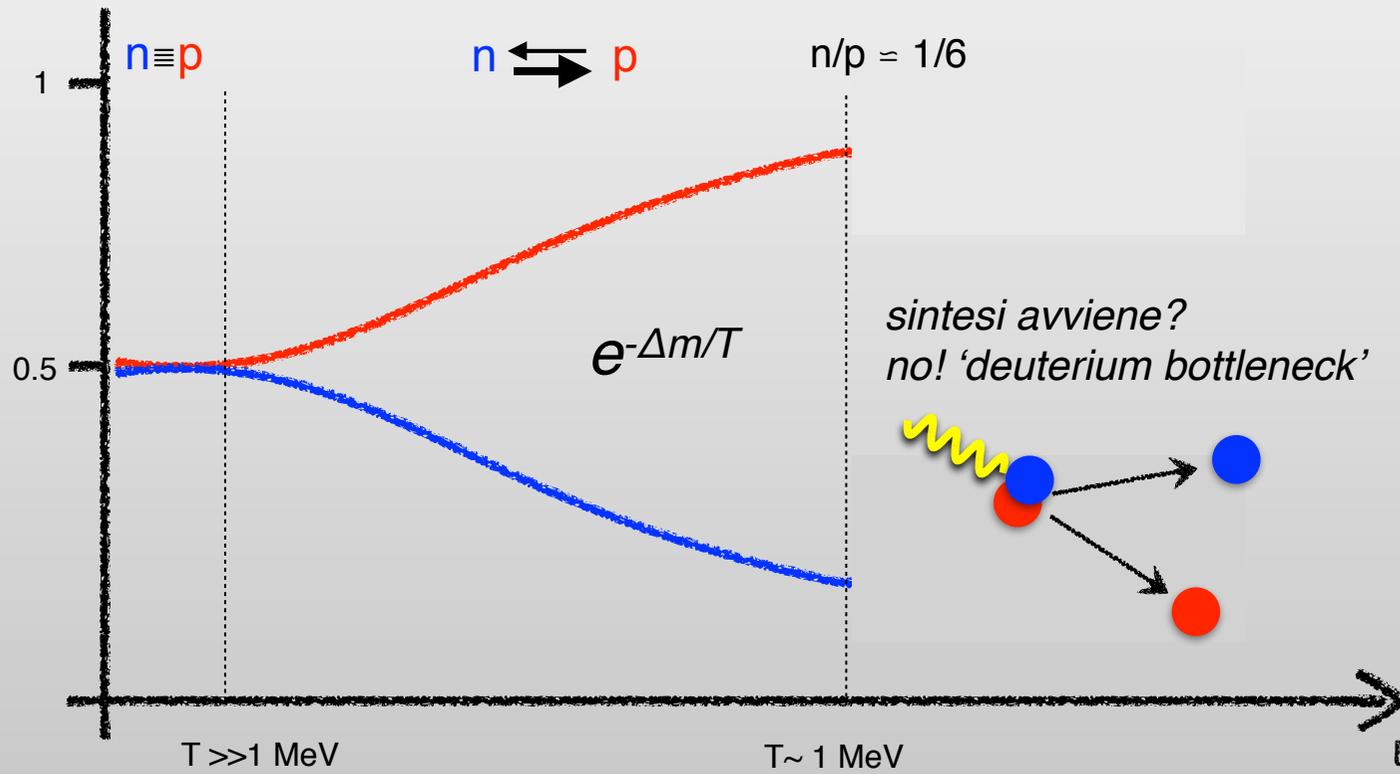
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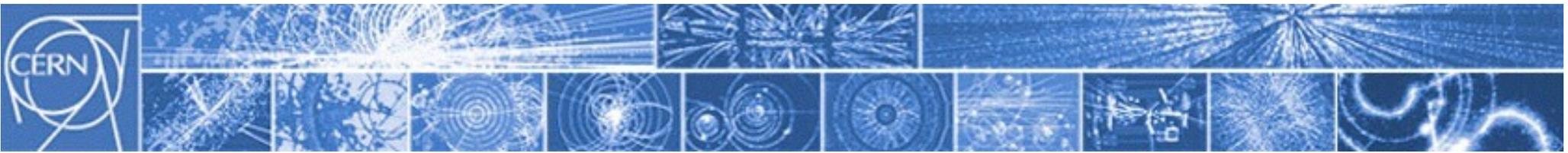
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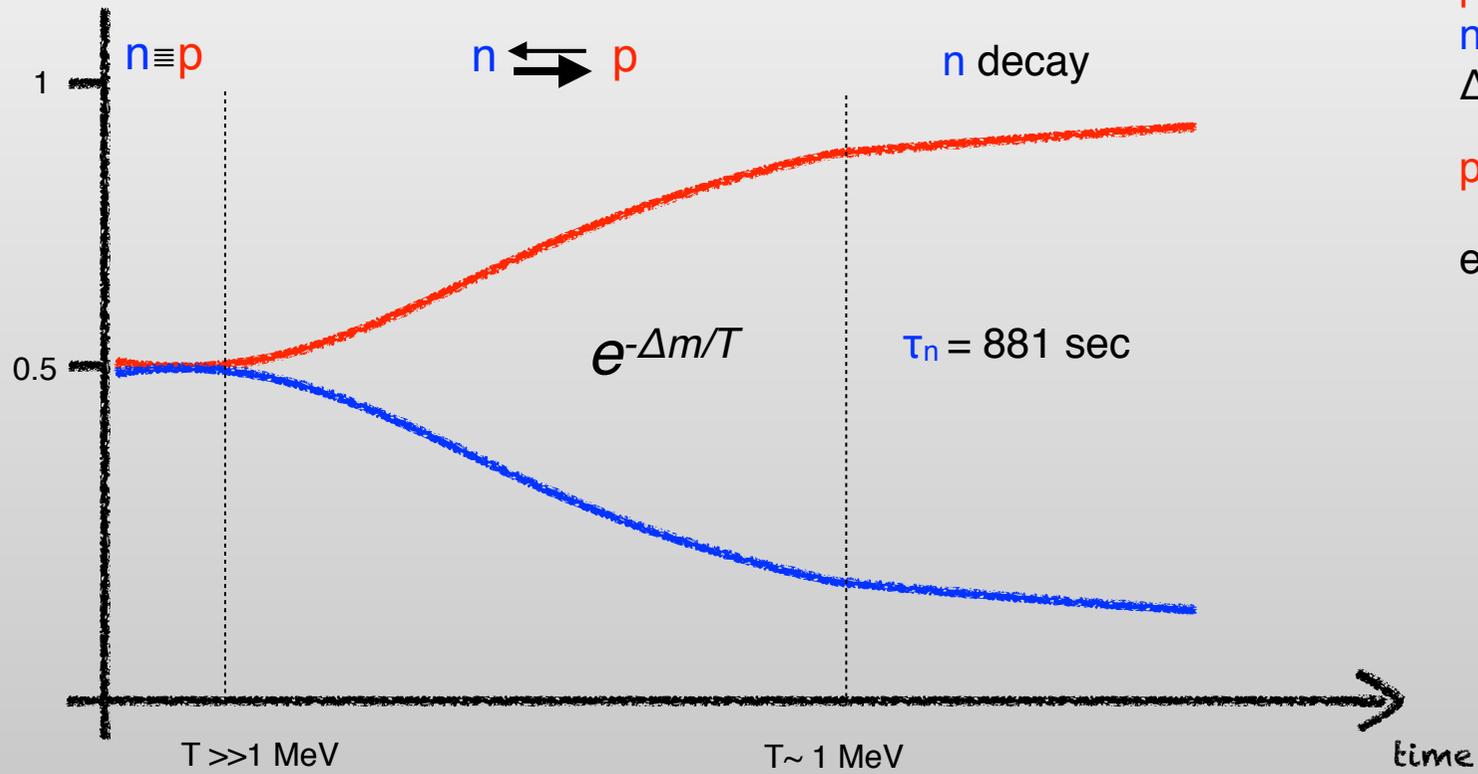
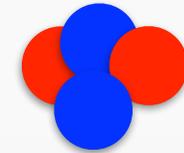
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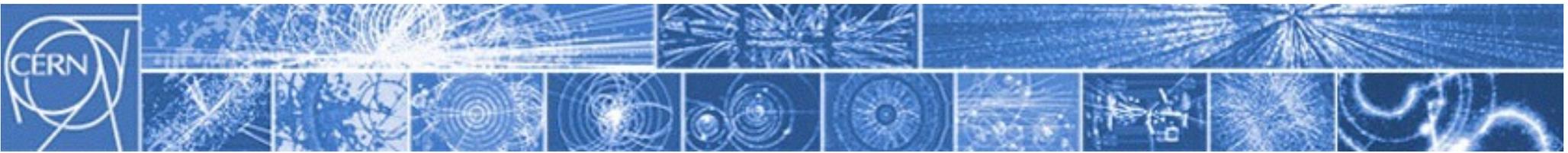
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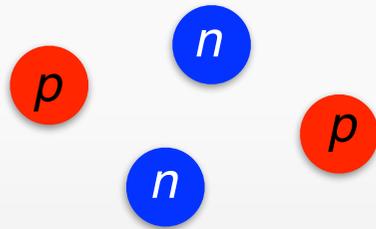
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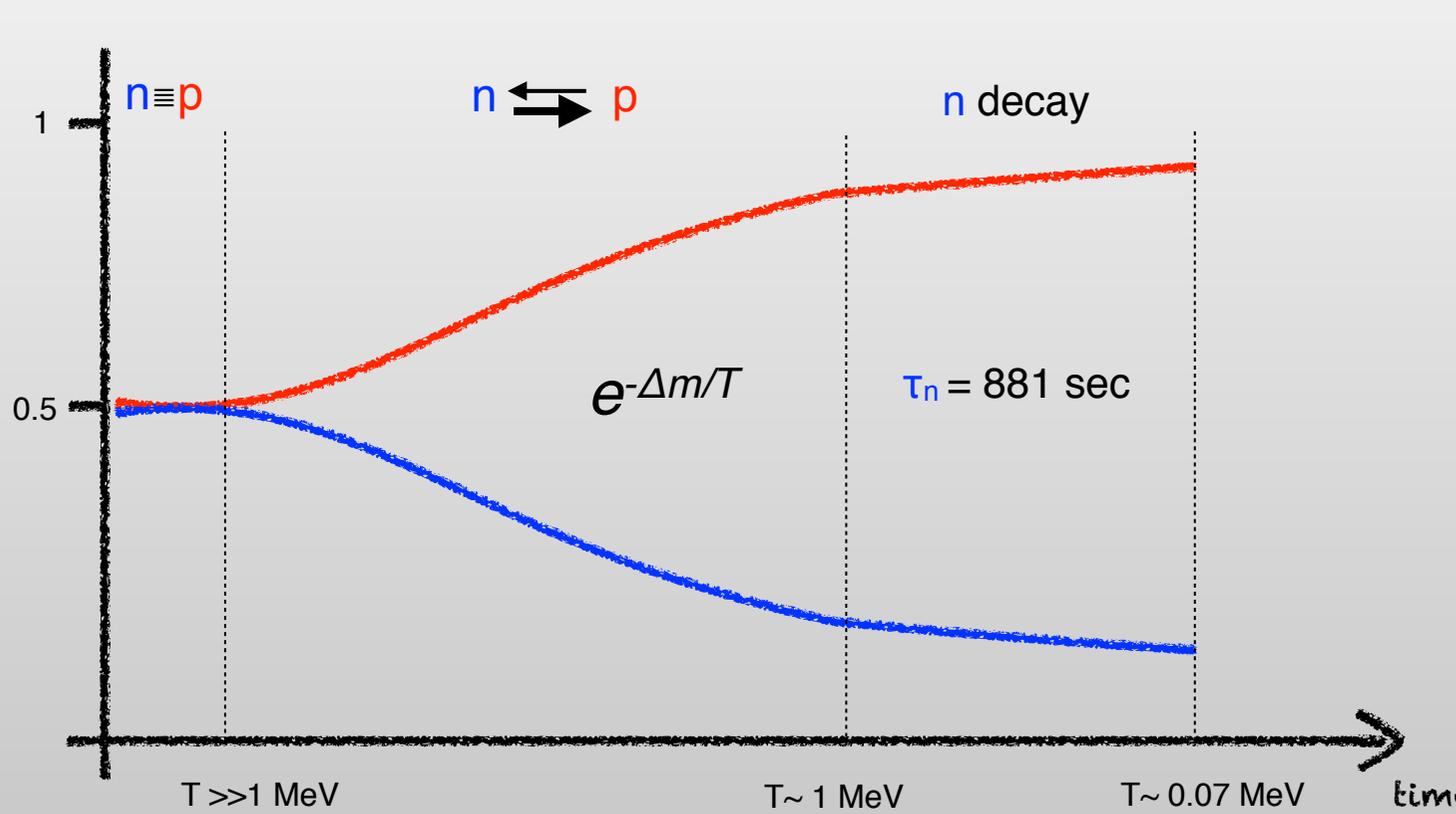
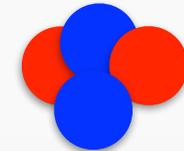
Nucleosintesi primordiale



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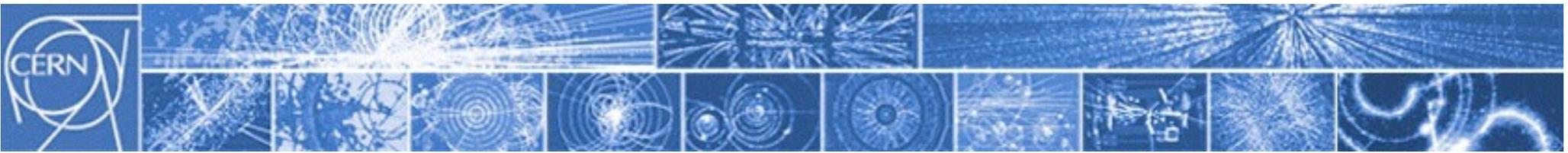
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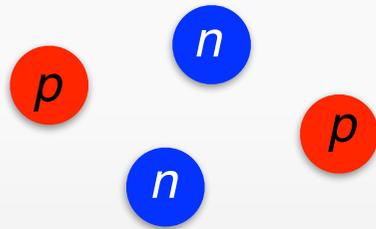
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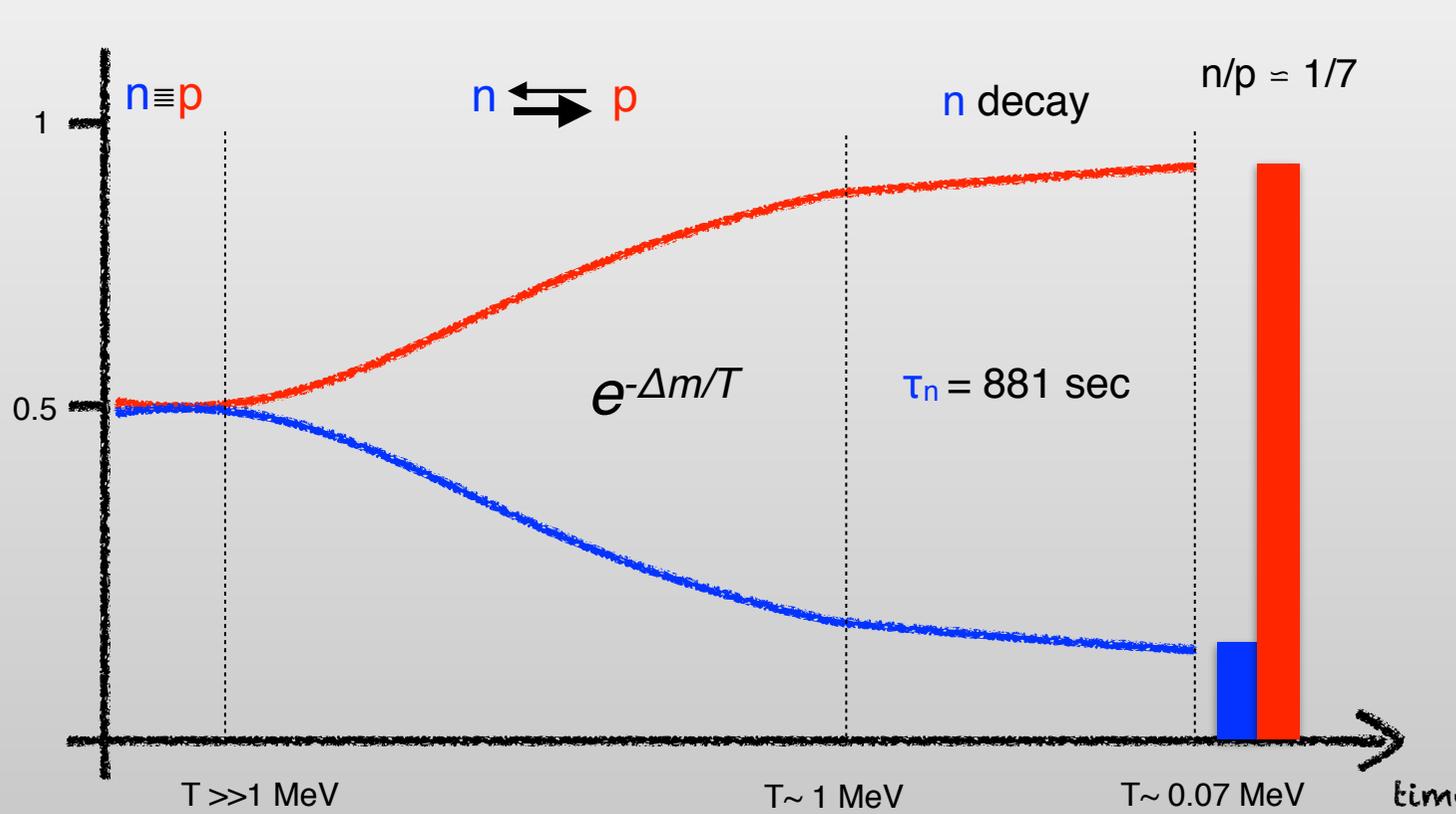
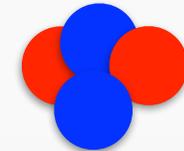
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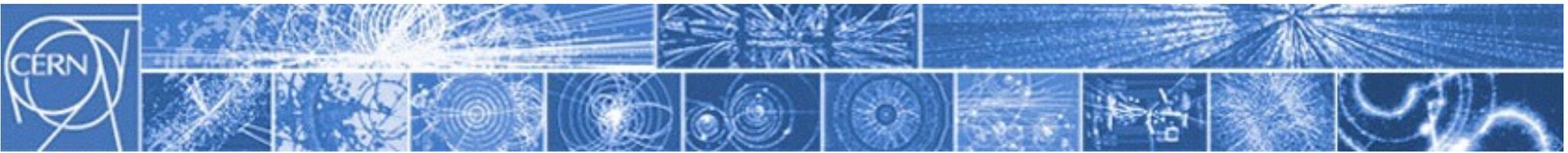
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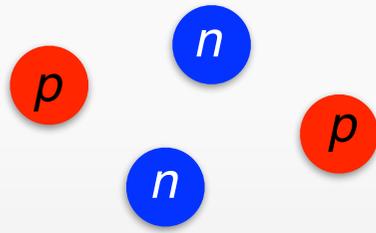
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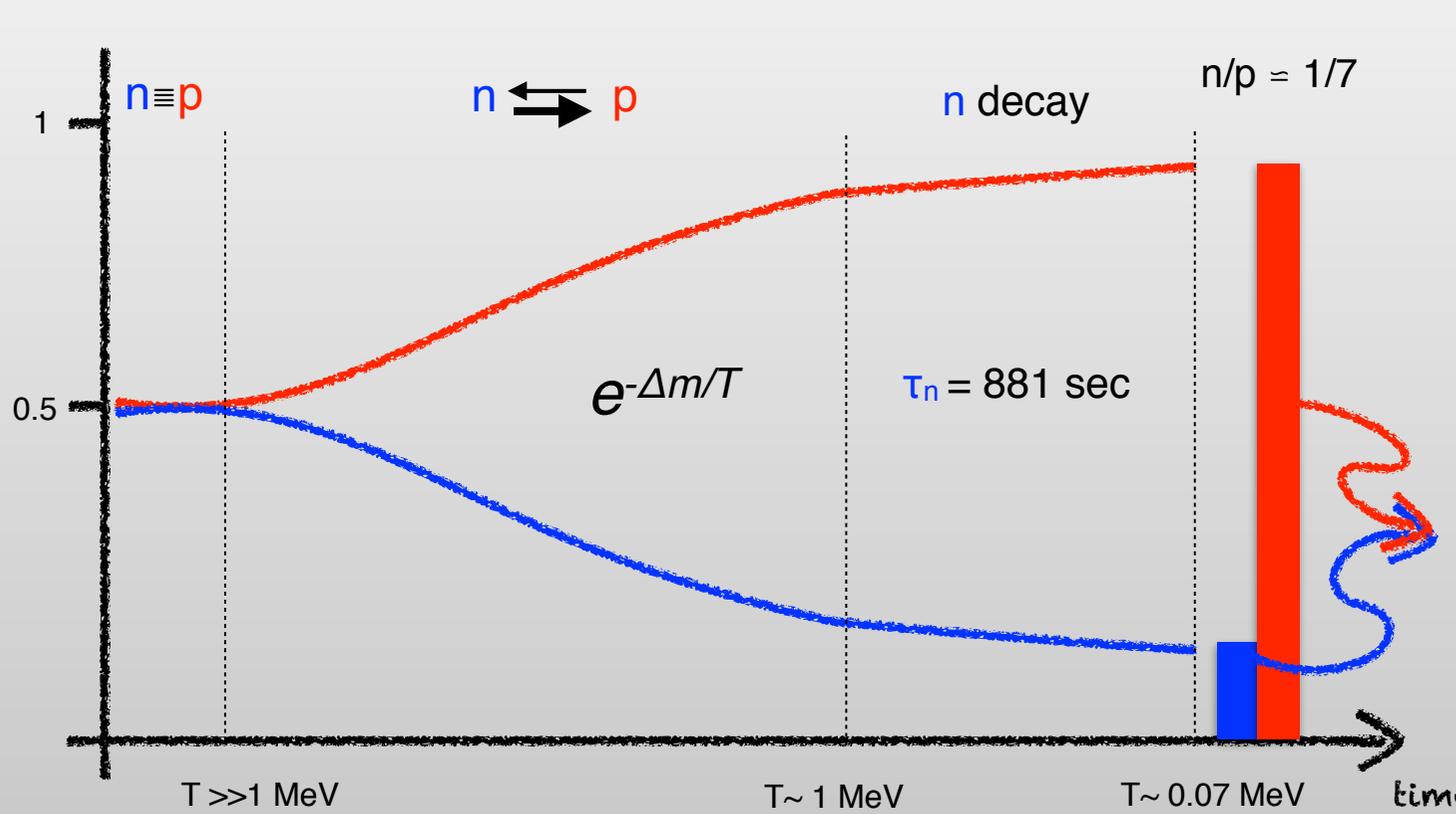
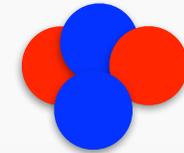


Nucleosintesi primordiale



Deuterio

Elio

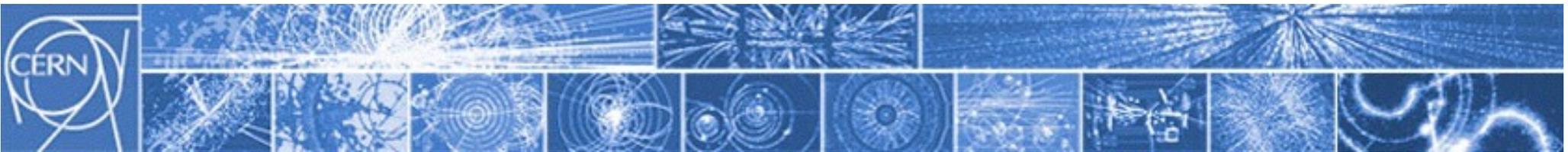


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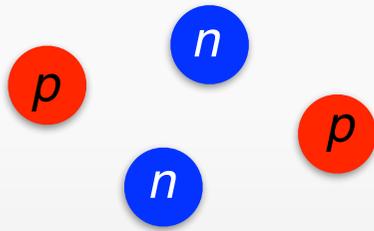
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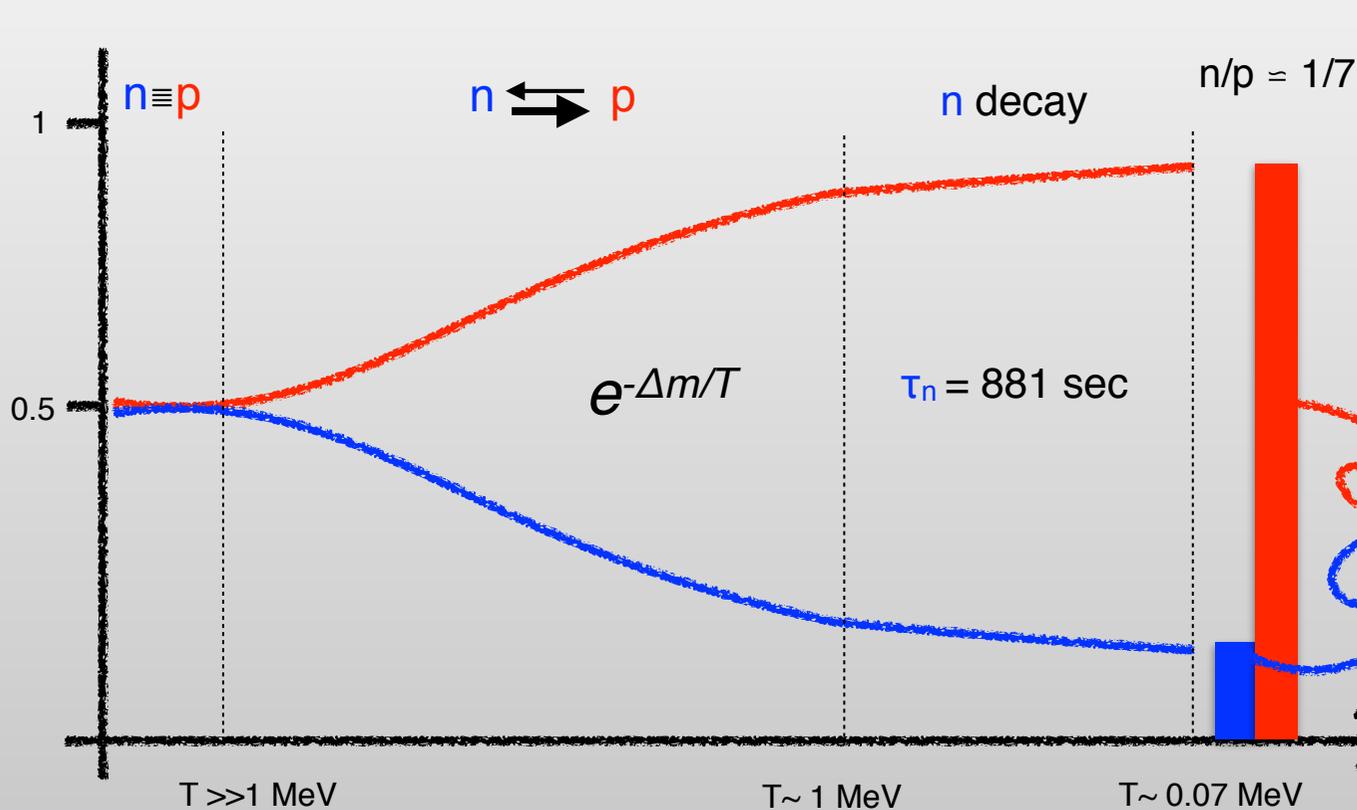
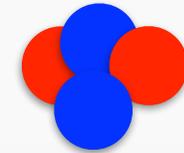
Nucleosintesi primordiale



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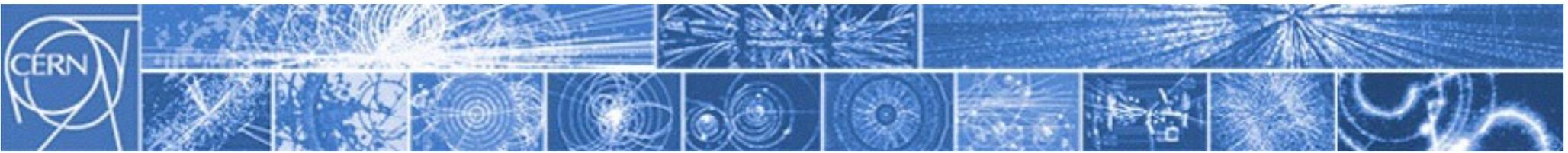
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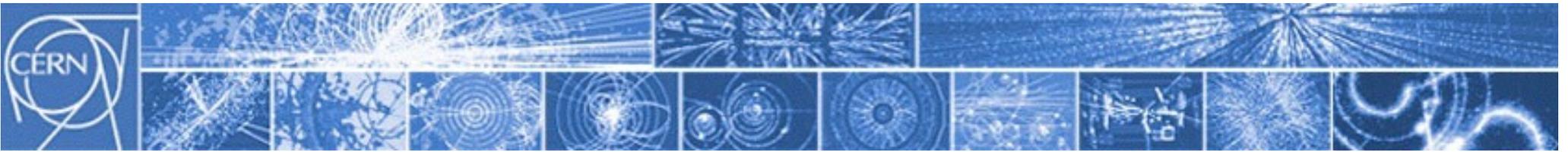
previsione:
 ${}^4\text{He} = 25\%$

osservazioni:
 ${}^4\text{He} = 24.9\% \pm 0.9\%$



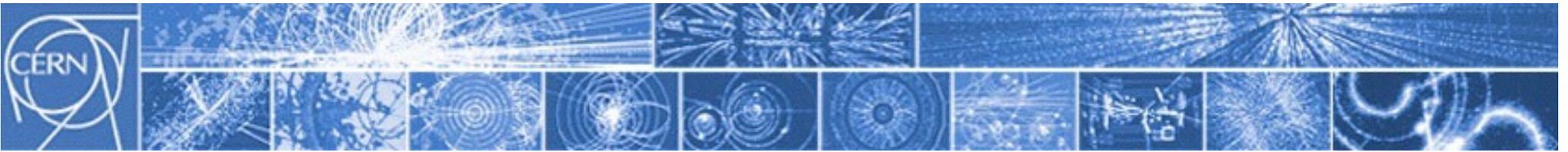
Come sono prodotti tutti gli altri elementi?

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18										
Period 1	1 H 1.008																	2 He 4.0026										
2	3 Li 6.94	4 Be 9.0122											5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180										
3	11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.085	15 P 30.974	16 S 32.06	17 Cl 35.45	18 Ar 39.948										
4	19 K 39.098	20 Ca 40.078											21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	32 Ge 72.63	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.798
5	37 Rb 85.468	38 Sr 87.62											39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.96	43 Tc [97.91]	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
6	55 Cs 132.91	56 Ba 137.33	*										71 Lu 174.97	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po [208.98]	85 At [209.99]	86 Rn [222.02]
7	87 Fr [223.02]	88 Ra [226.03]	**										103 Lr [262.11]	104 Rf [265.12]	105 Db [268.13]	106 Sg [271.13]	107 Bh [270]	108 Hs [277.15]	109 Mt [276.15]	110 Ds [281.16]	111 Rg [280.16]	112 Cn [285.17]	113 Uut [284.16]	114 Fl [289.19]	115 Uup [288.19]	116 Lv [293]	117 Uus [294]	118 Uuo [294]
*Lanthanoids			*	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm [144.91]	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05											
**Actinoids			**	89 Ac [227.03]	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np [237.05]	94 Pu [244.06]	95 Am [243.06]	96 Cm [247.07]	97 Bk [247.07]	98 Cf [251.08]	99 Es [262.08]	100 Fm [267.10]	101 Md [268.10]	102 No [269.10]											



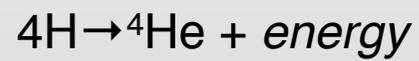
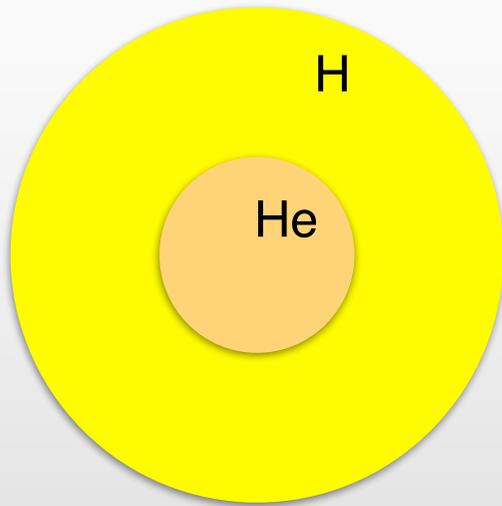
Come sono prodotti tutti gli altri elementi?

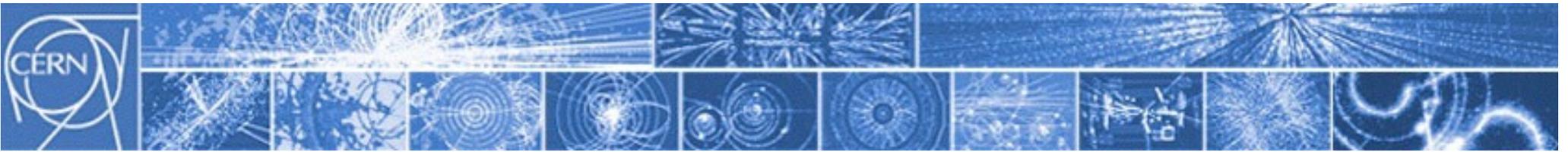
Nucleosintesi stellare



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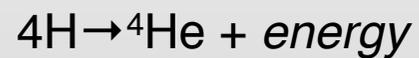
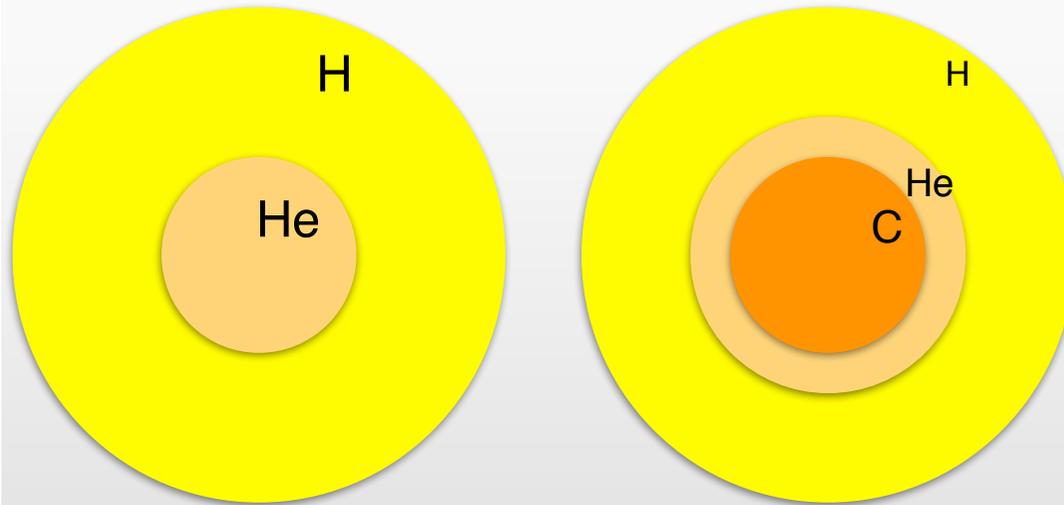
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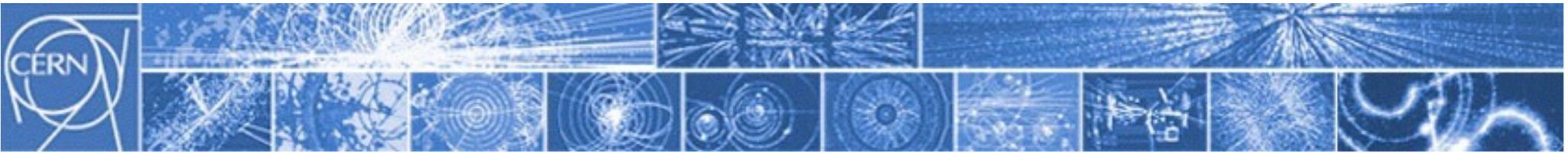


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Nucleosintesi stellare

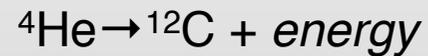
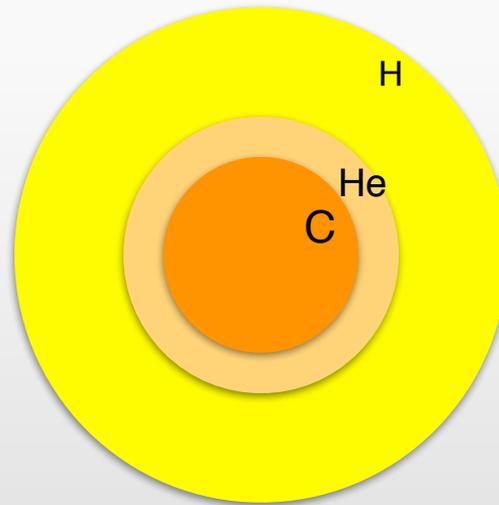
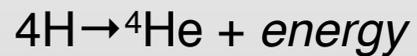
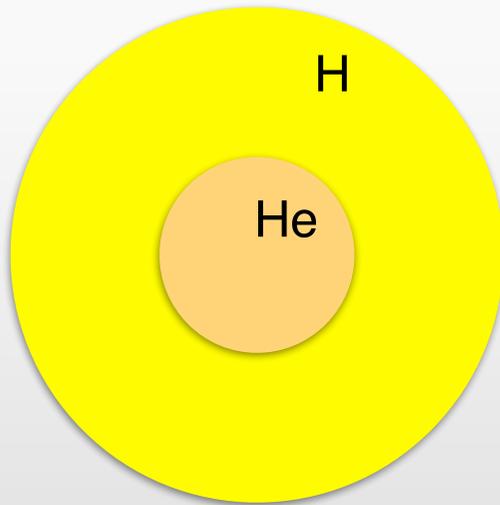


Fusione nucleare produce nuclei pesanti
e fornisce pressione di sostegno

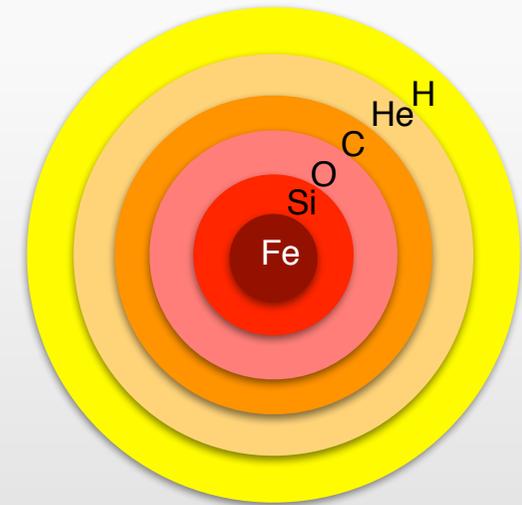


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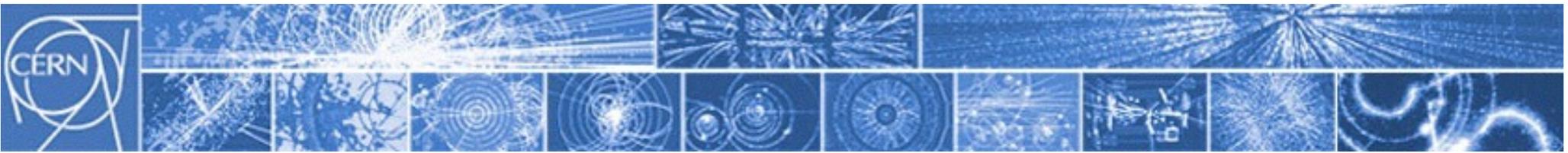
Nucleosintesi stellare



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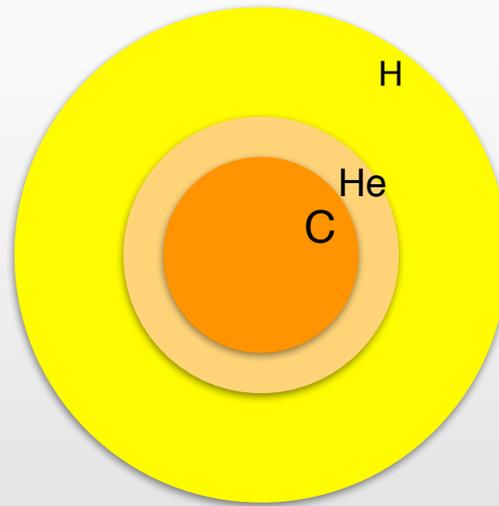
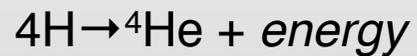
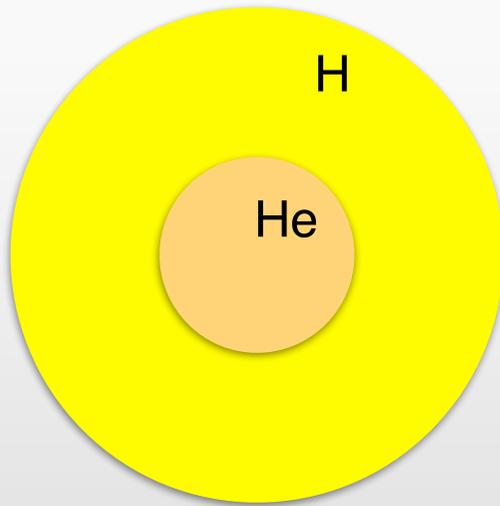


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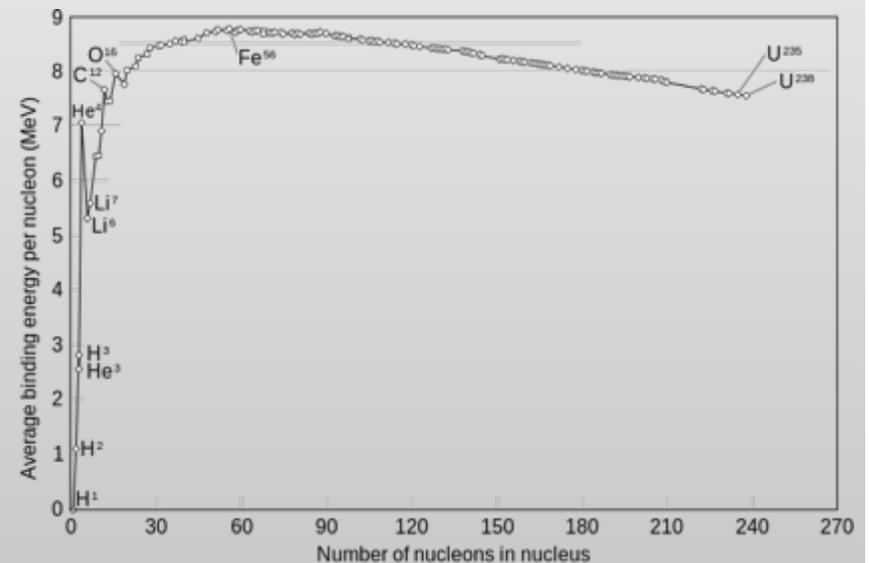
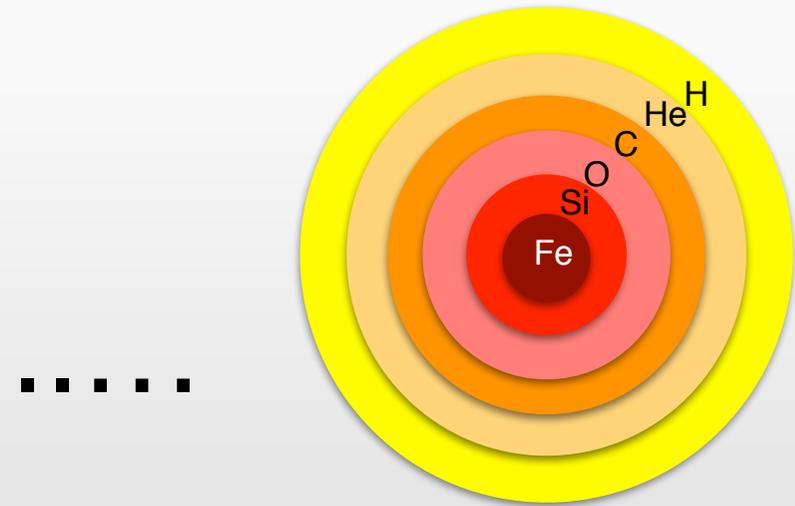


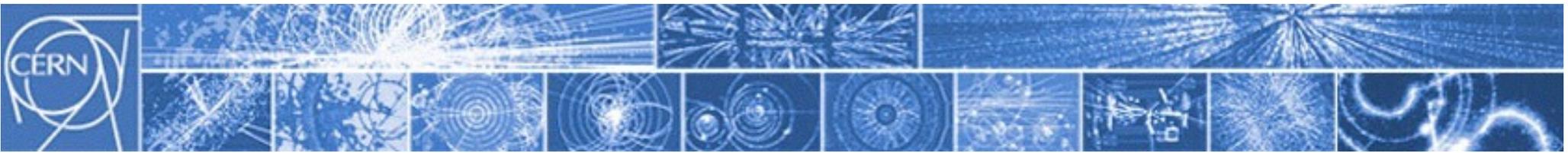
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Nucleosintesi stellare



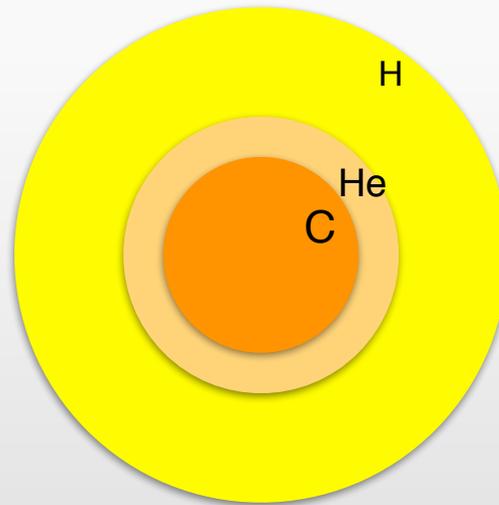
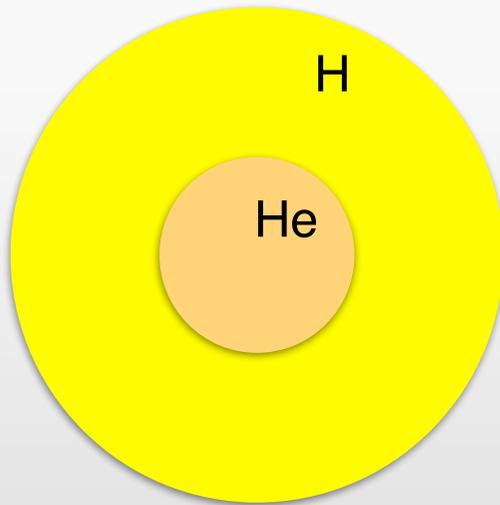
Fusione nucleare produce nuclei pesanti e fornisce pressione di sostegno



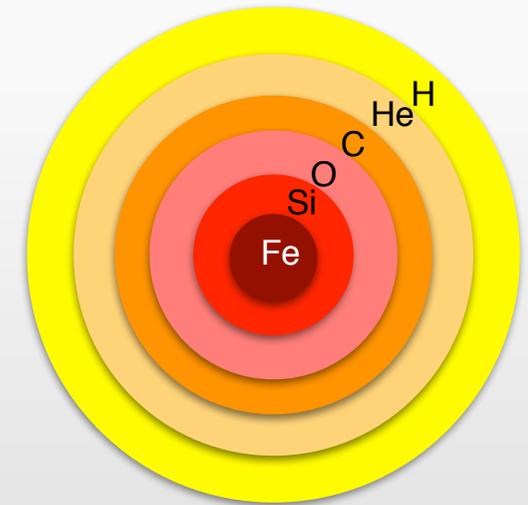


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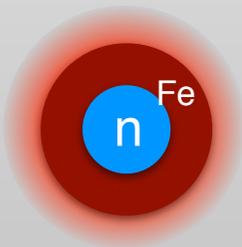
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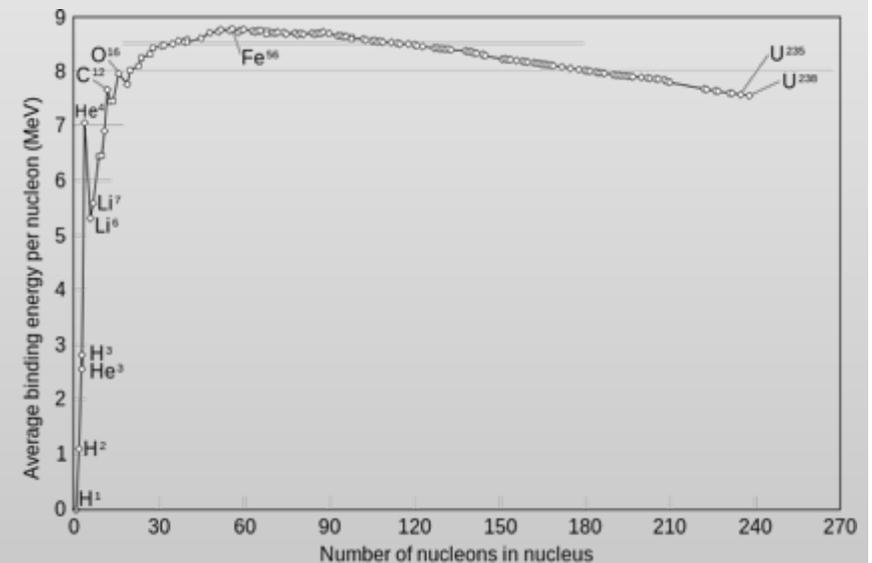
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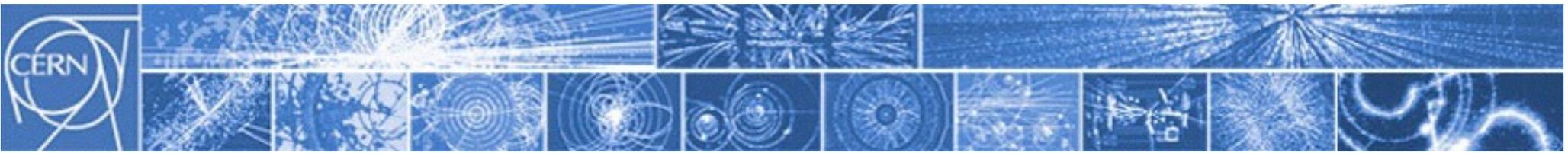


Nucleosintesi nelle supernovae



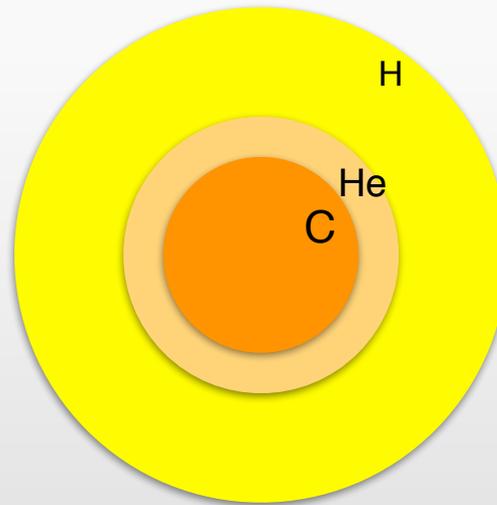
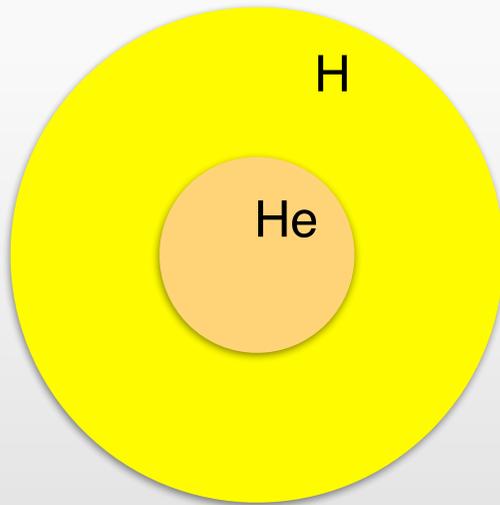
Appena prima dell'esplosione, neutronizzazione del nocciolo e cattura rapida di neutroni



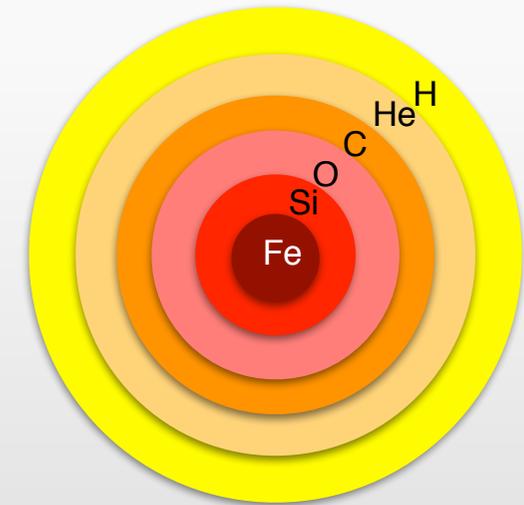


Come sono prodotti tutti gli altri elementi?

Nucleosintesi stellare

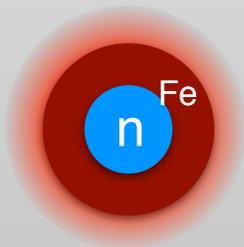


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Fusione nucleare produce nuclei pesanti e fornisce pressione di sostegno

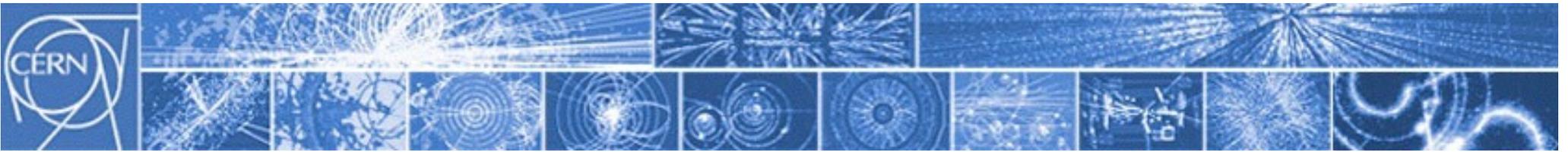
Nucleosintesi nelle supernovae



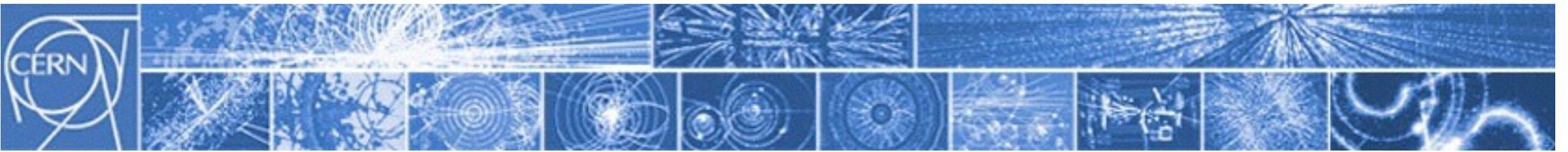
Appena prima dell'esplosione, neutronizzazione del nocciolo e cattura rapida di neutroni

The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars. We are made of starstuff.

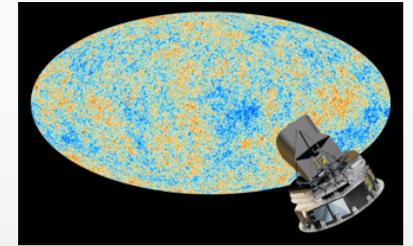
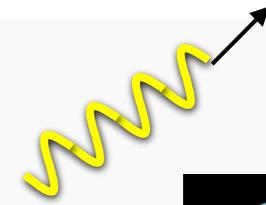
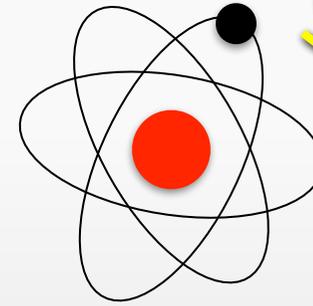
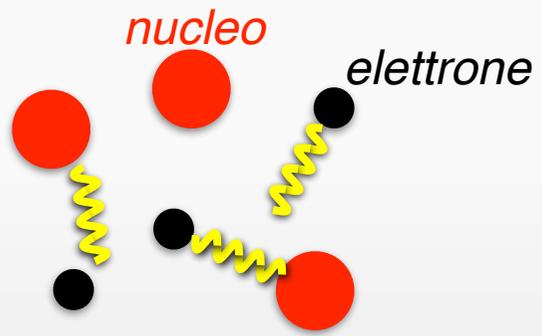
Carl Sagan

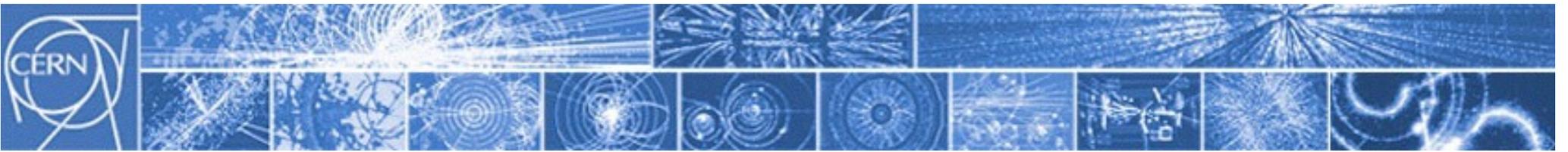


Radiazione Cosmica di fondo (Cosmic Microwave Background) (*CMB*)



CMB

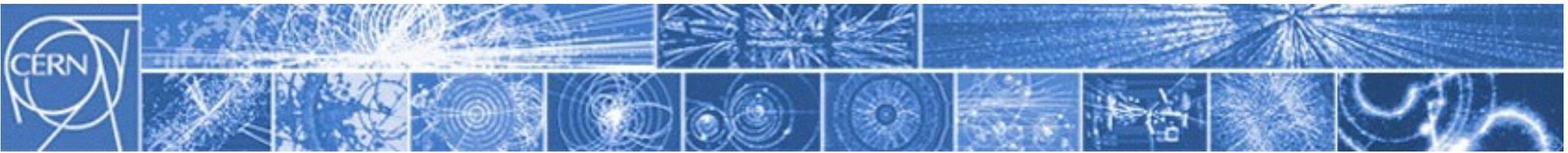




CMB



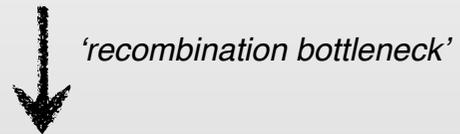
Energia ionizzazione H: 13.6 eV



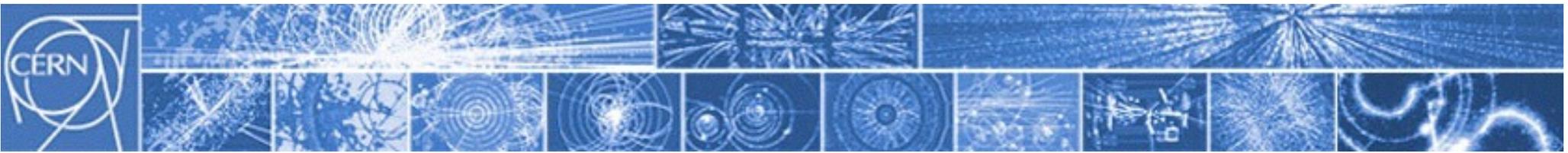
CMB



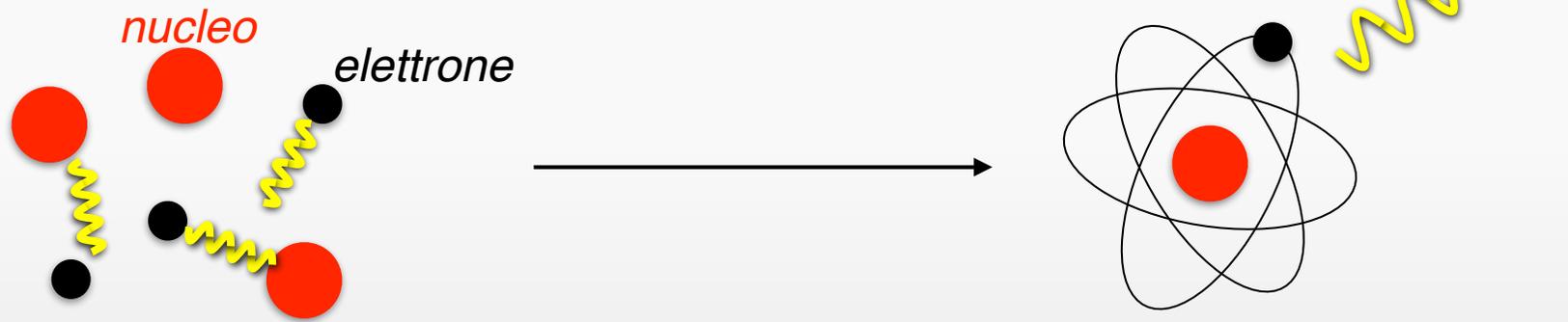
Energia ionizzazione H: 13.6 eV



Temperatura ricombinazione H: 0.25 eV
 $\approx 3000 \text{ K}$



CMB



Energia ionizzazione H: 13.6 eV

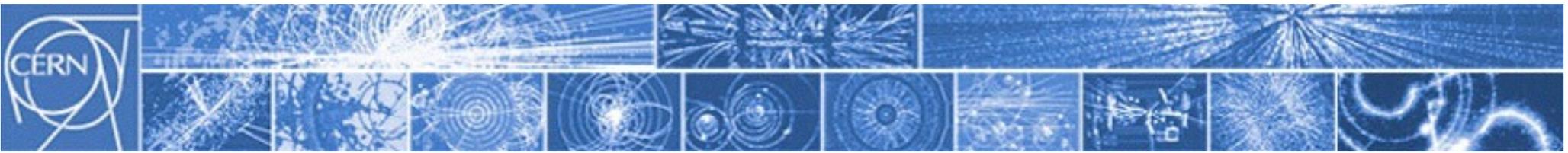


Temperatura ricombinazione H: 0.25 eV
 ≈ 3000 K

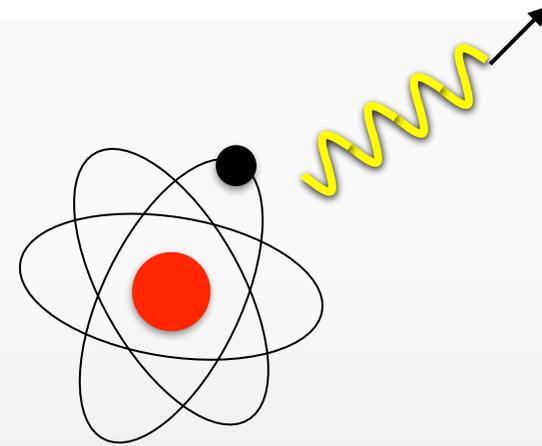
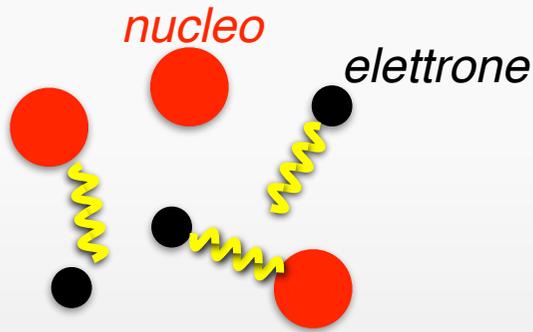


$z = 1100$

Temperatura oggi: 2.725 K



CMB



Energia ionizzazione H: 13.6 eV

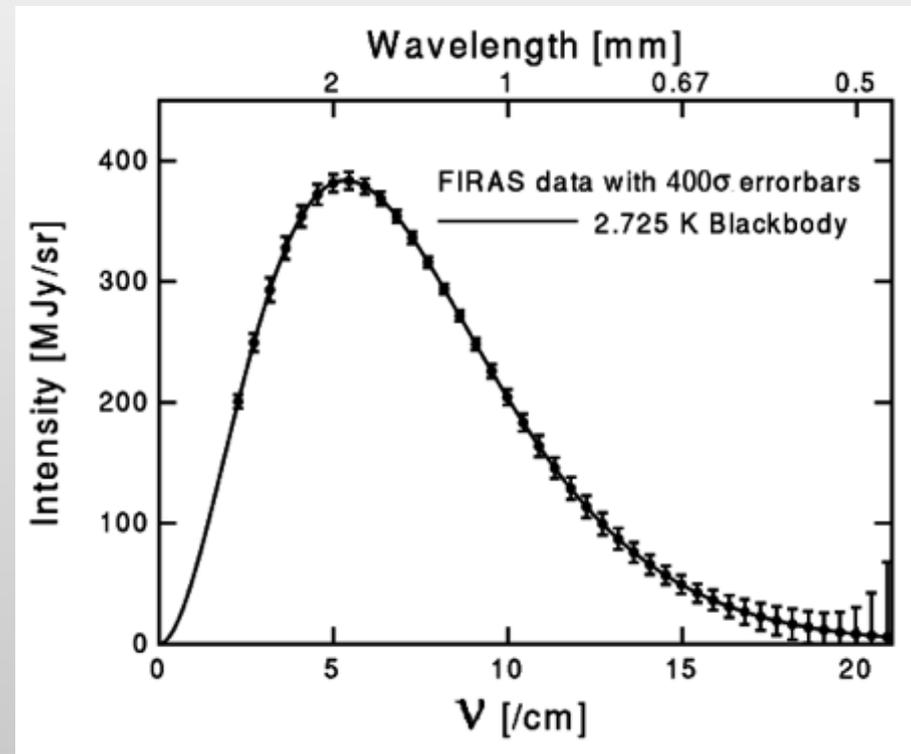


Temperatura ricombinazione H: 0.25 eV
 ≈ 3000 K

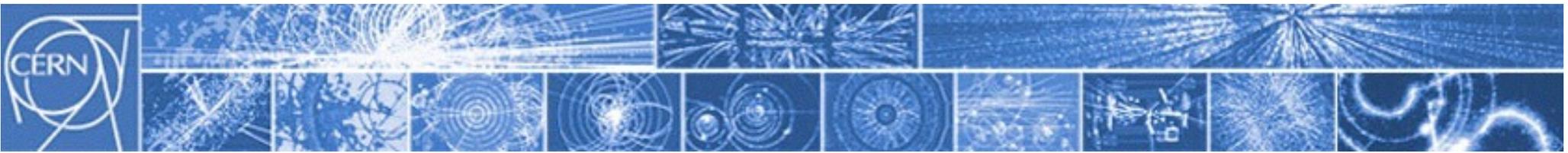


$z = 1100$

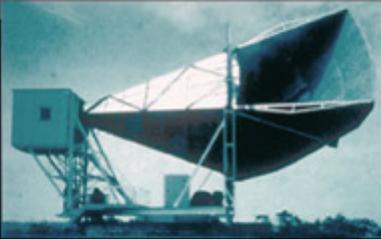
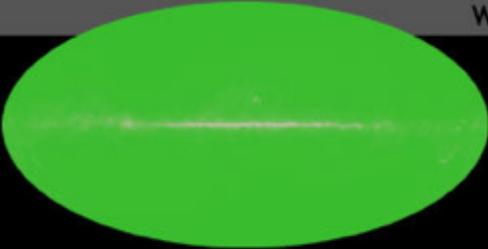
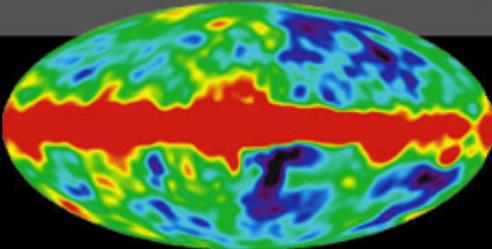
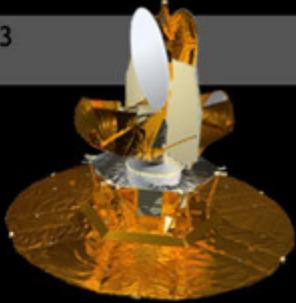
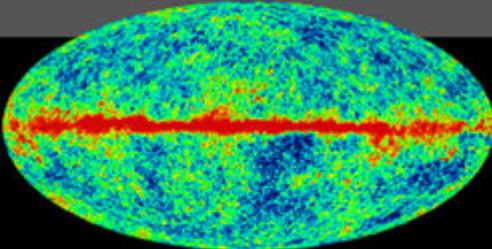
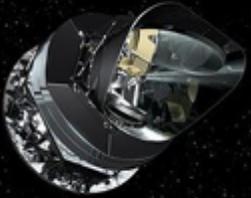
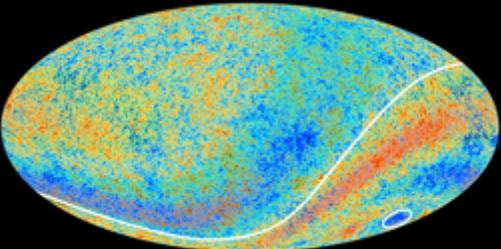
Temperatura oggi: 2.725 K



NB: 'Microwave' perché $\lambda \sim 1$ mm, come il wifi, i GSM o il famoso forno (niente a che vedere con il micron, anche se, alla ricombinazione, $\lambda \sim 1 \mu\text{m}$!)

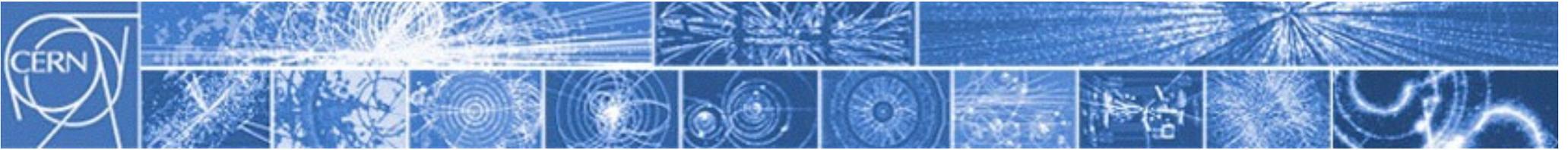


CMB - storia

1965			Penzias and Wilson
1992			COBE
2003			WMAP
2013			Planck

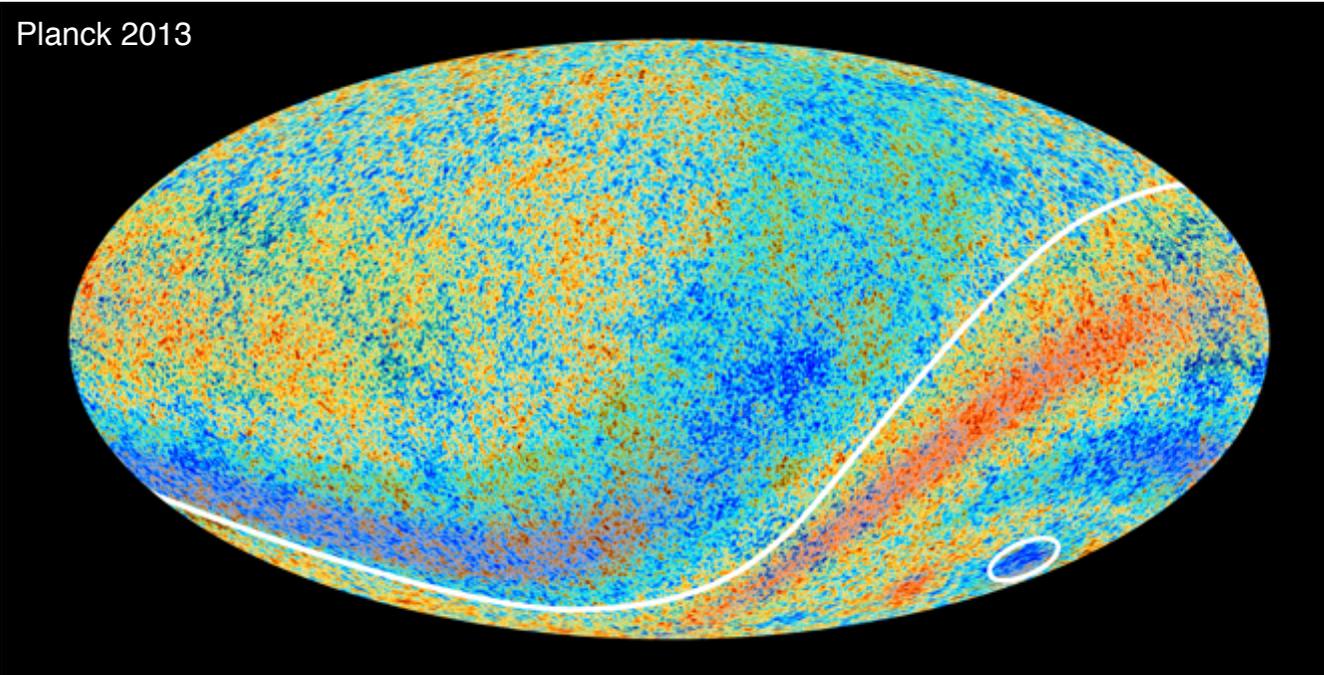


>200 scienziati
IT+F+...



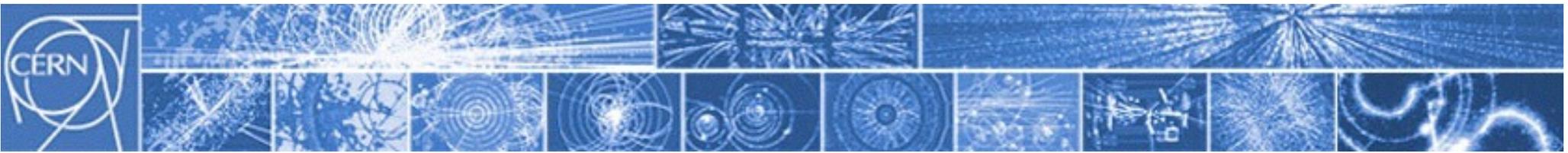
CMB - fluttuazioni

Planck 2013

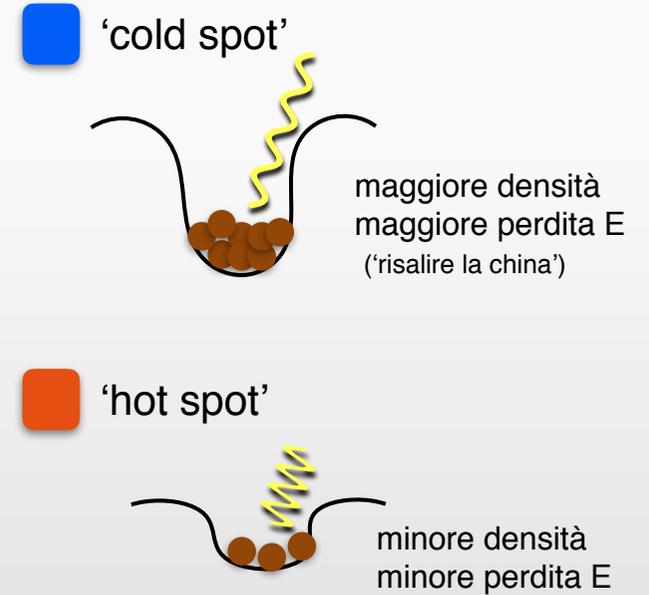
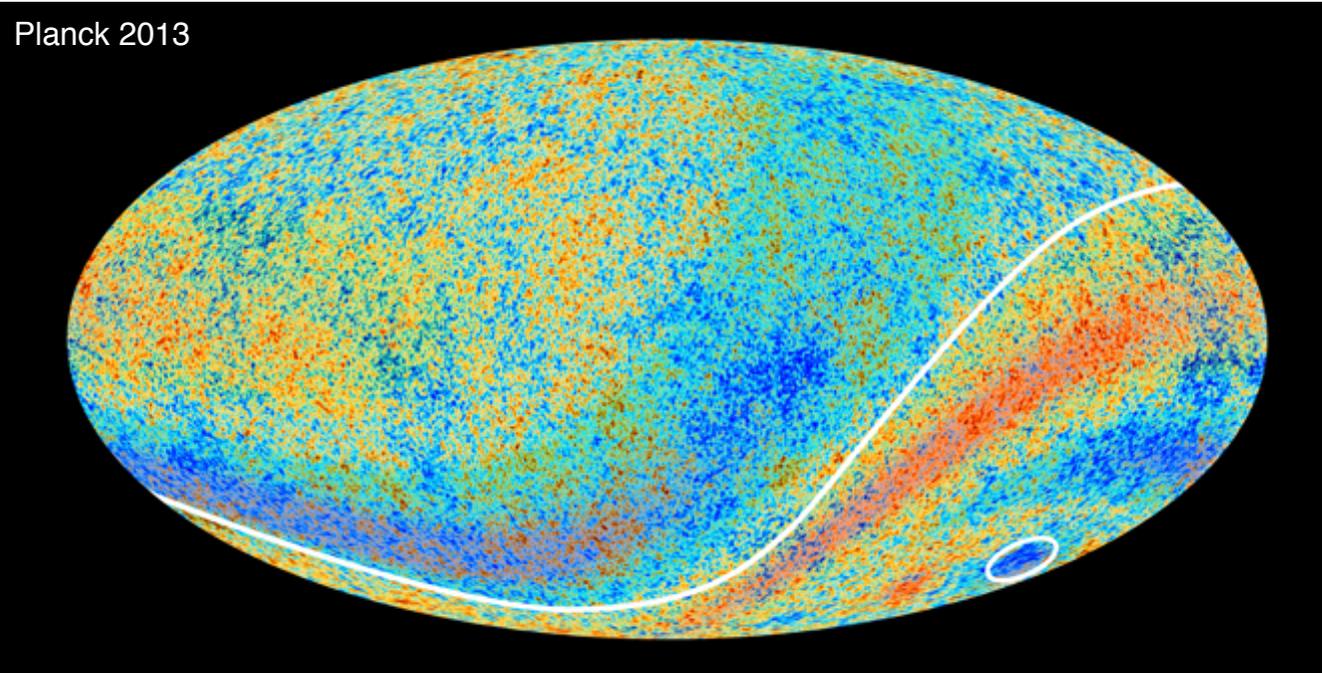


$$T = 2.725^{\circ} K$$

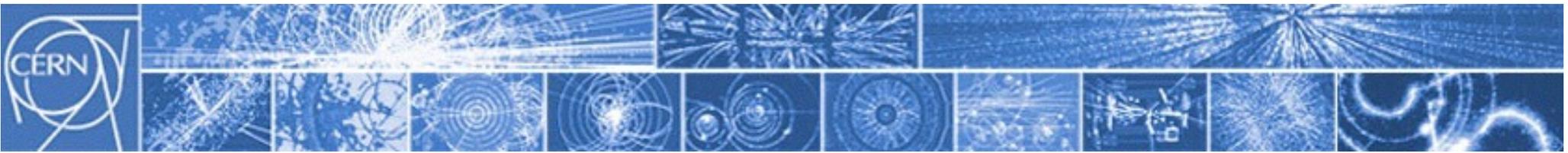
$$\frac{\delta T}{T} \sim 10^{-5}$$



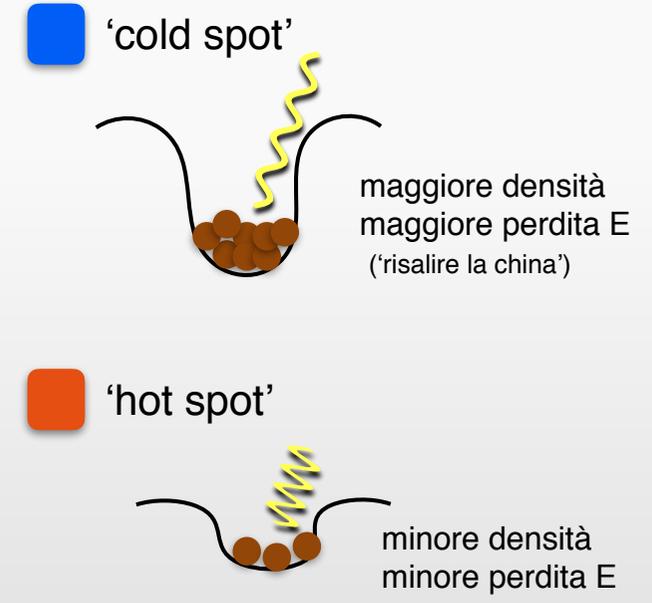
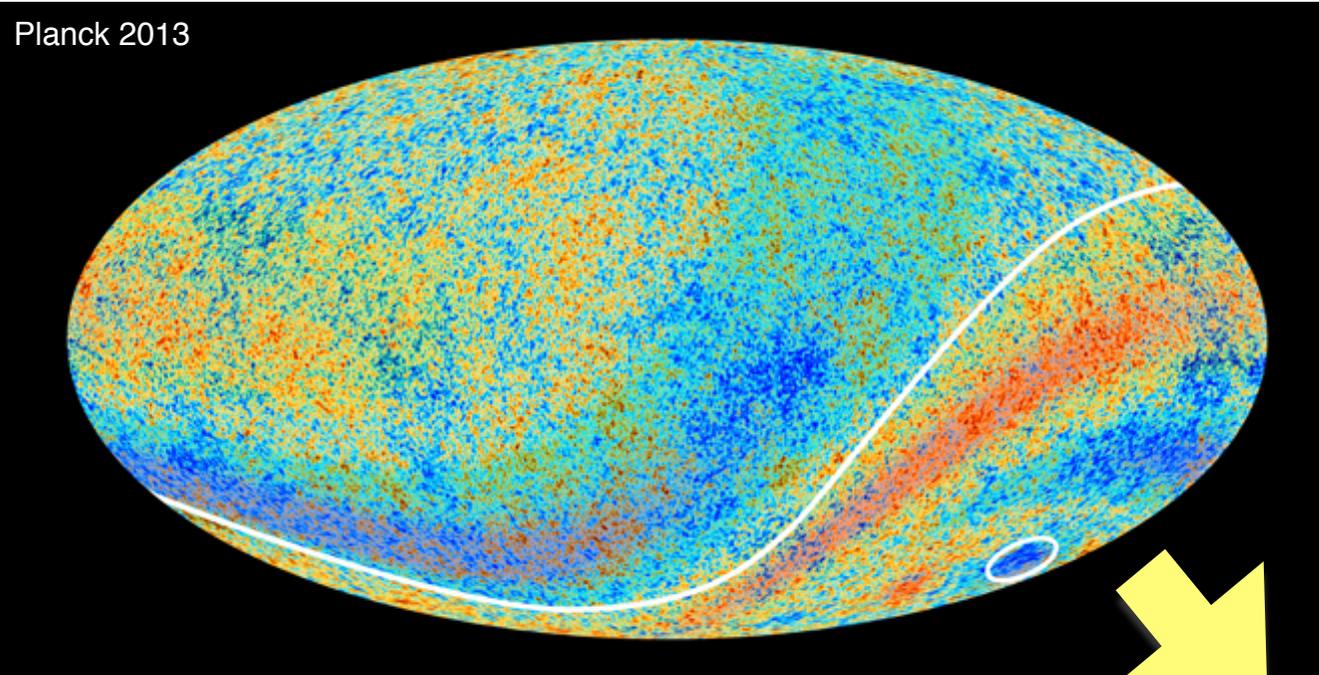
CMB - fluttuazioni



$$T = 2.725^{\circ} K$$
$$\frac{\delta T}{T} \sim 10^{-5}$$



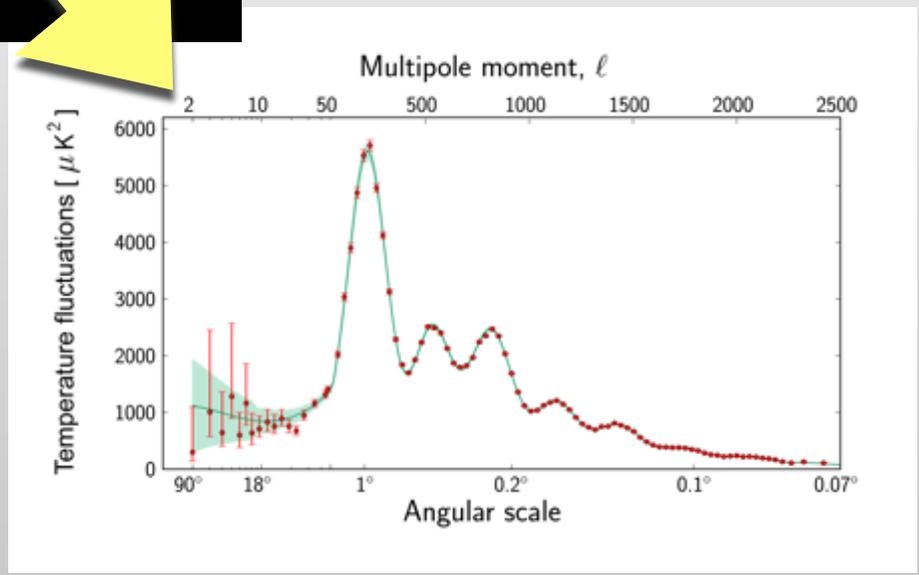
CMB - fluttuazioni

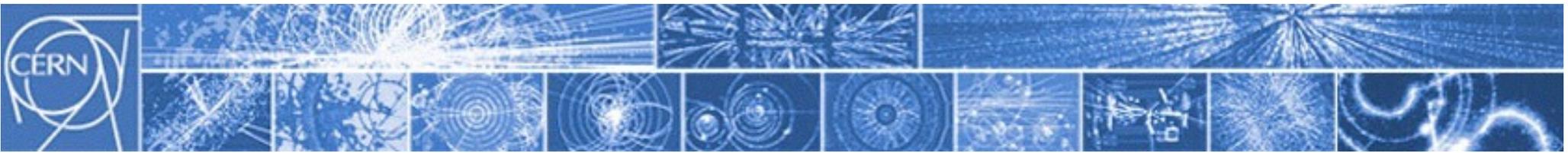


$$T = 2.725^{\circ} K$$

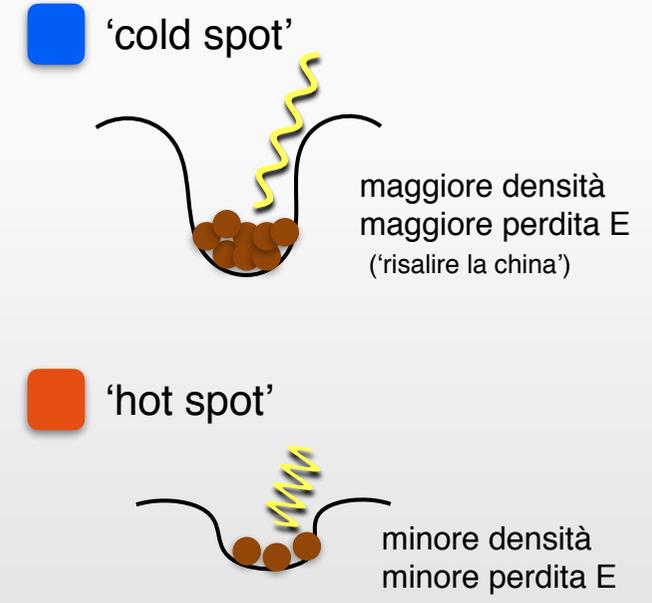
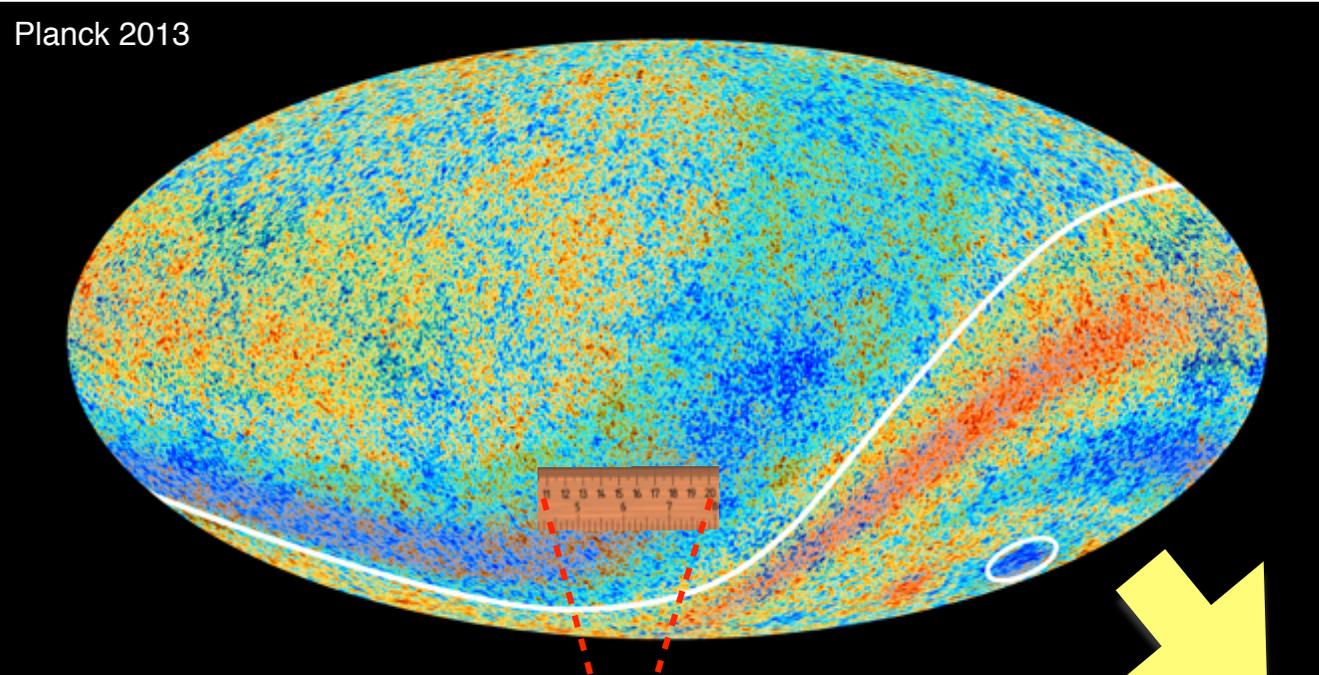
$$\frac{\delta T}{T} \sim 10^{-5}$$

Spettro di potenza della CMB
(CMB power spectrum)





CMB - fluttuazioni

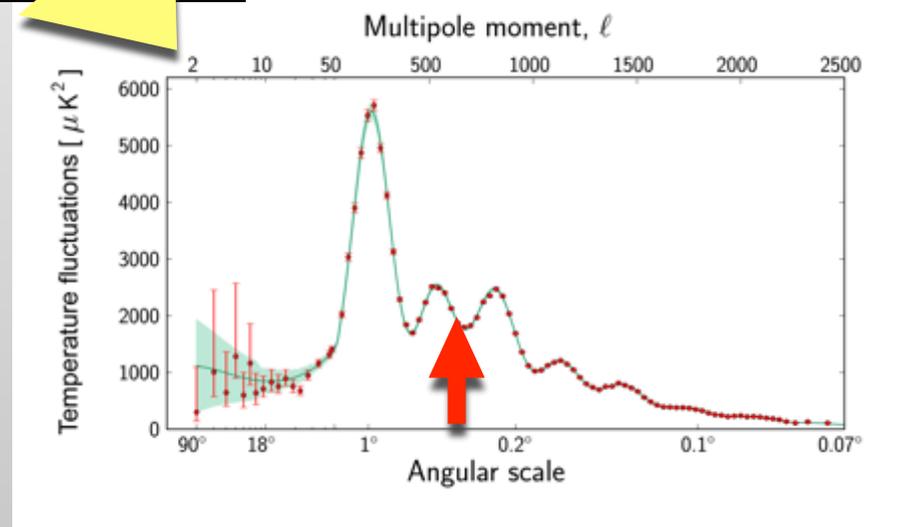


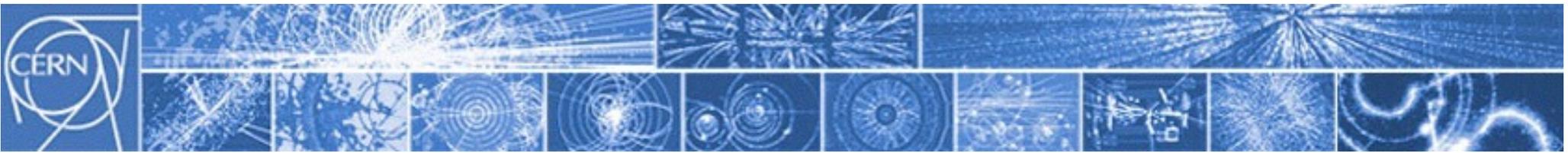
$$T = 2.725^{\circ} K$$

$$\frac{\delta T}{T} \sim 10^{-5}$$

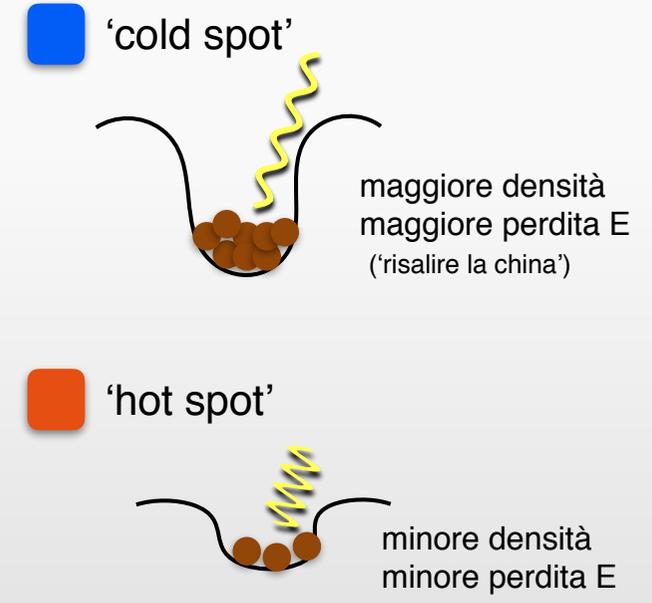
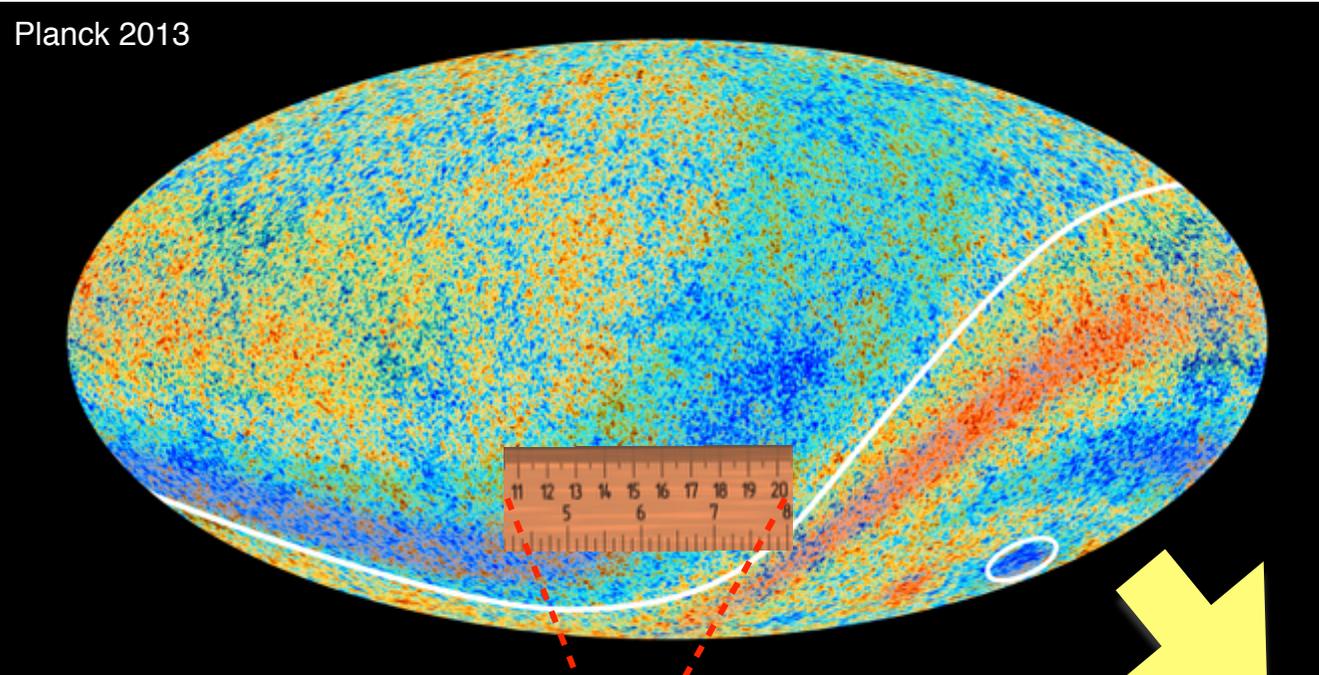
0.5°

Spettro di potenza della CMB
 (CMB power spectrum)





CMB - fluttuazioni

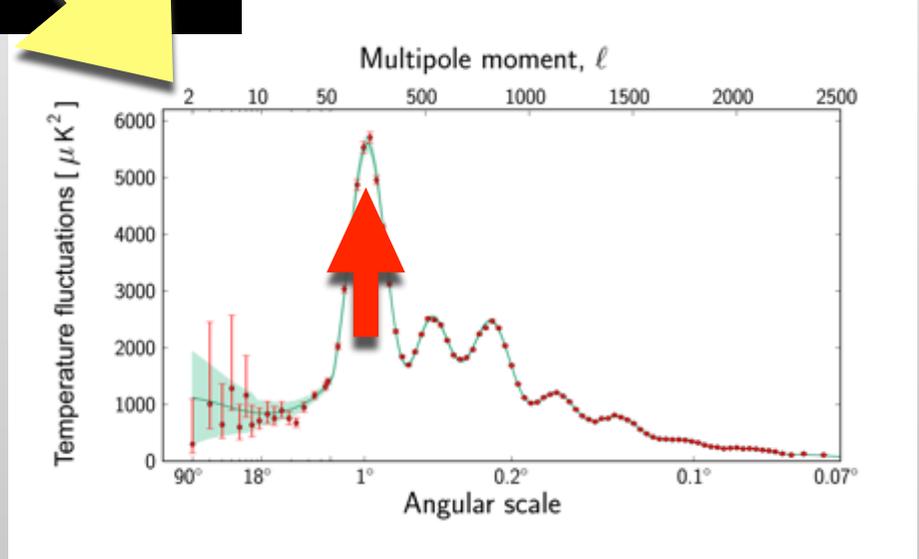


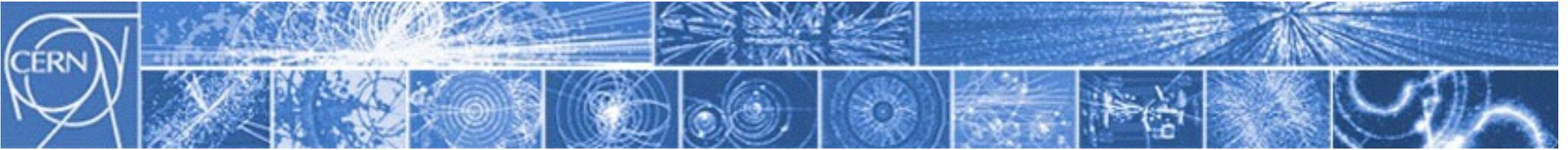
$$T = 2.725^{\circ} K$$

$$\frac{\delta T}{T} \sim 10^{-5}$$

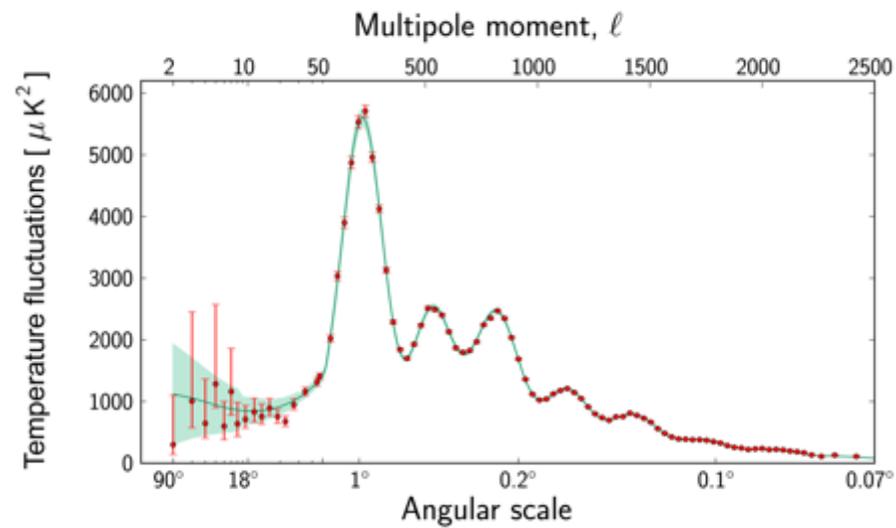
1°

Spettro di potenza della CMB
(CMB power spectrum)

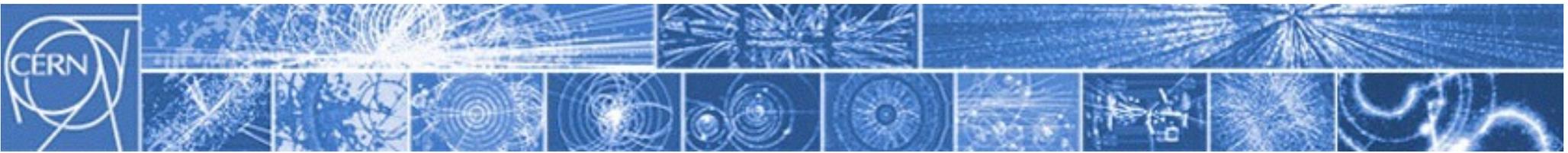




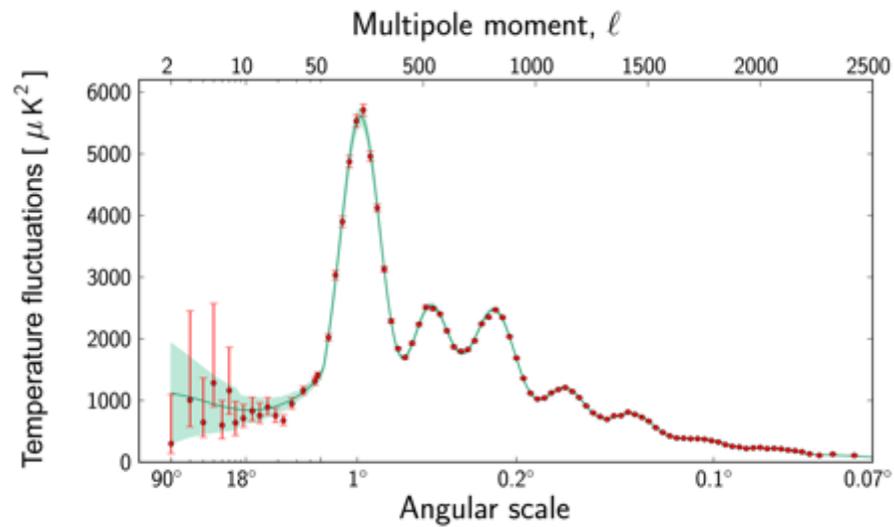
CMB - fluttuazioni



Lo spettro di potenza della CMB è un'eccezionale miniera di informazioni sulle proprietà dell'Universo



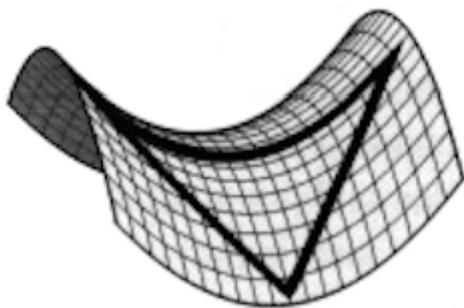
CMB - fluttuazioni



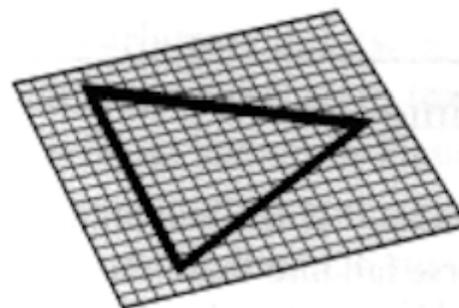
Lo spettro di potenza della CMB è un'eccezionale miniera di informazioni sulle proprietà dell'Universo

E.g.: curvatura dell'Universo

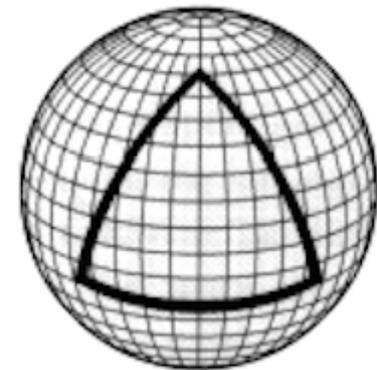
(somewhat oversimplified, but ok)



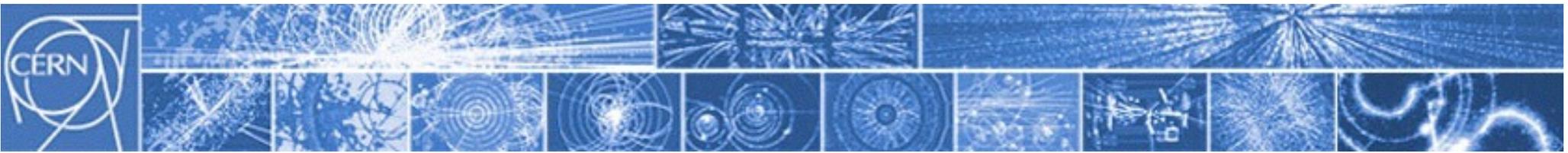
Negative Curvature



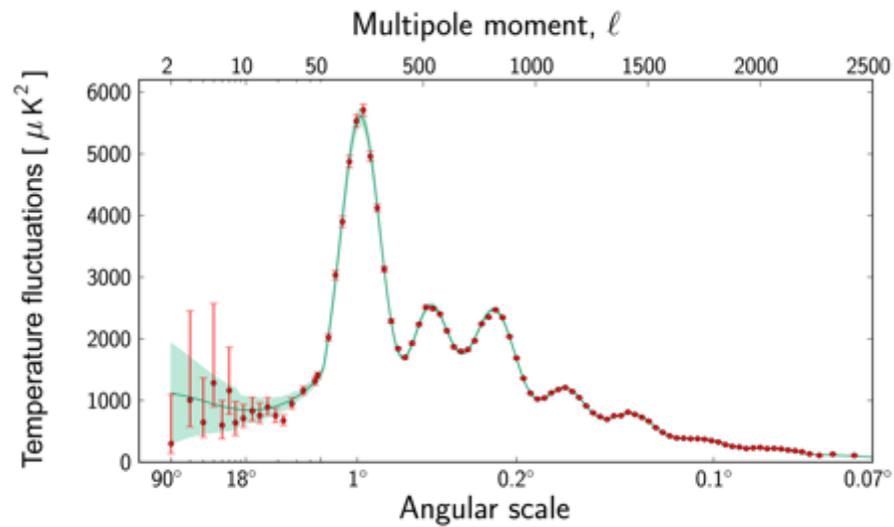
Flat Curvature



Positive Curvature

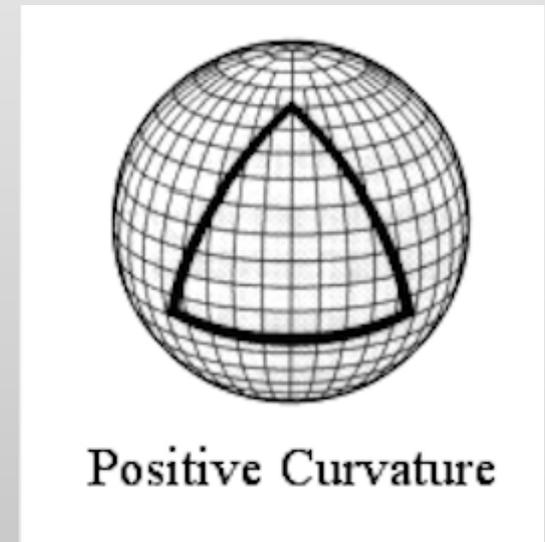
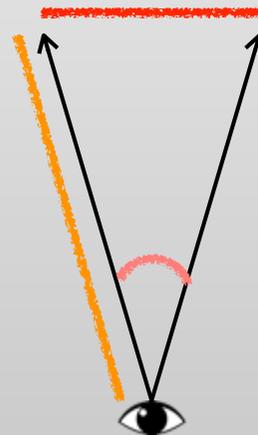
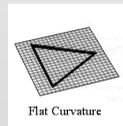


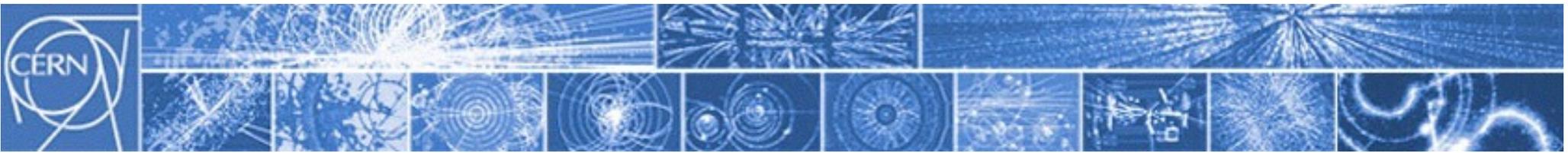
CMB - fluttuazioni



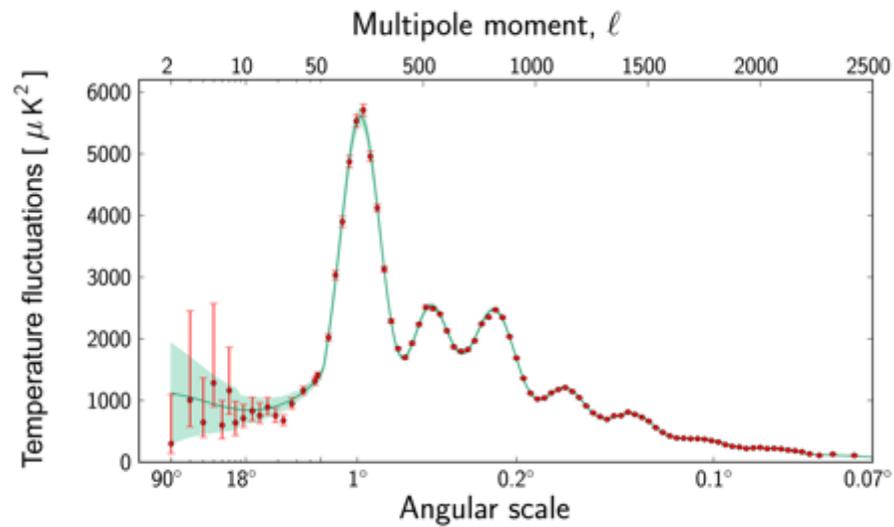
Lo spettro di potenza della CMB è un'eccezionale miniera di informazioni sulle proprietà dell'Universo

E.g.: curvatura dell'Universo



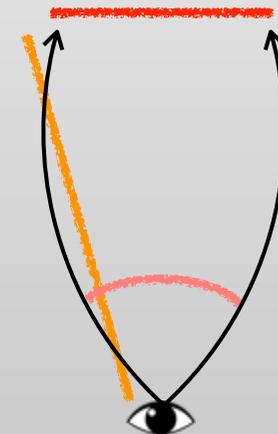
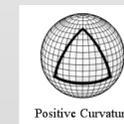
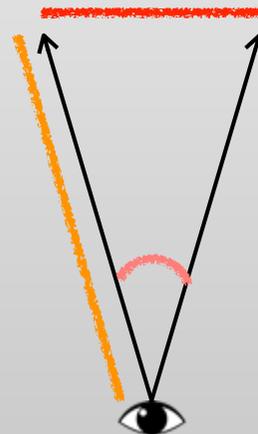
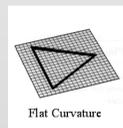
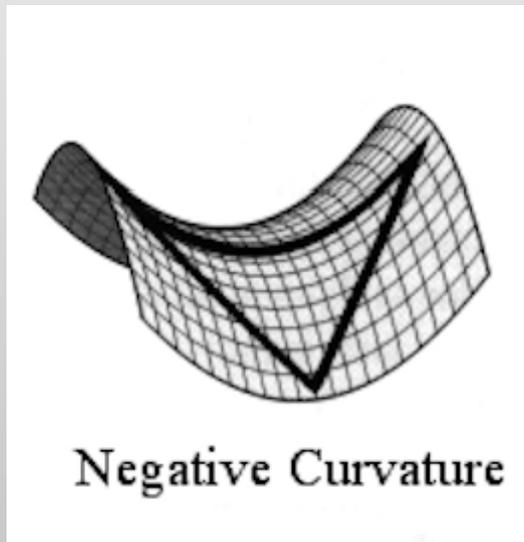


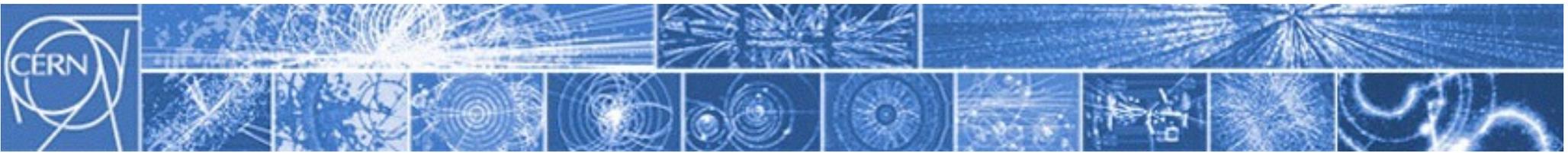
CMB - fluttuazioni



Lo spettro di potenza della CMB è un'eccezionale miniera di informazioni sulle proprietà dell'Universo

E.g.: curvatura dell'Universo

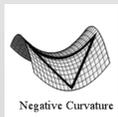
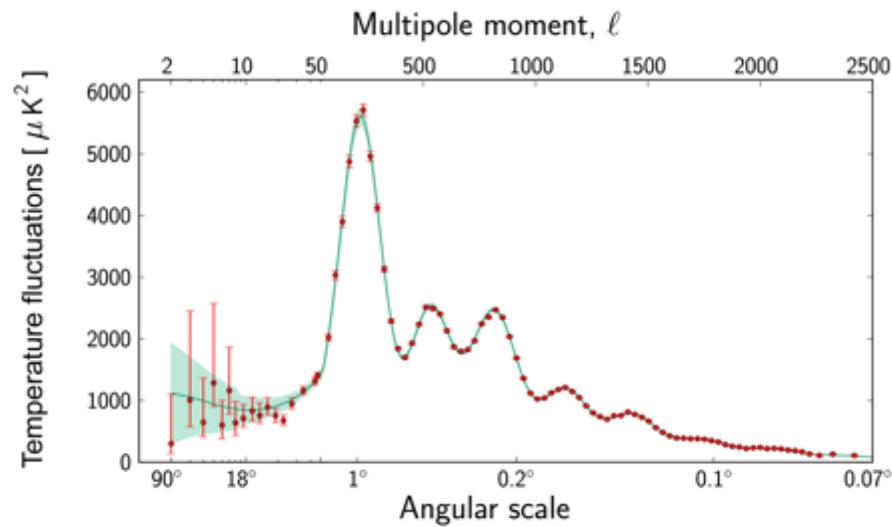




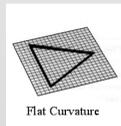
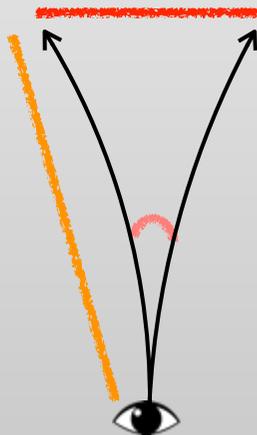
CMB - fluttuazioni

Lo spettro di potenza della CMB è un'eccezionale miniera di informazioni sulle proprietà dell'Universo

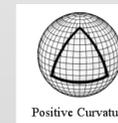
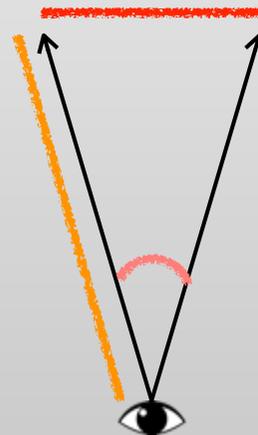
E.g.: curvatura dell'Universo



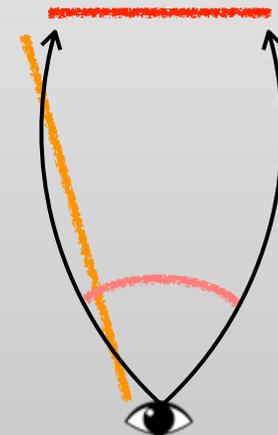
Negative Curvature

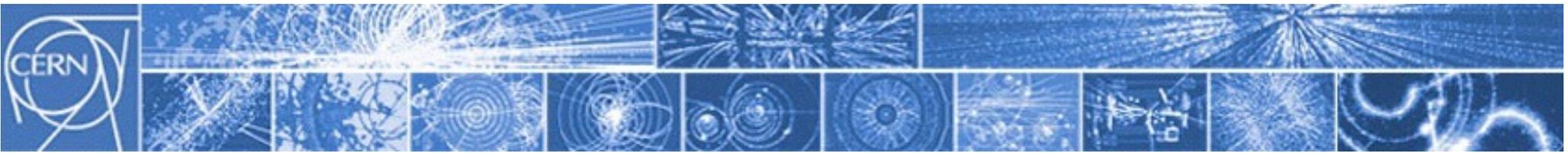


Flat Curvature

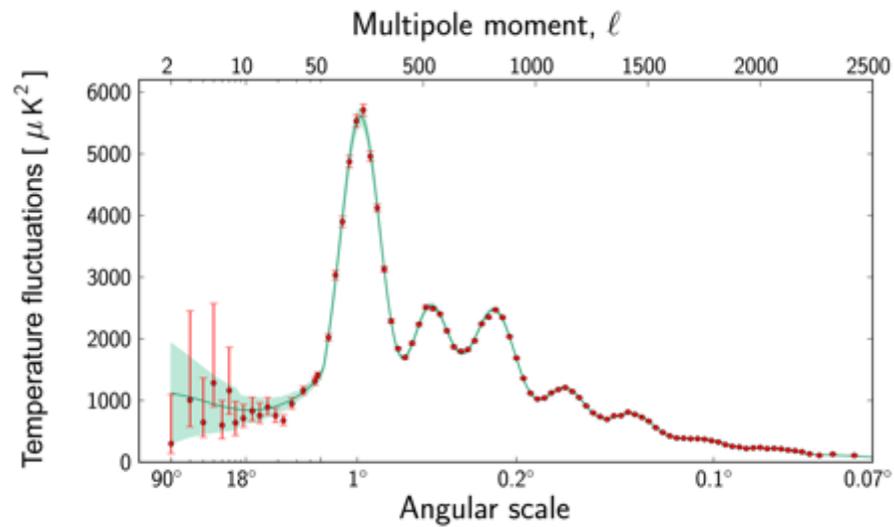


Positive Curvature





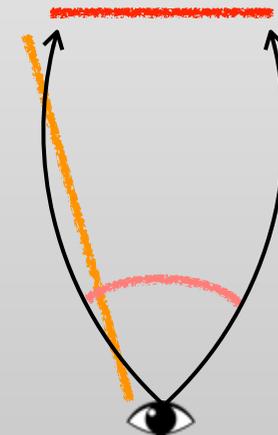
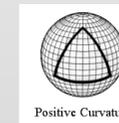
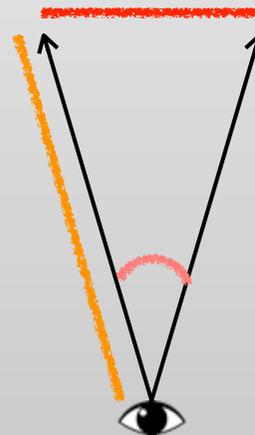
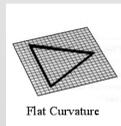
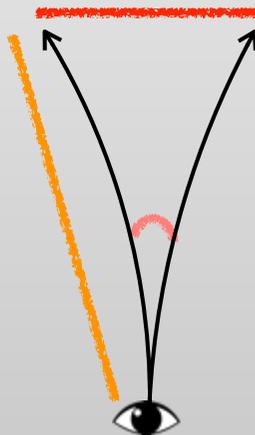
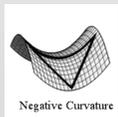
CMB - fluttuazioni

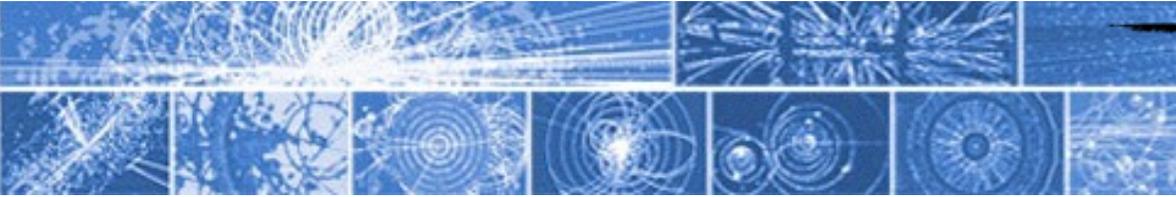


Lo spettro di potenza della CMB è un'eccezionale miniera di informazioni sulle proprietà dell'Universo

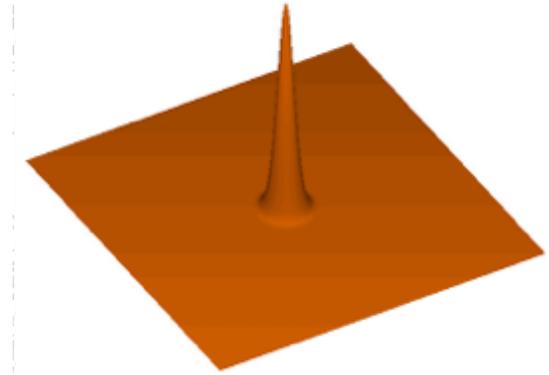
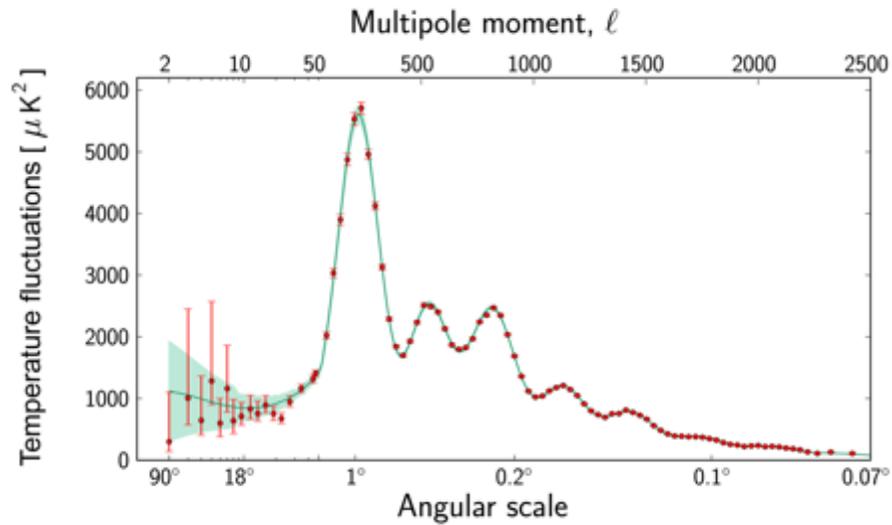
E.g.: curvatura dell'Universo

 lunghezza nota: la distanza percorsa da un'onda di materia dal Big Bang alla ricombinazione





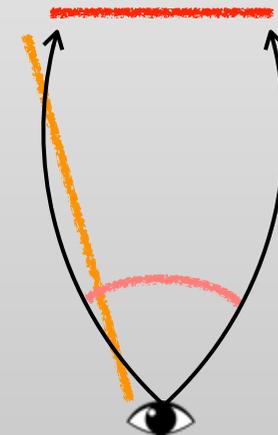
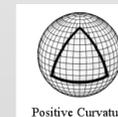
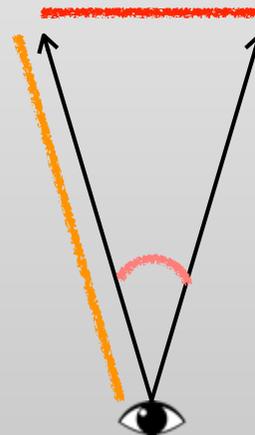
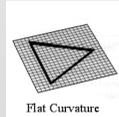
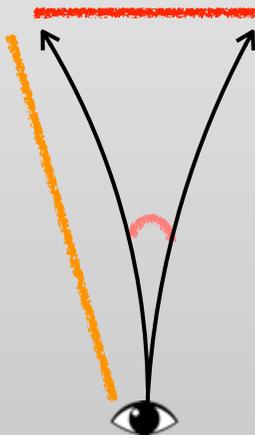
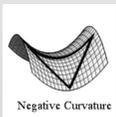
CMB - fluttuazioni

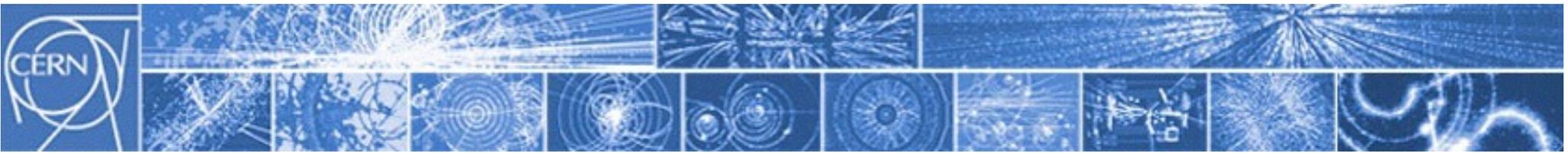


Lo spettro di un'eccezionale sulle proprietà

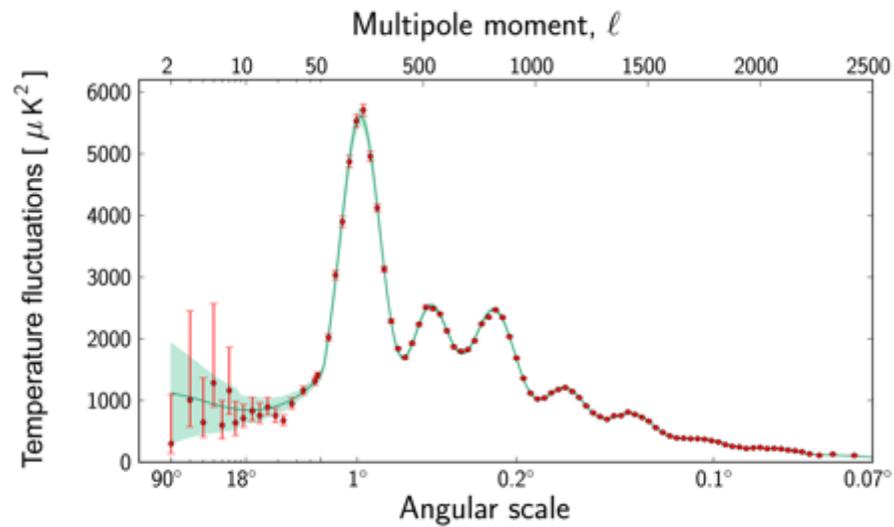
E.g.: curvatura dell'Universo

 lunghezza nota: la distanza percorsa da un'onda di materia dal Big Bang alla ricombinazione





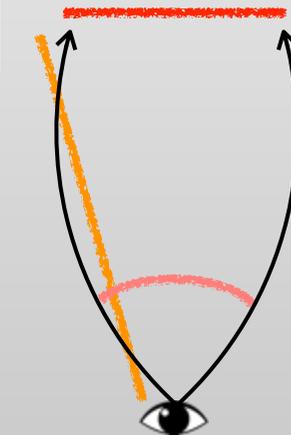
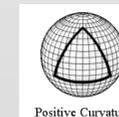
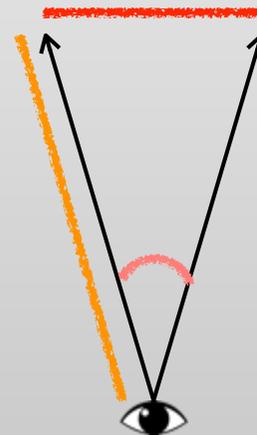
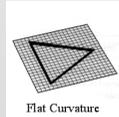
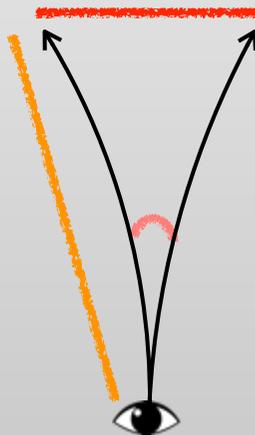
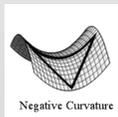
CMB - fluttuazioni

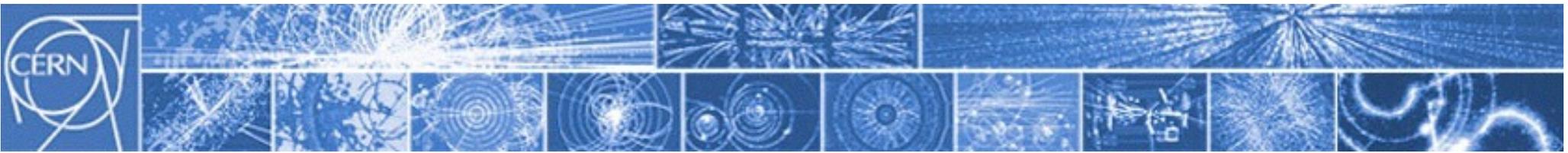


Lo spettro di potenza della CMB è un'eccezionale miniera di informazioni sulle proprietà dell'Universo

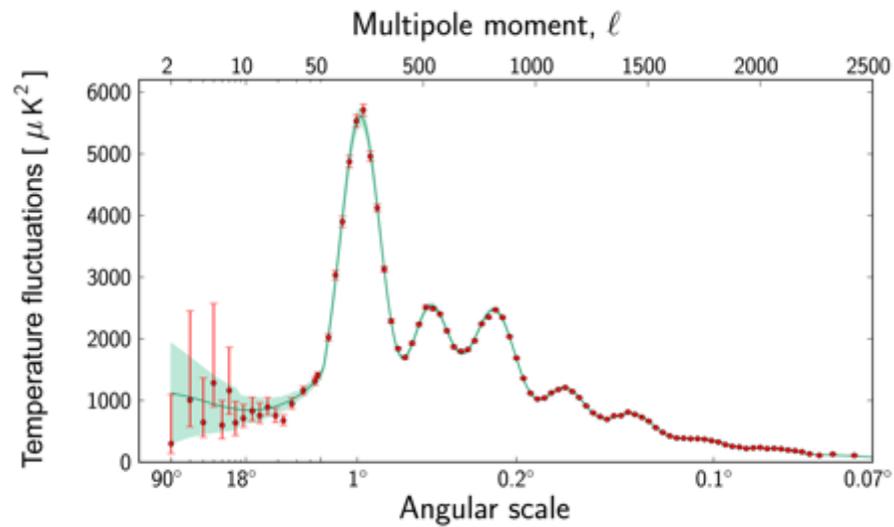
E.g.: curvatura dell'Universo

- lunghezza nota: la distanza percorsa da un'onda di materia dal Big Bang alla ricombinazione
- distanza nota: la distanza percorsa dai fotoni CMB fino ad oggi





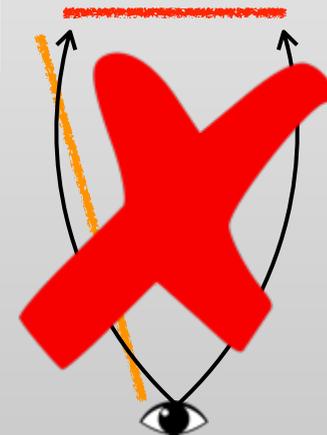
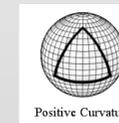
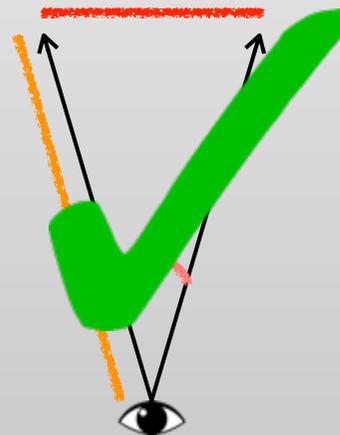
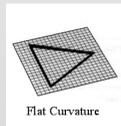
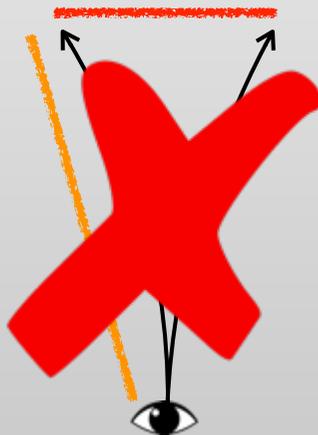
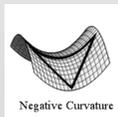
CMB - fluttuazioni

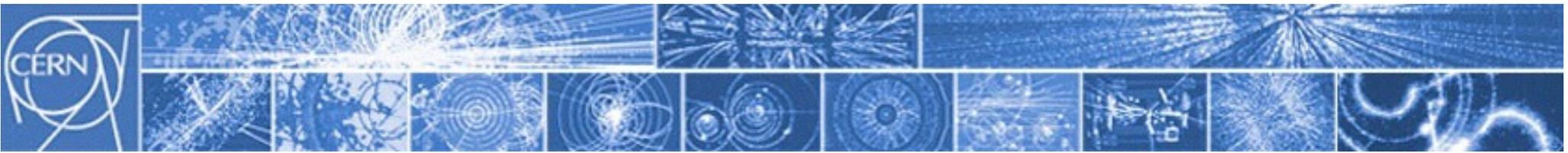


Lo spettro di potenza della CMB è un'eccezionale miniera di informazioni sulle proprietà dell'Universo

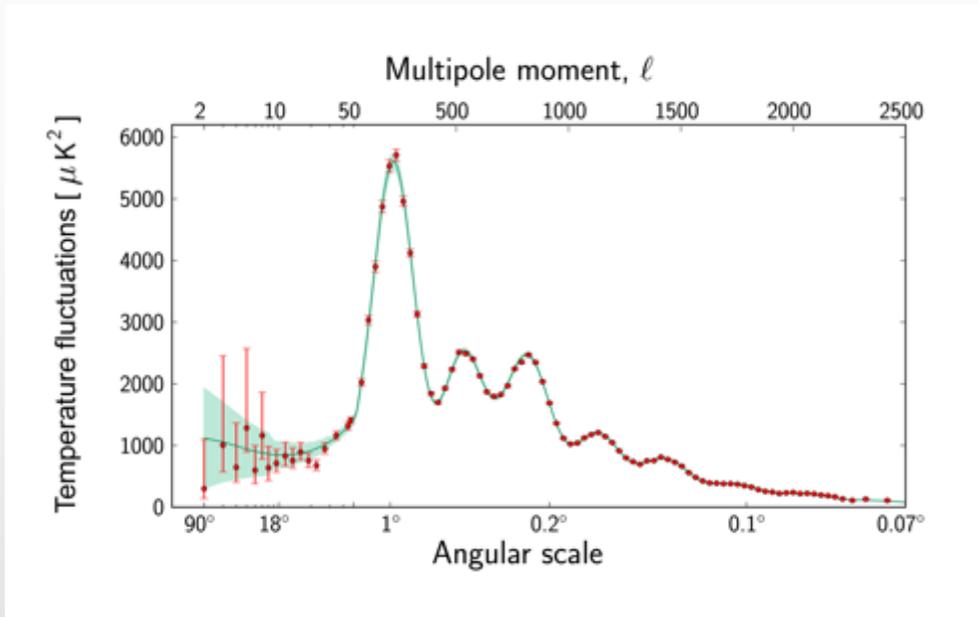
E.g.: curvatura dell'Universo

-  lunghezza nota: la distanza percorsa da un'onda di materia dal Big Bang alla ricombinazione
-  distanza nota: la distanza percorsa dai fotoni CMB fino ad oggi





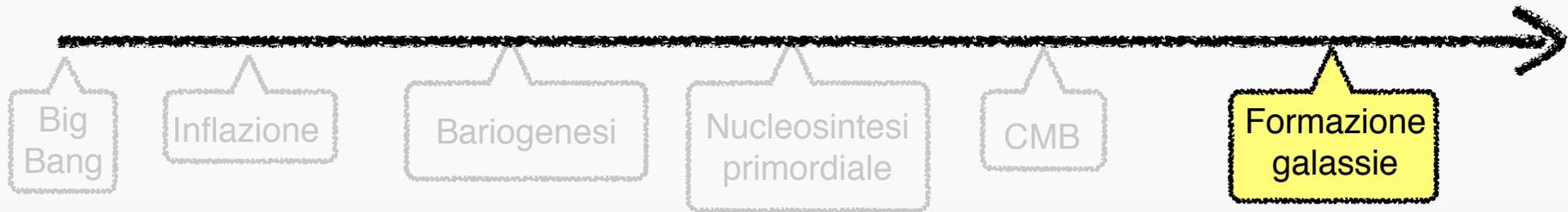
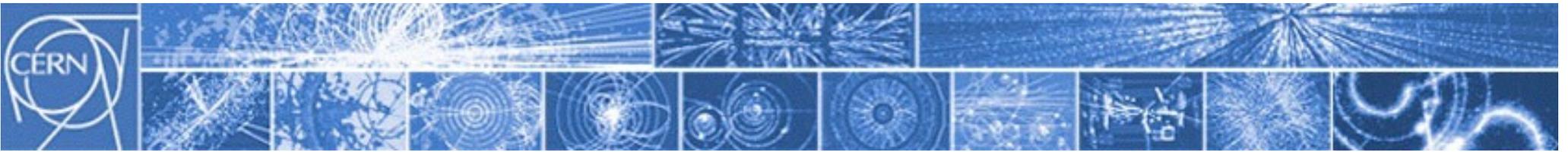
CMB - fluttuazioni



Lo spettro di potenza della CMB è un'eccezionale miniera di informazioni sulle proprietà dell'Universo

Parameter	TT+lowP 68 % limits
$\Omega_b h^2$	0.02222 ± 0.00023
$\Omega_c h^2$	0.1197 ± 0.0022
$100\theta_{MC}$	1.04085 ± 0.00047
τ	0.078 ± 0.019
$\ln(10^{10} A_s)$	3.089 ± 0.036
n_s	0.9655 ± 0.0062
H_0	67.31 ± 0.96
Ω_Λ	0.685 ± 0.013
Ω_m	0.315 ± 0.013
$\Omega_m h^2$	0.1426 ± 0.0020
$\Omega_m h^3$	0.09597 ± 0.00045
σ_8	0.829 ± 0.014
$\sigma_8 \Omega_m^{0.5}$	0.466 ± 0.013
$\sigma_8 \Omega_m^{0.25}$	0.621 ± 0.013
z_{re}	$9.9^{+1.8}_{-1.6}$
$10^9 A_s$	$2.198^{+0.076}_{-0.085}$
$10^9 A_s e^{-2\tau}$	1.880 ± 0.014
Age/Gyr	13.813 ± 0.038
z_*	1090.09 ± 0.42
r_*	144.61 ± 0.49
$100\theta_*$	1.04105 ± 0.00046
z_{drag}	1059.57 ± 0.46
r_{drag}	147.33 ± 0.49
k_D	0.14050 ± 0.00052
z_{eq}	3393 ± 49

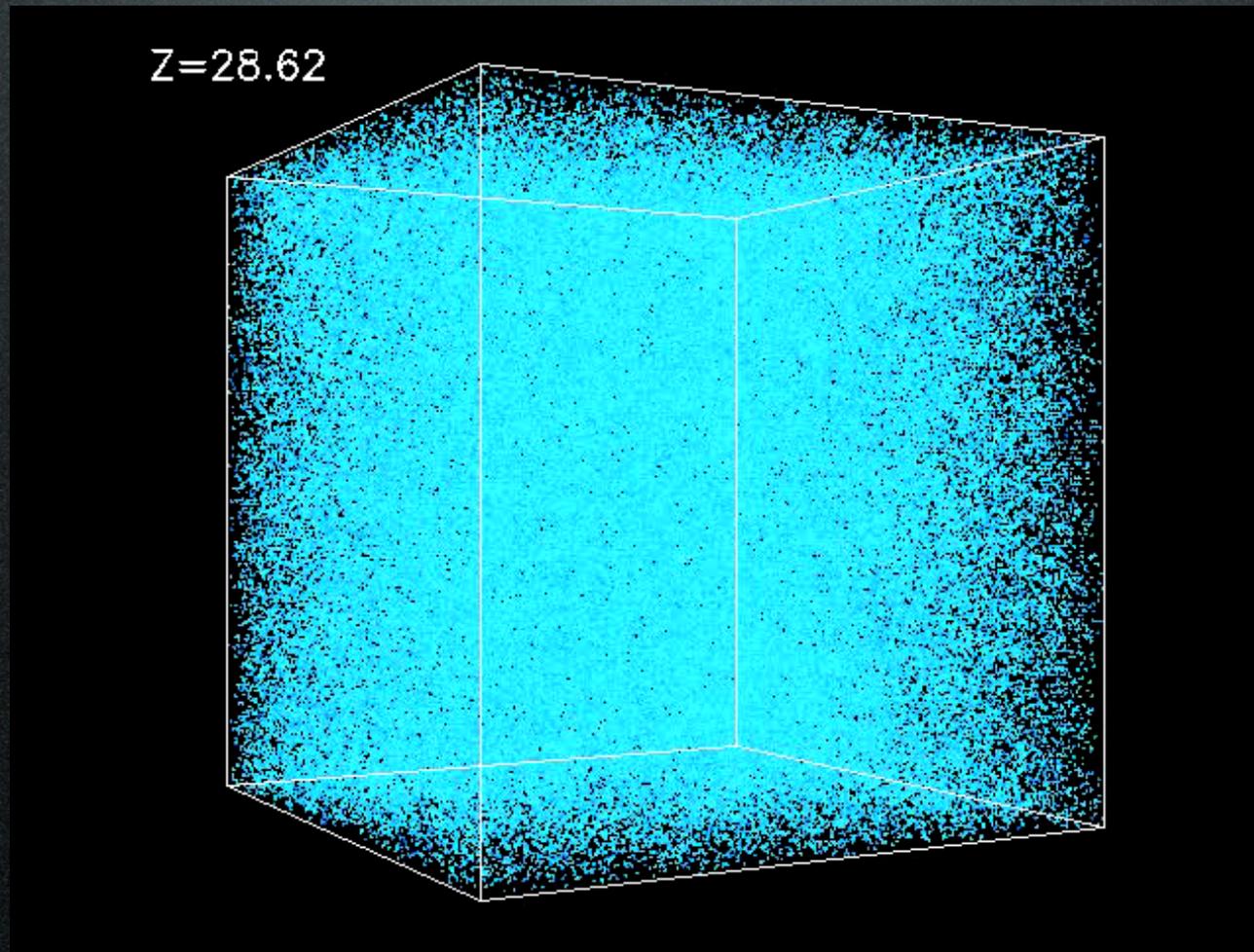




Formazione Galassie, Ammassi (*LSS formation*)

DM N-body simulations

2×10^6 CDM particles, 43 Mpc cubic box



DM N-body simulations

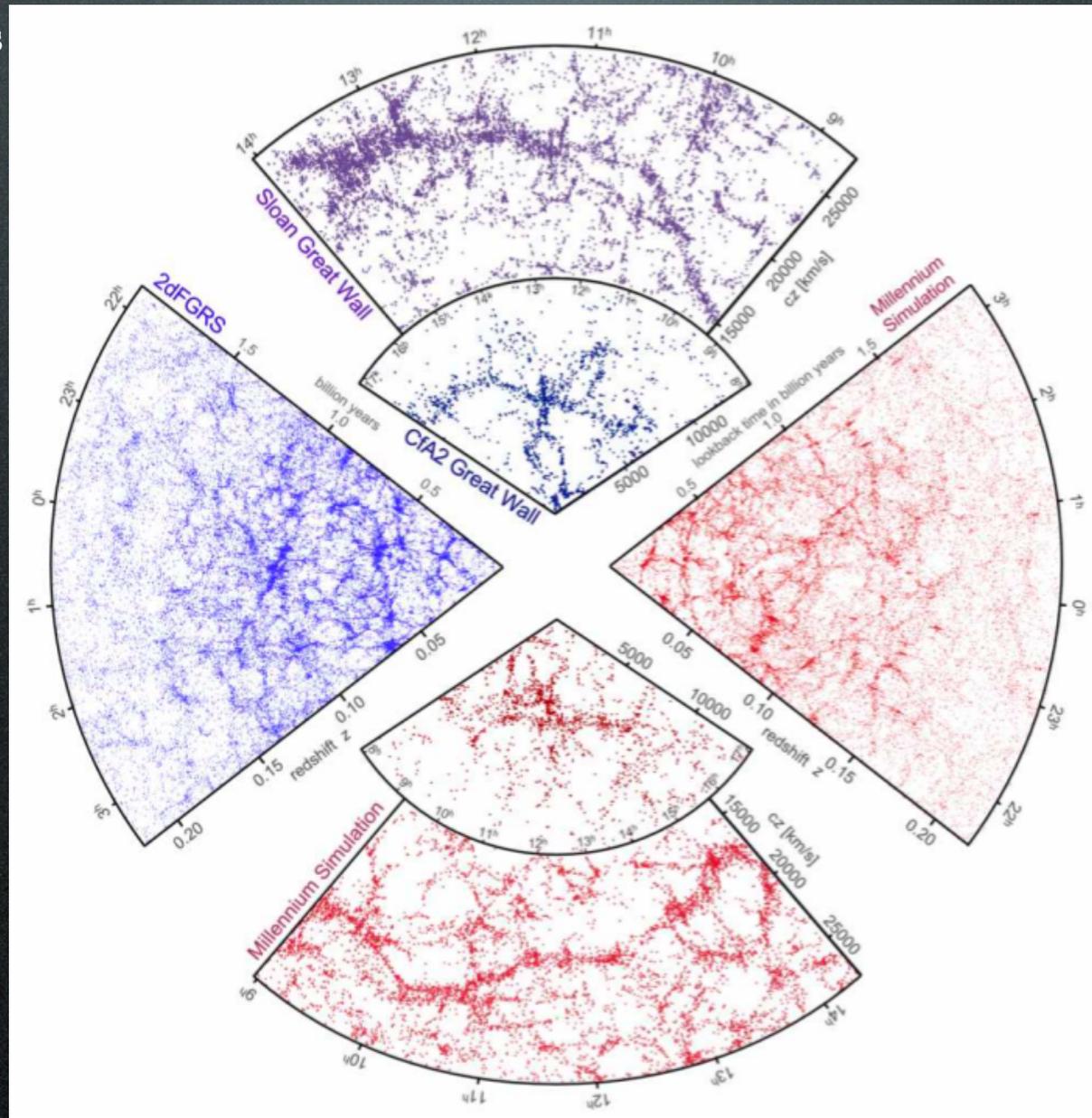
Aquarius project of the VIRGO coll.:

$1.5 \cdot 10^9$ CDM particles, single galactic halo



DM N-body simulations

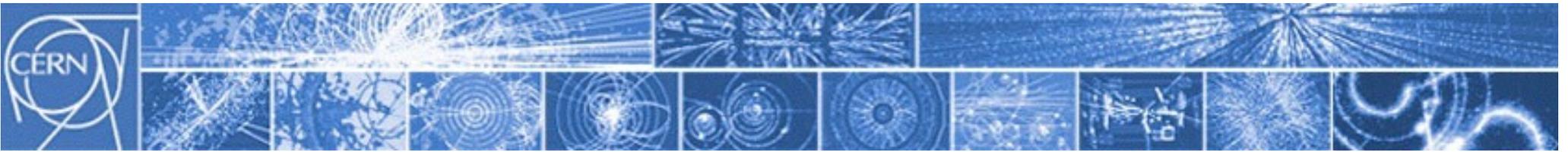
2dF: 2.2×10^5 galaxies
SDSS: 10^6 galaxies,
2 billion yr



Of course, you have to
infer galaxies within the
DM simulation

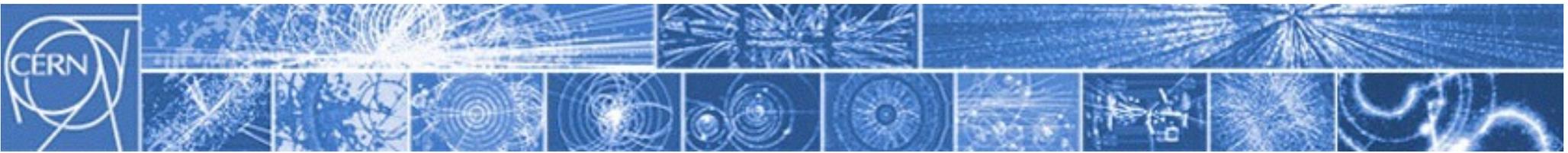
Springel, Frenk, White, Nature 440 (2006)

Millennium:
 10^{10} particles,
 $500 h^{-1}$ Mpc

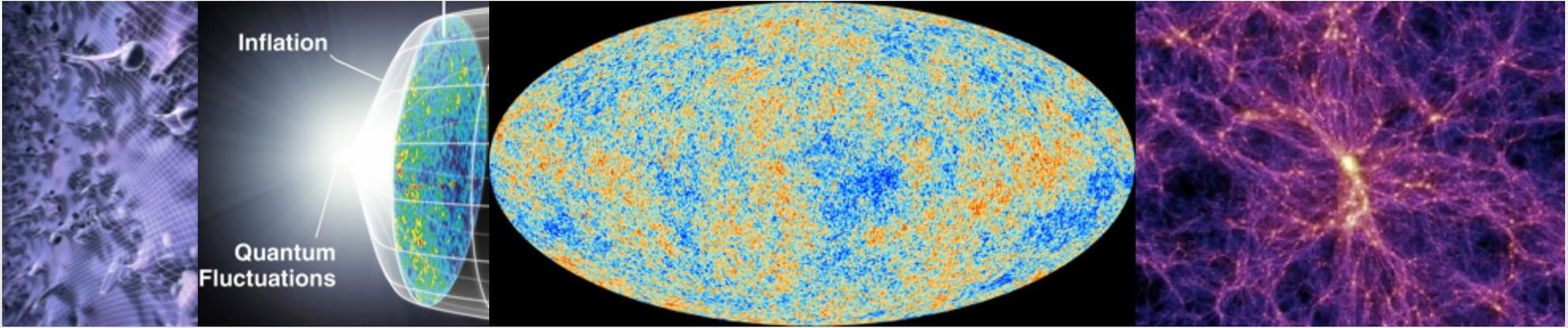


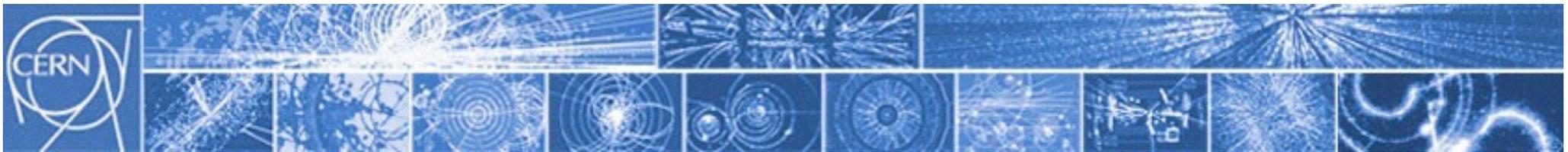
(non in scala!)



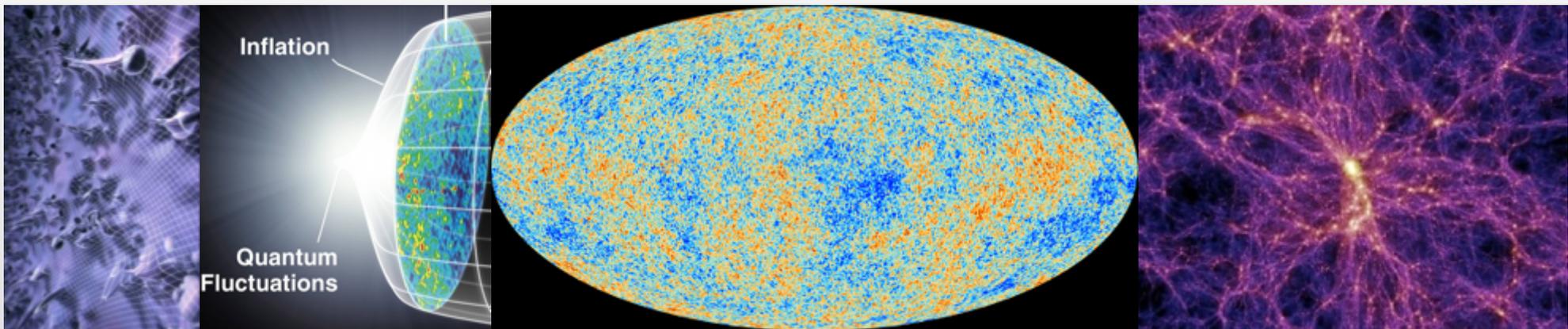


(non in scala!)





(non in scala!)



According to inflation, the more than 100 billion galaxies, sparkling throughout space like heavenly diamonds, are nothing but quantum mechanics writ large across the sky. To me, this realization is one of the greatest wonders of the modern scientific age.

Brian Greene