17 novembre 2018
Société Astronomique de Montgeron

À la recherche de la **Matière Noire**

Marco Cirelli
(CNRS LPTHE Jussieu)

cnrs dépasser les frontières

LPTHE
LABORATOIRE DE PHYSIQUE THEORIQUE ET HAUTES ENERGIES

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CRÉATEURS DE FUTURS DEPUIS 1257

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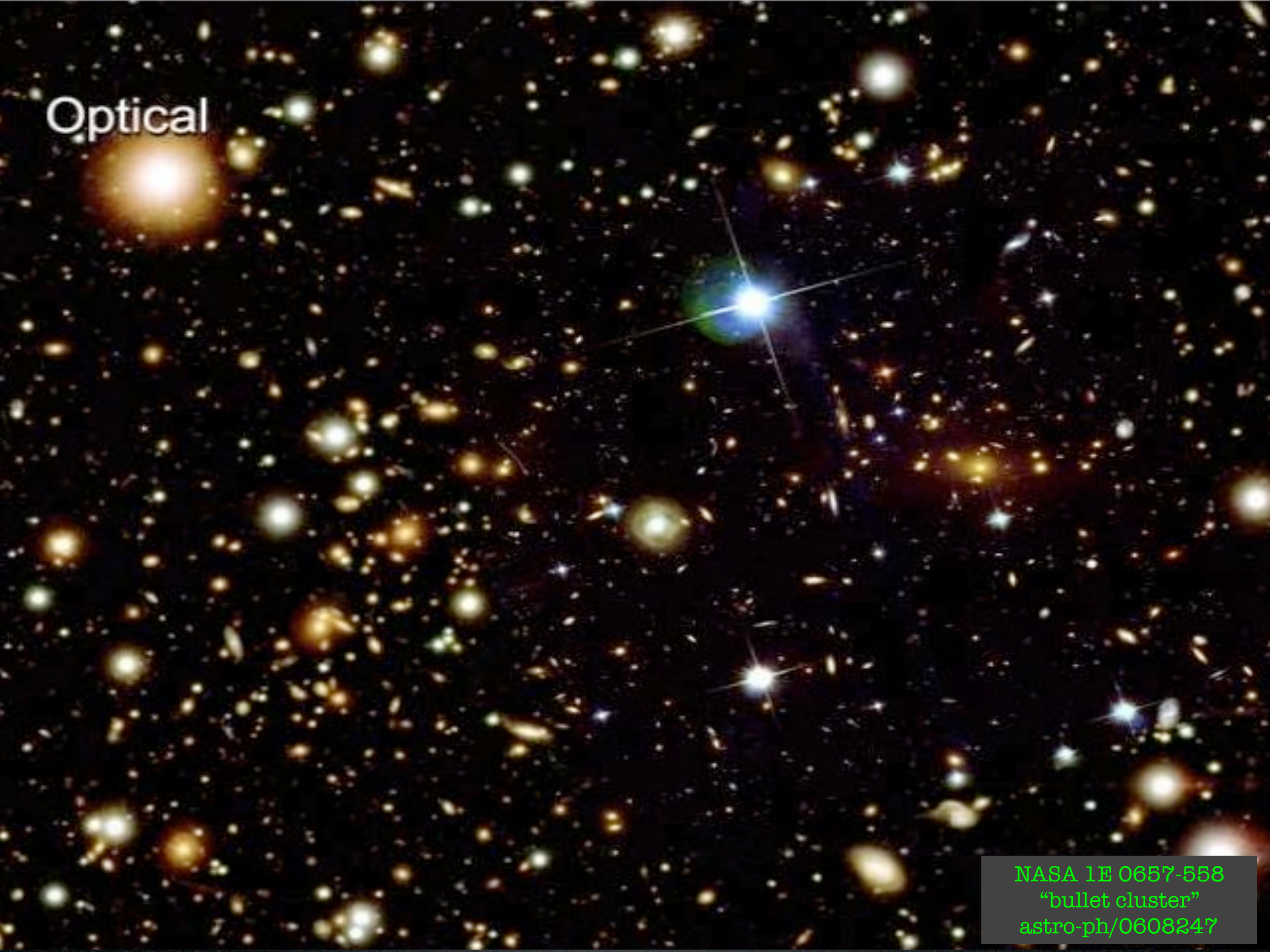
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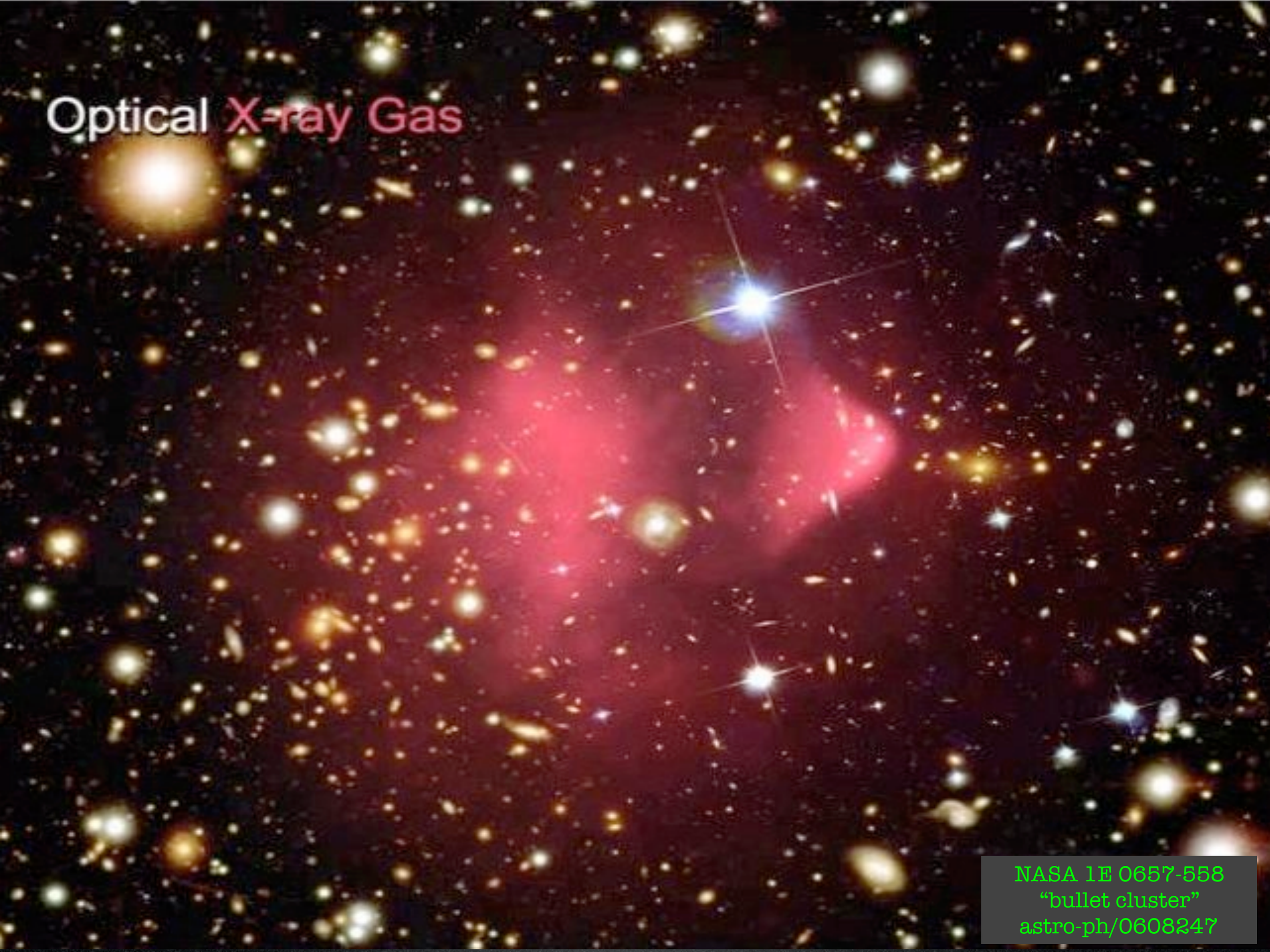
NASA 1E 0657-558
“bullet cluster”
astro-ph/0608247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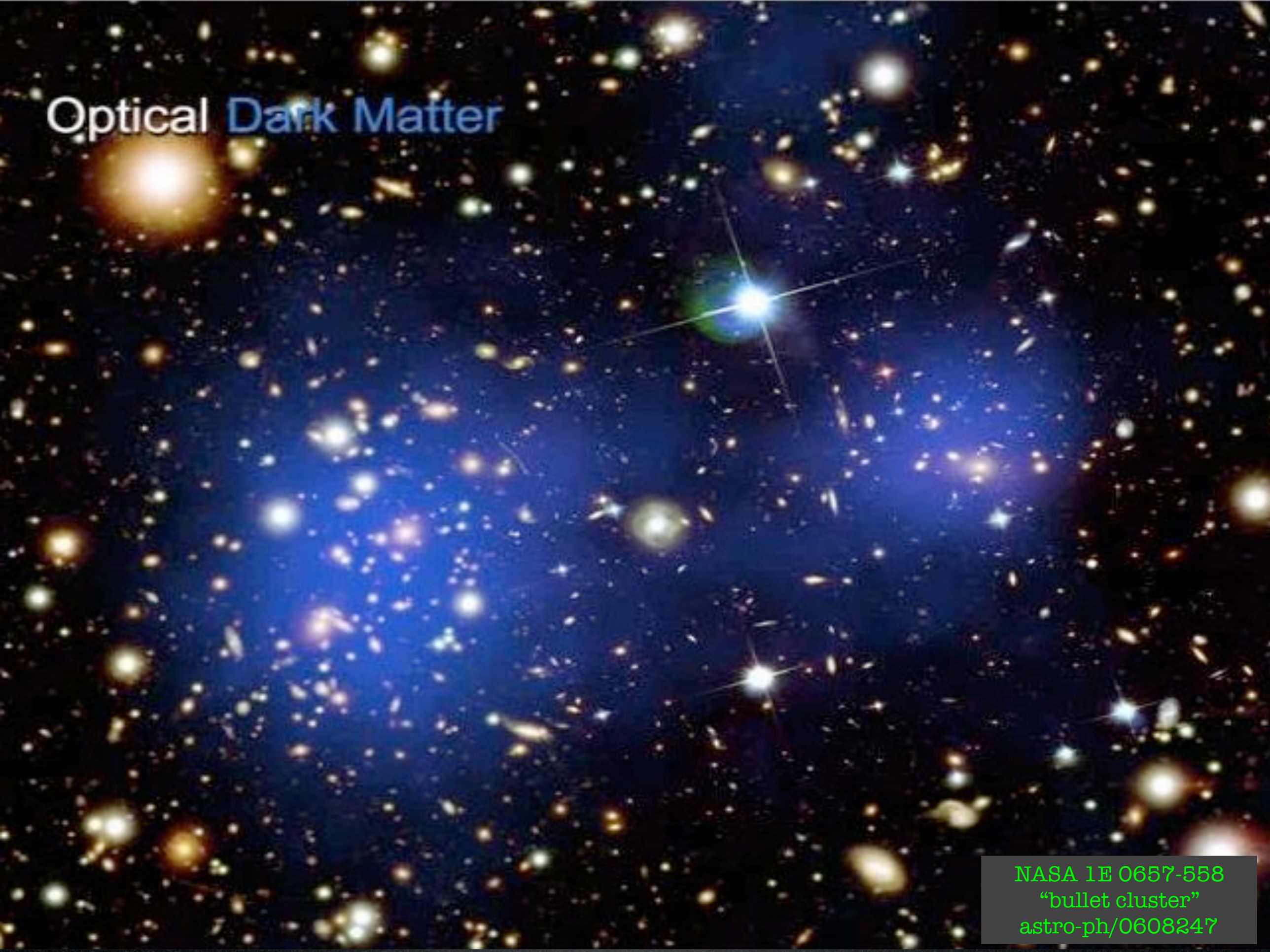
Optical Dark Matter
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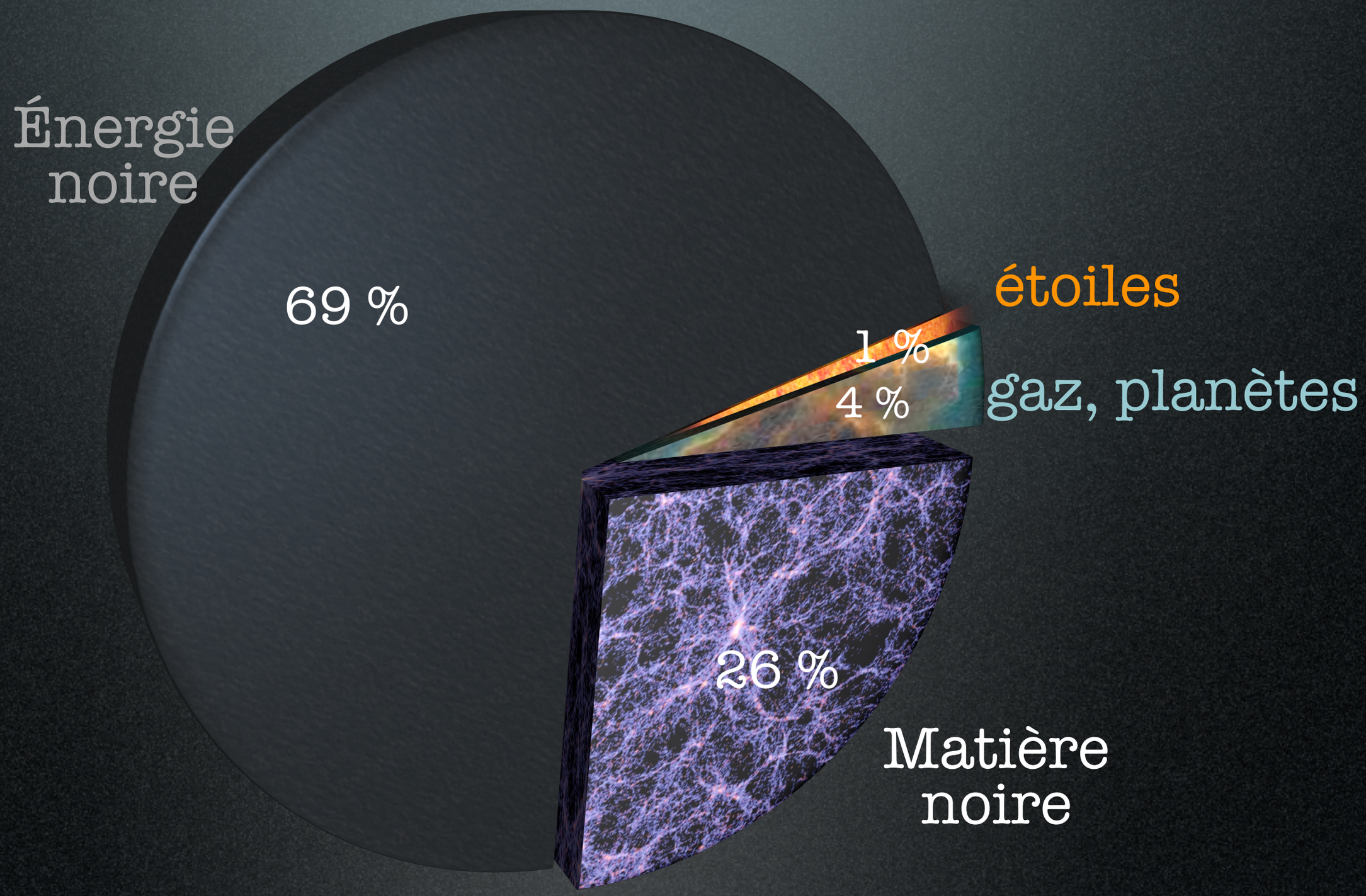
95% de notre Univers est inconnu, noir



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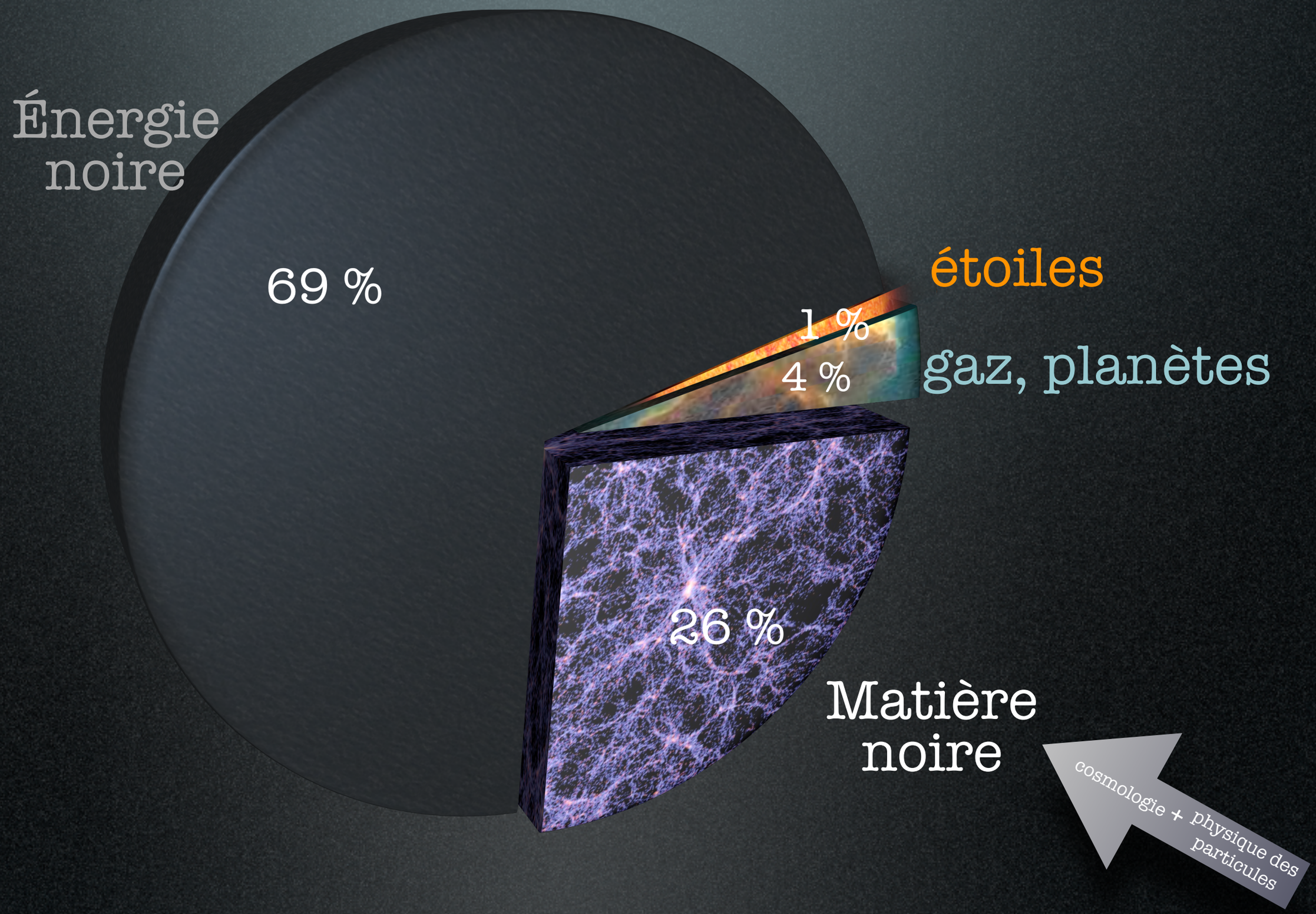


Comment prouver
l'**existence**
de la Matière Noire ?

Preuves d'existence

1) courbes de rotation galactiques

2) amas de galaxies

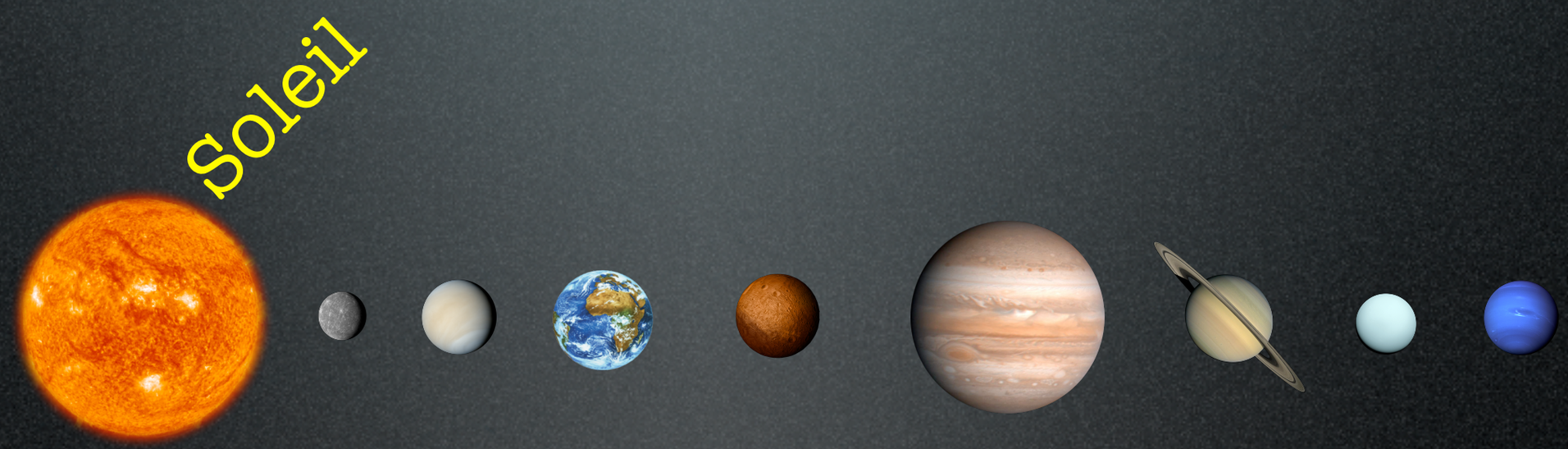
3) 'cosmologie de précision'

Preuves d'existence

1) courbes de rotation galactiques

Preuves d'existence

1) courbes de rotation galactiques



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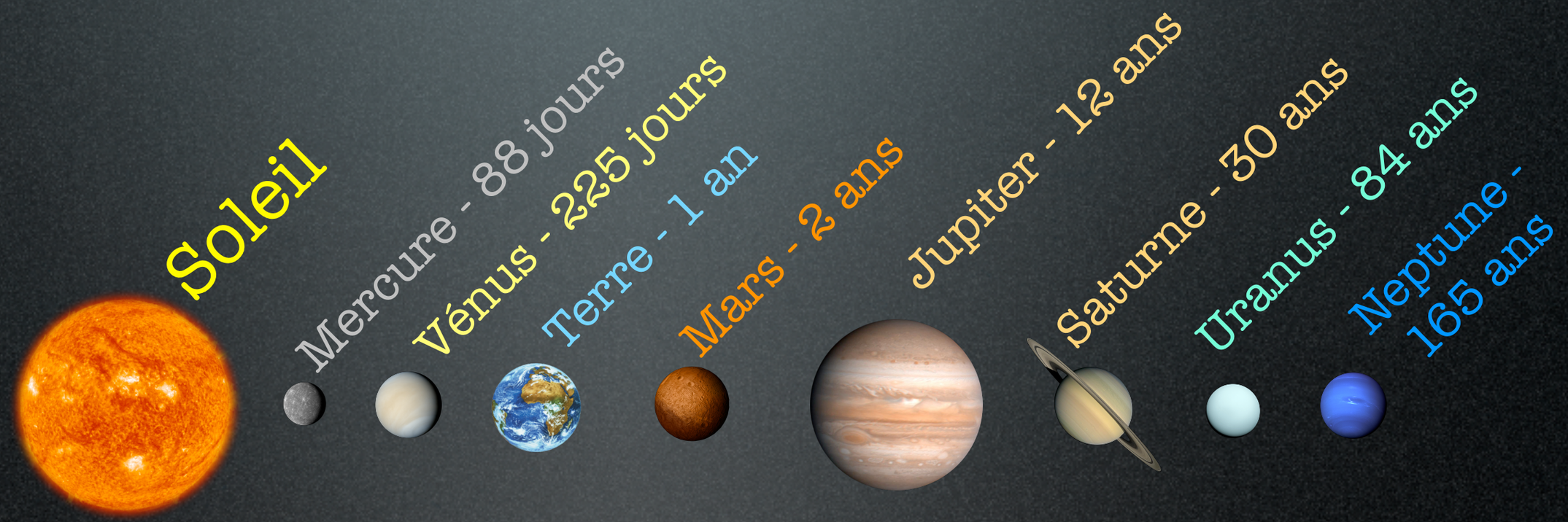

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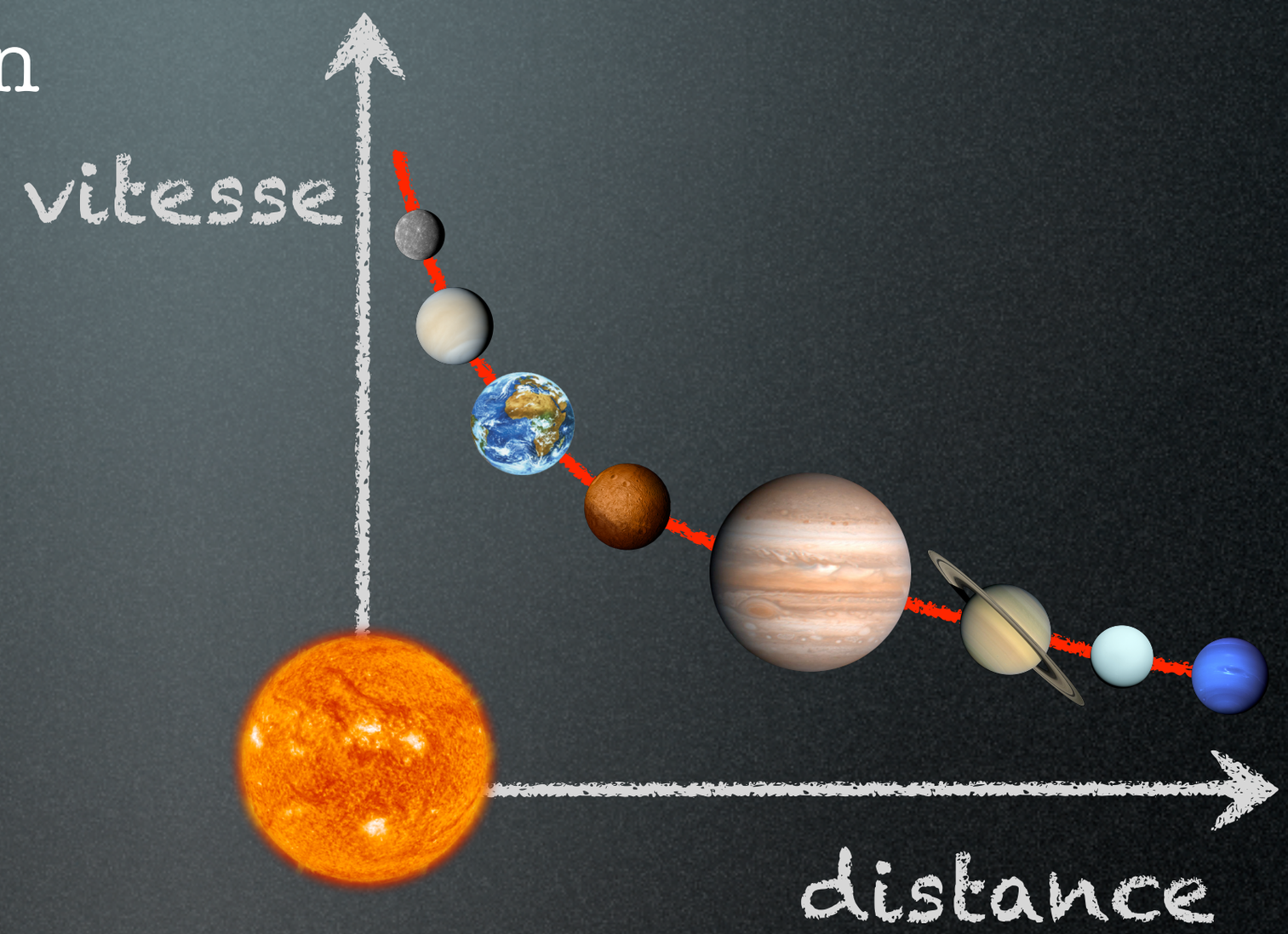

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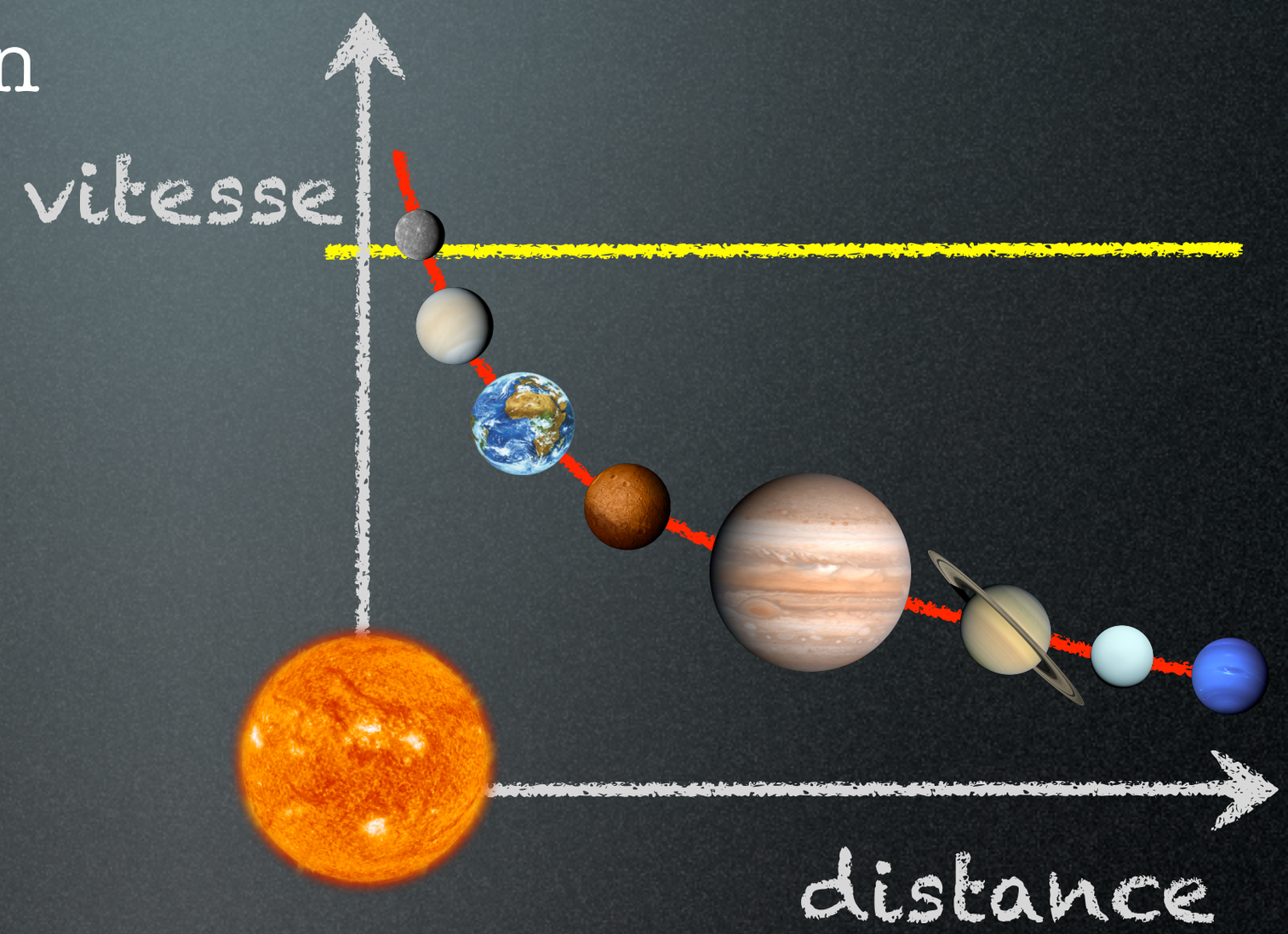

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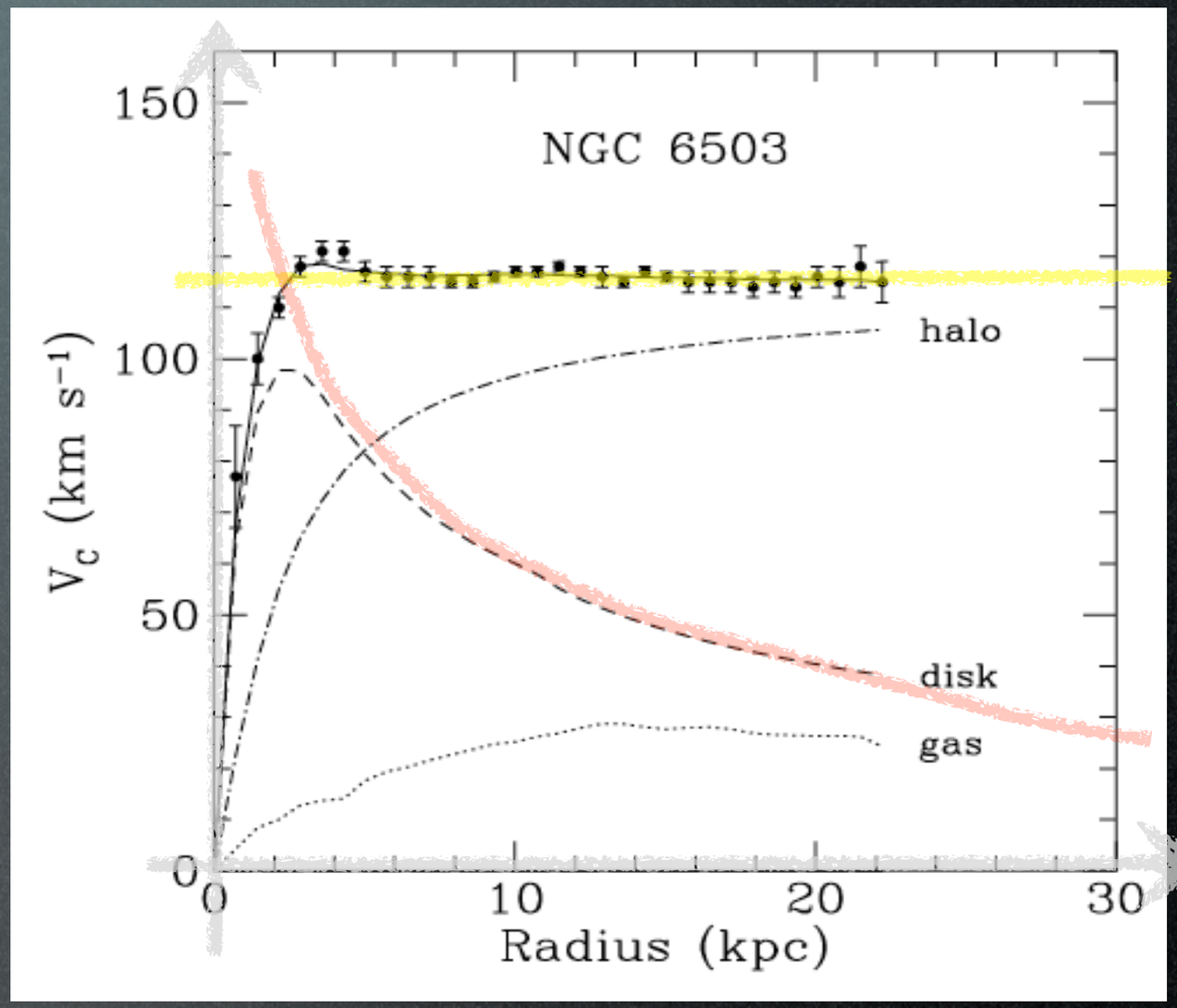
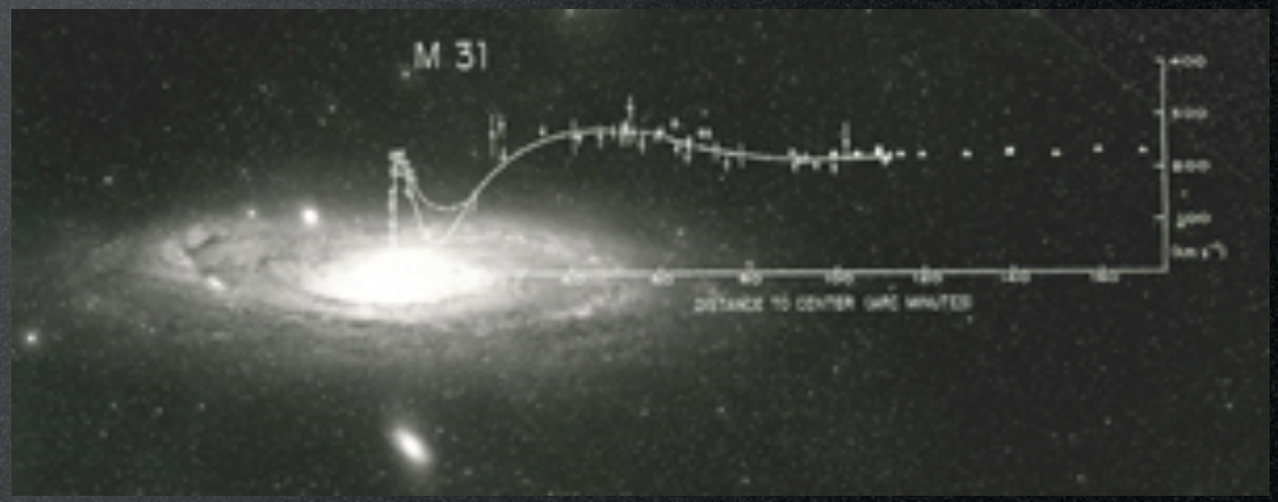


Begeman et al., MNRAS 249 (1991)



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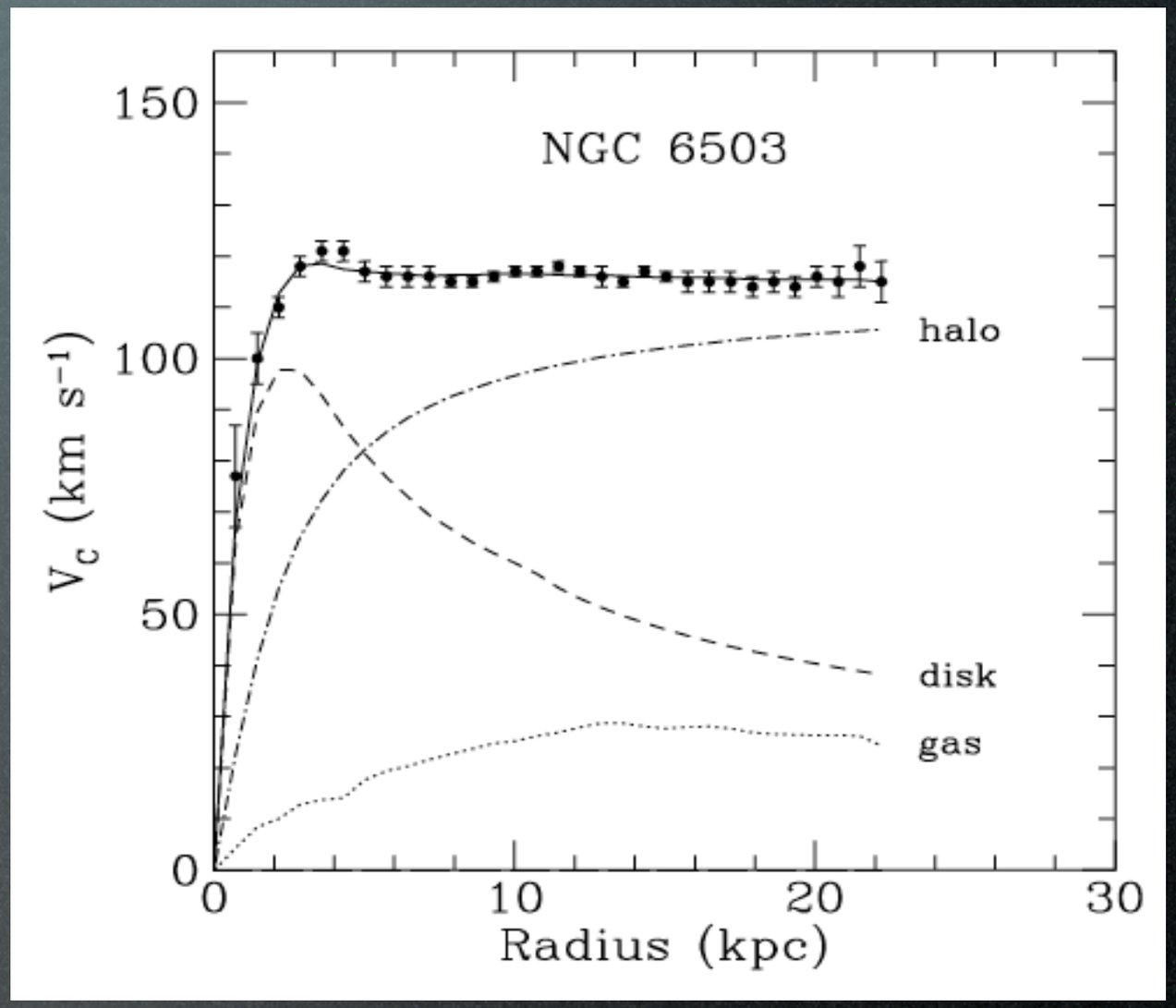
'centrifuge' 'centripète'



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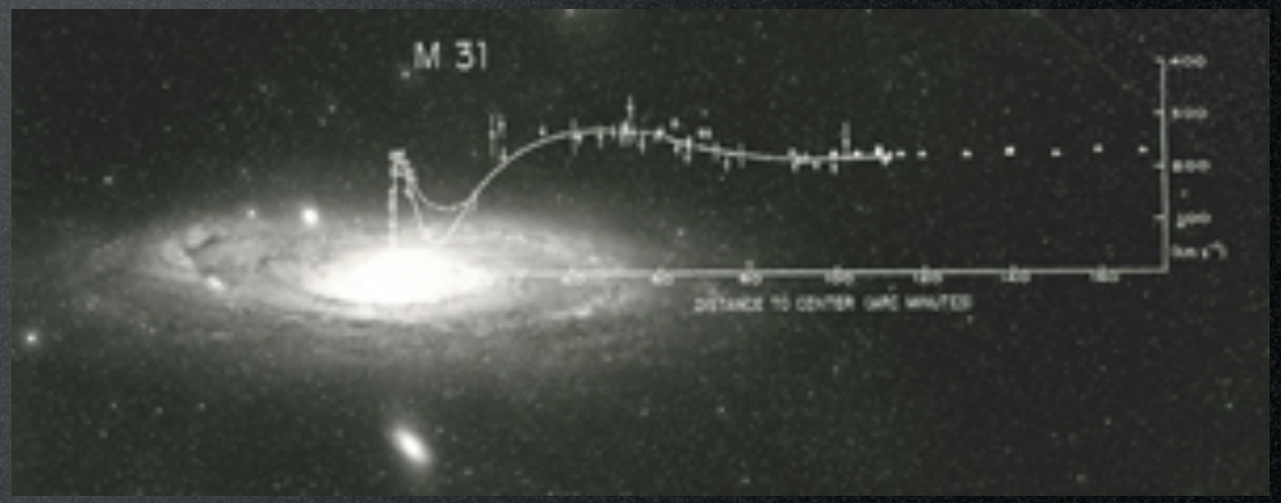

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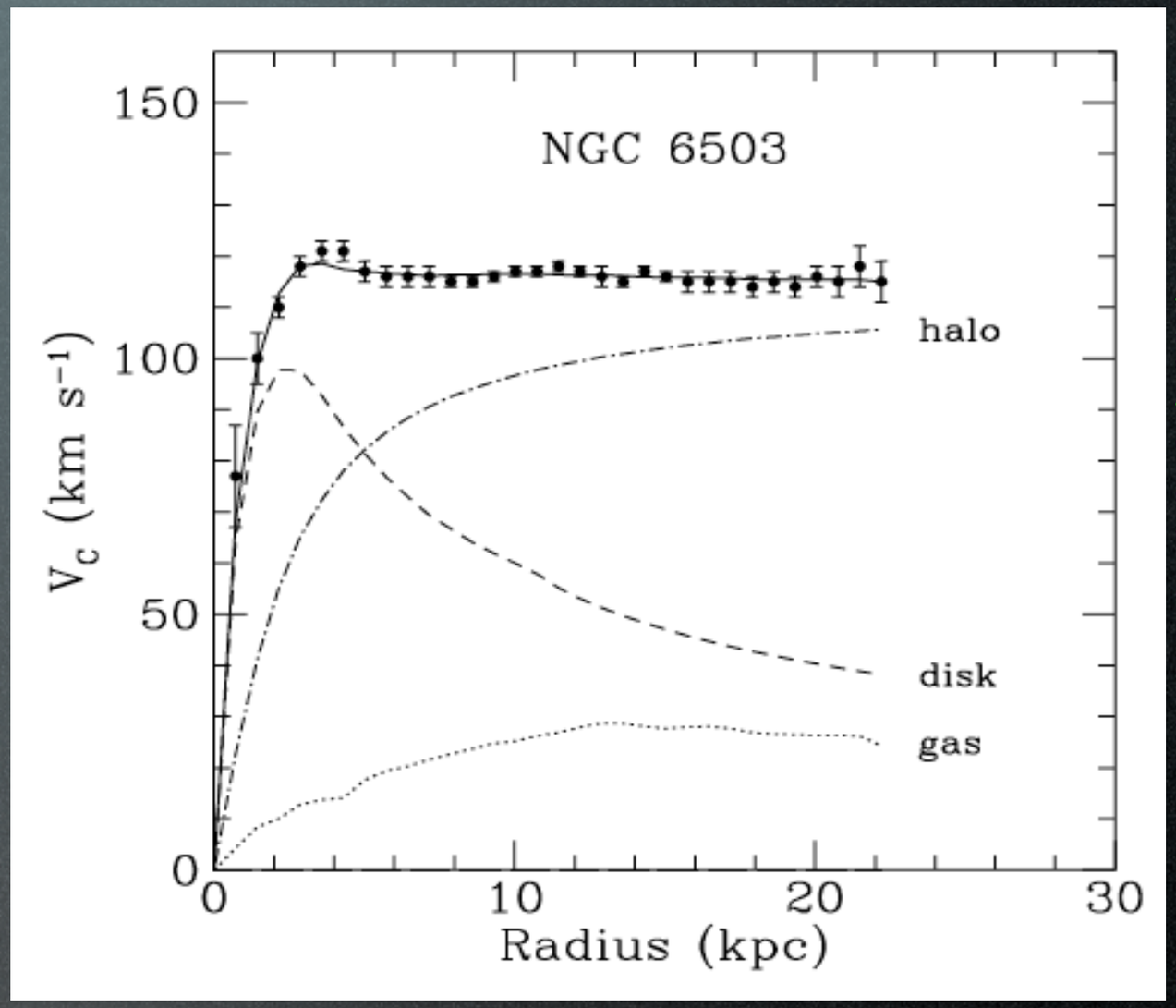

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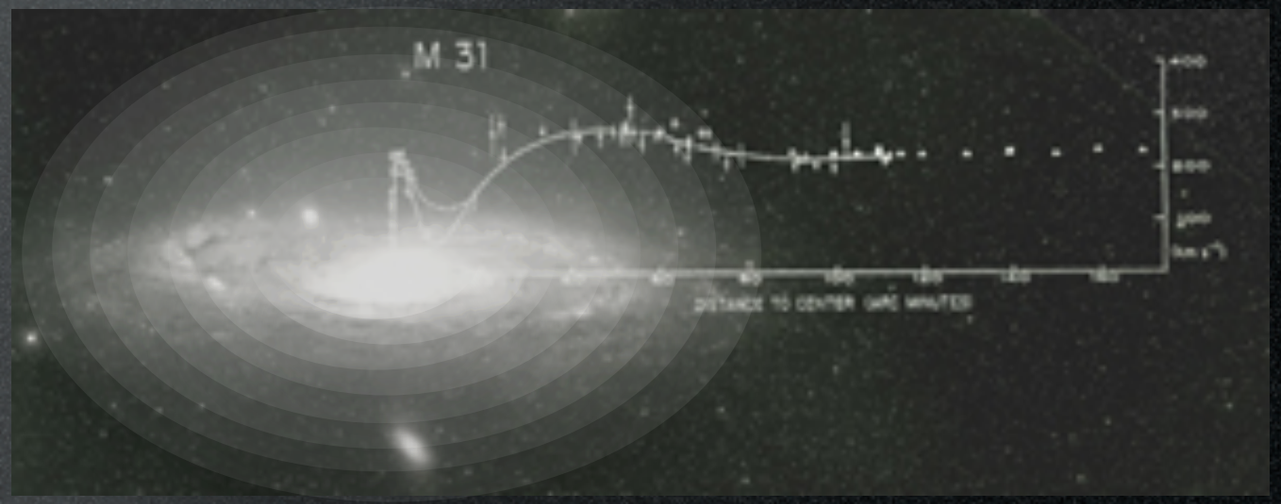

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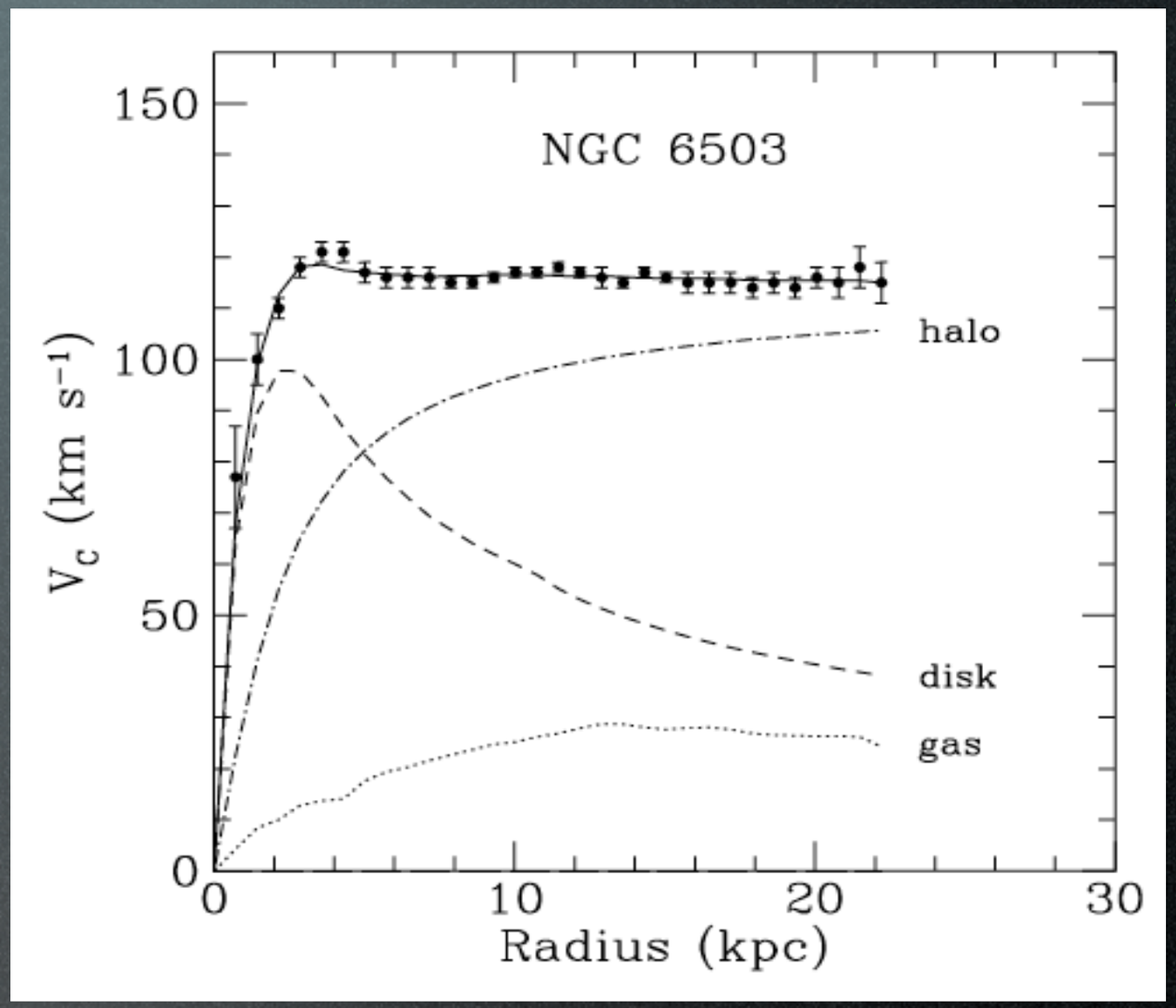

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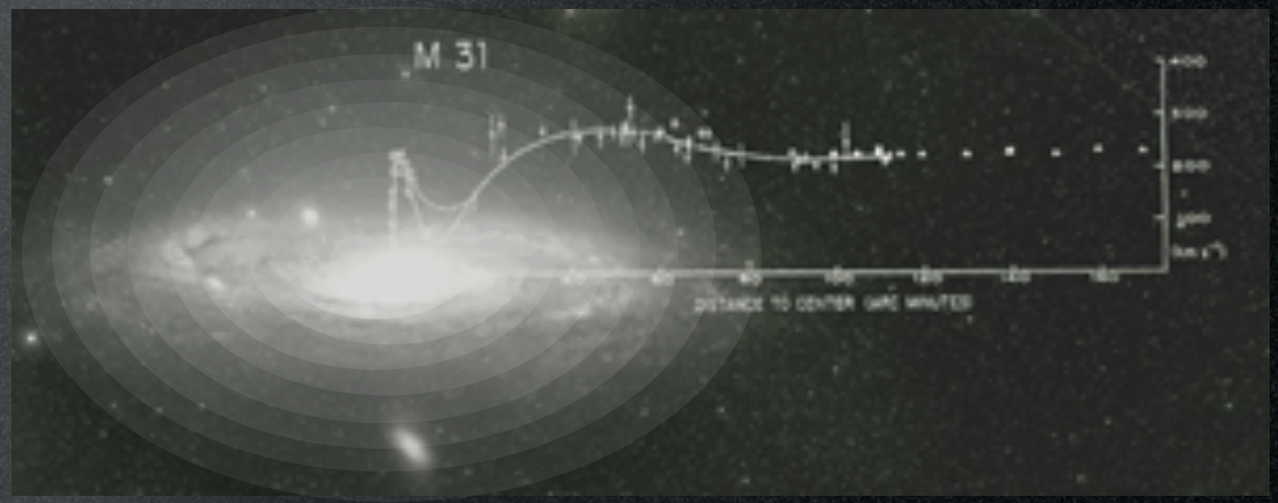

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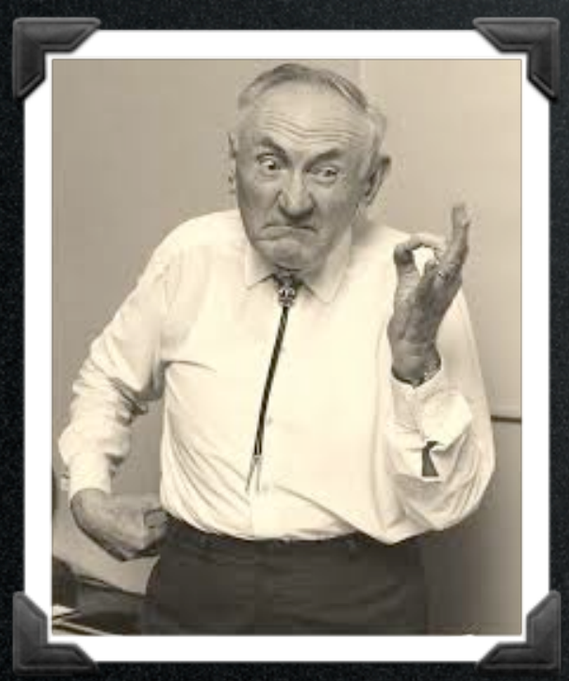

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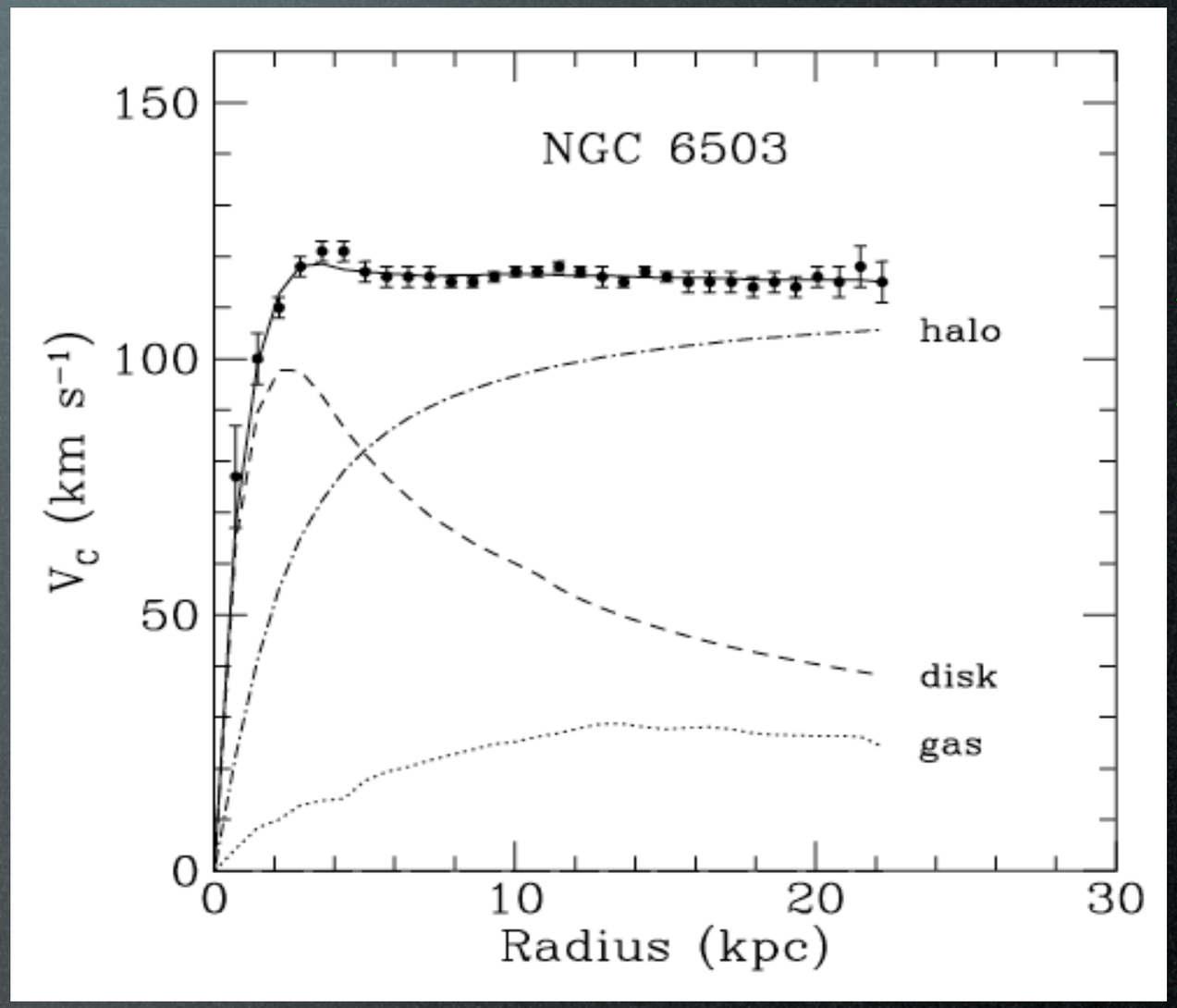

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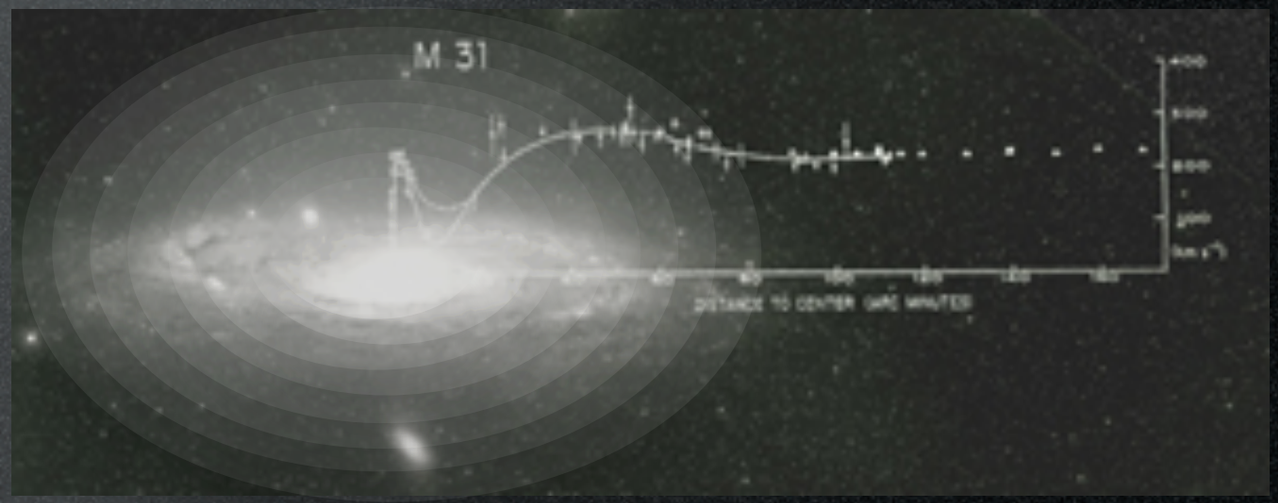

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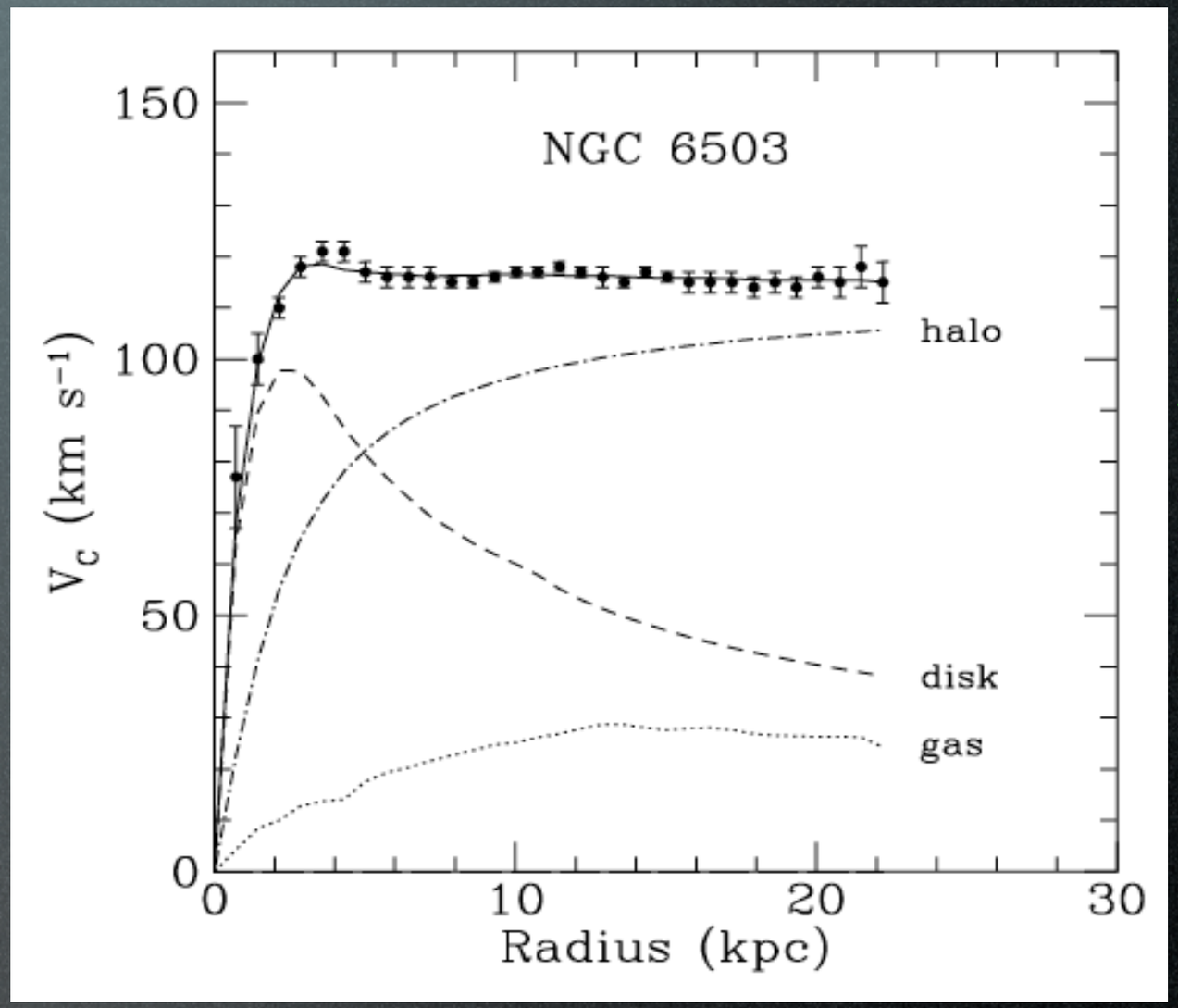

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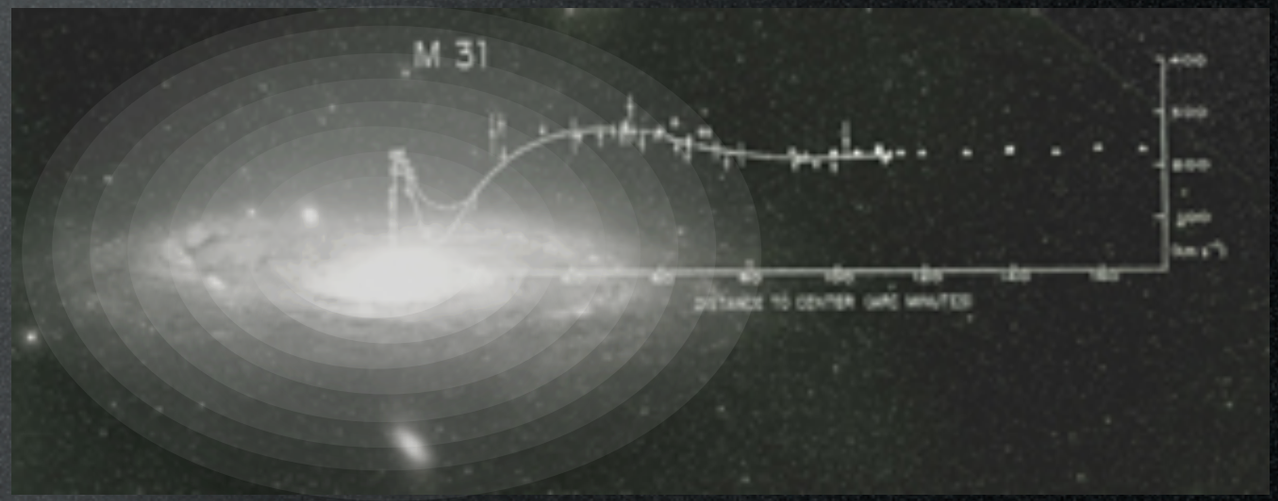

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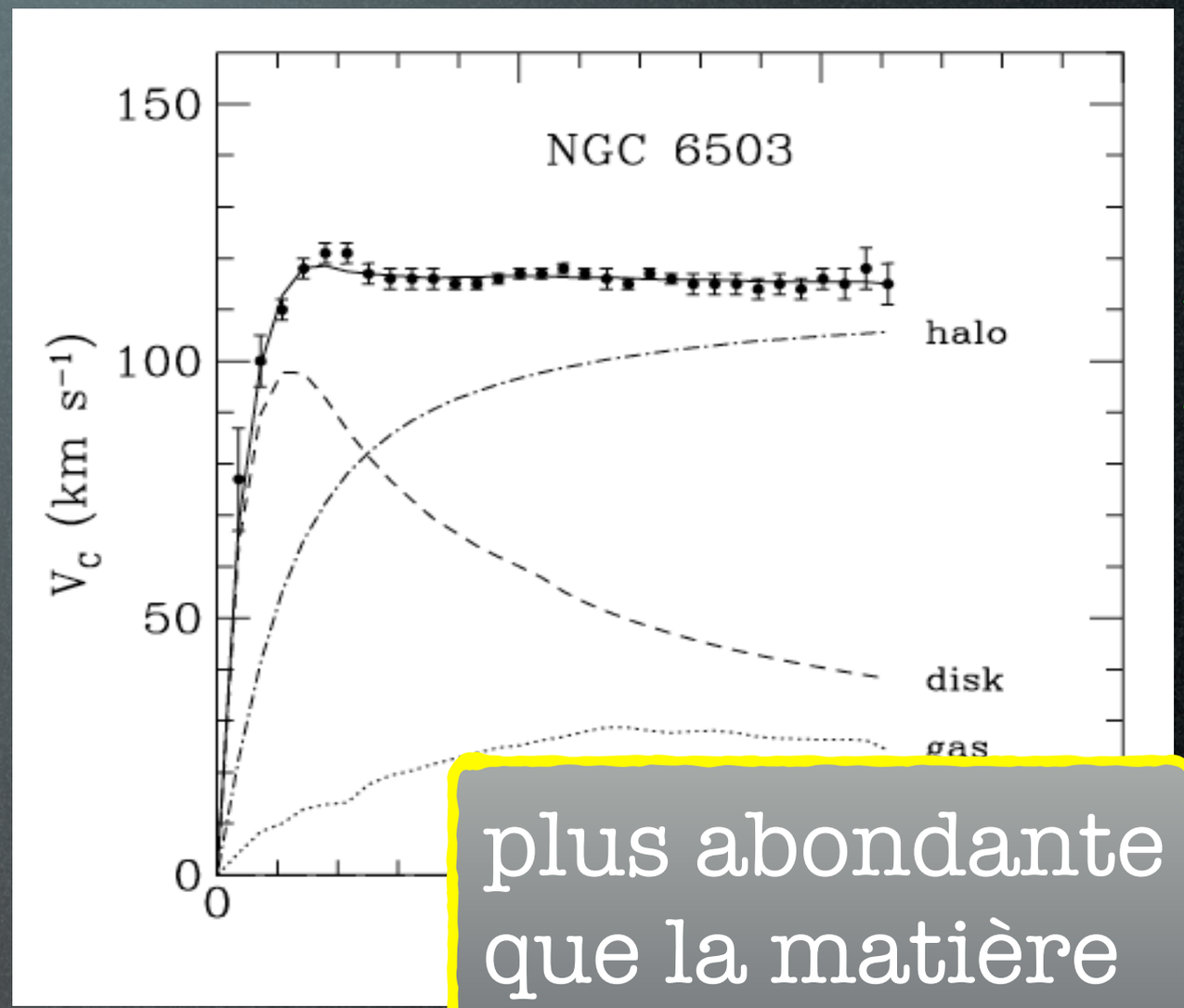

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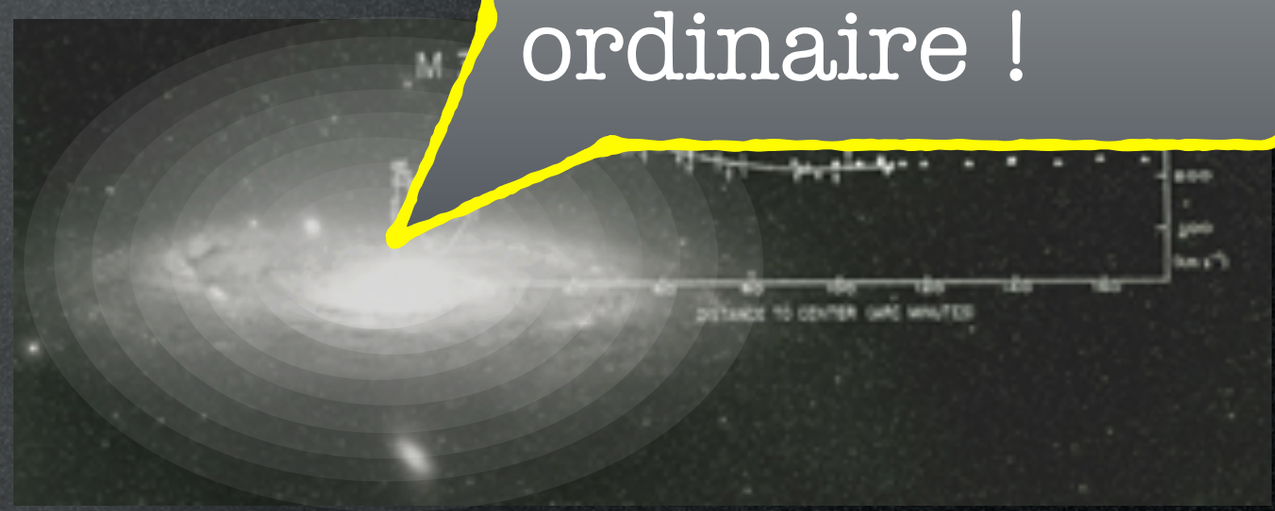
plus abondante que la matière ordinaire !



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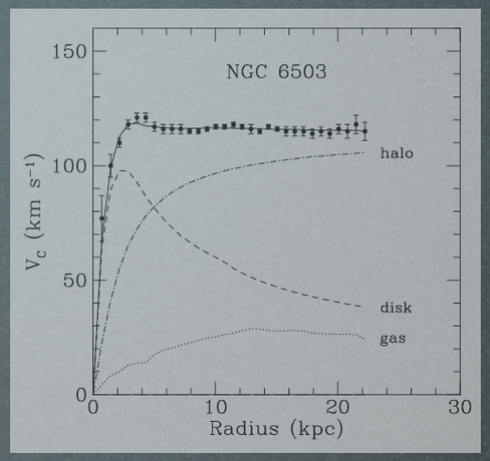

2) amas de galaxies

- lentille gravitationnelle

"bullet cluster" - NASA
astro-ph/0608247

[further developments]

Preuves d'existence

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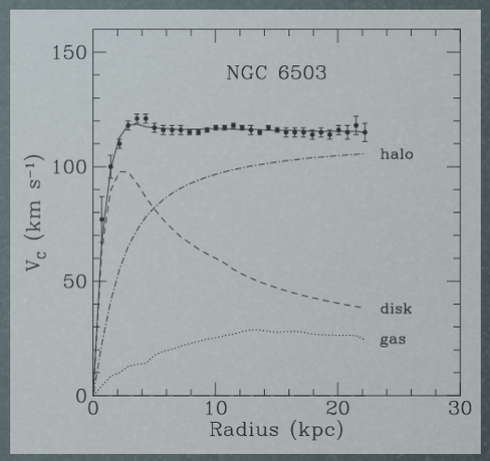

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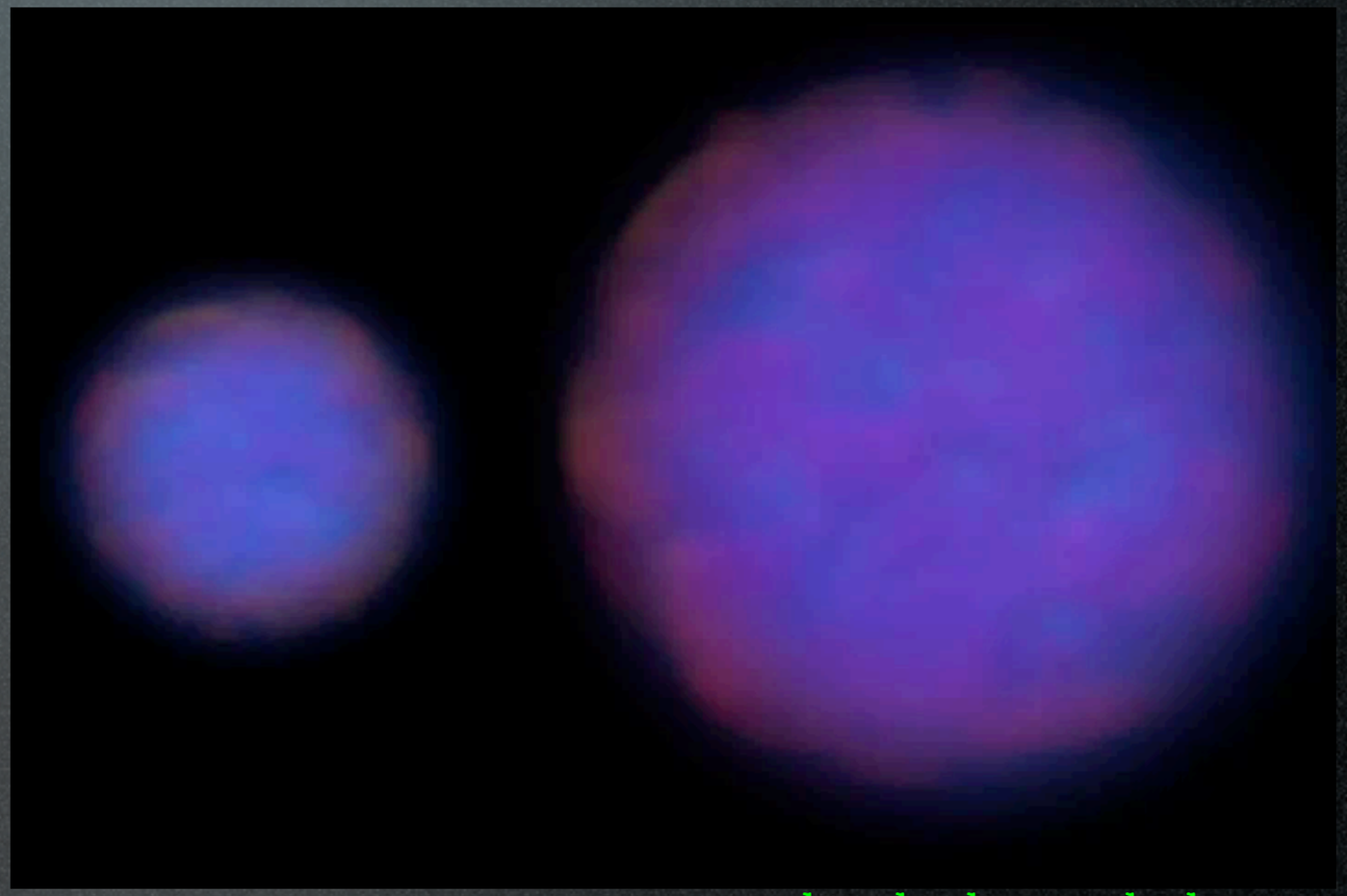

chandra.harvard.edu

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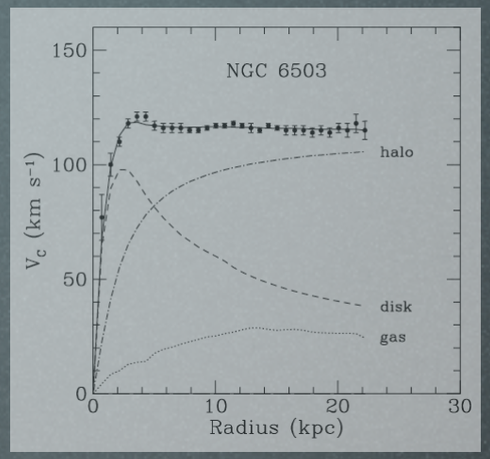

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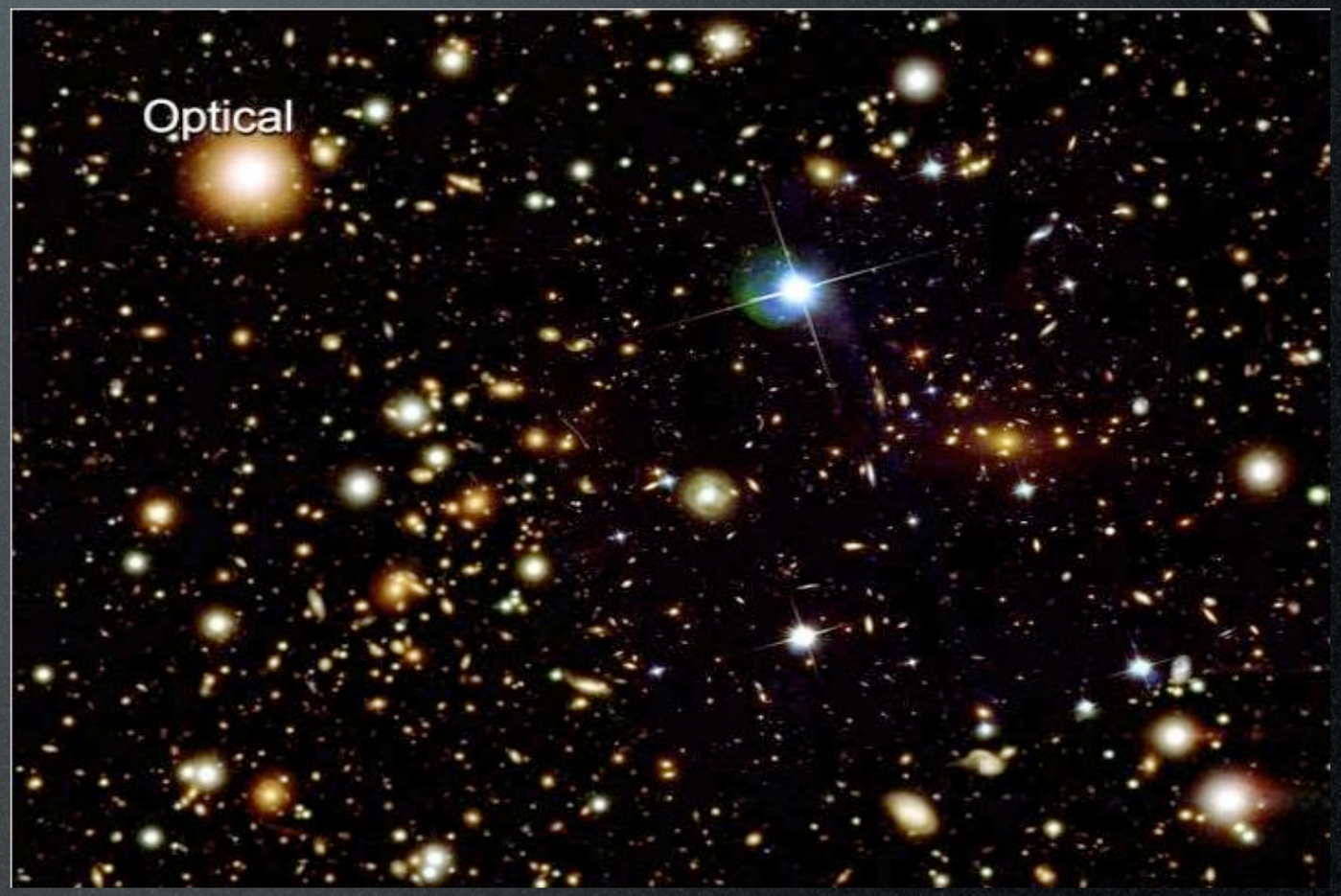

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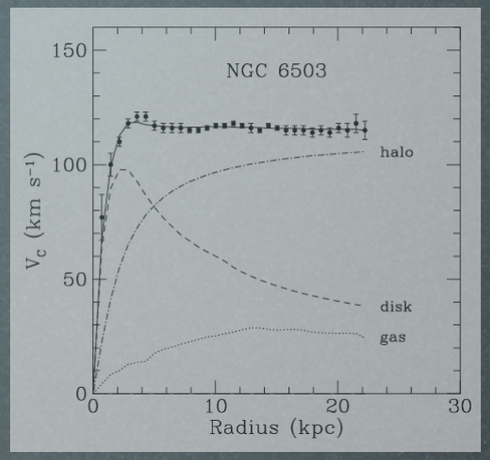

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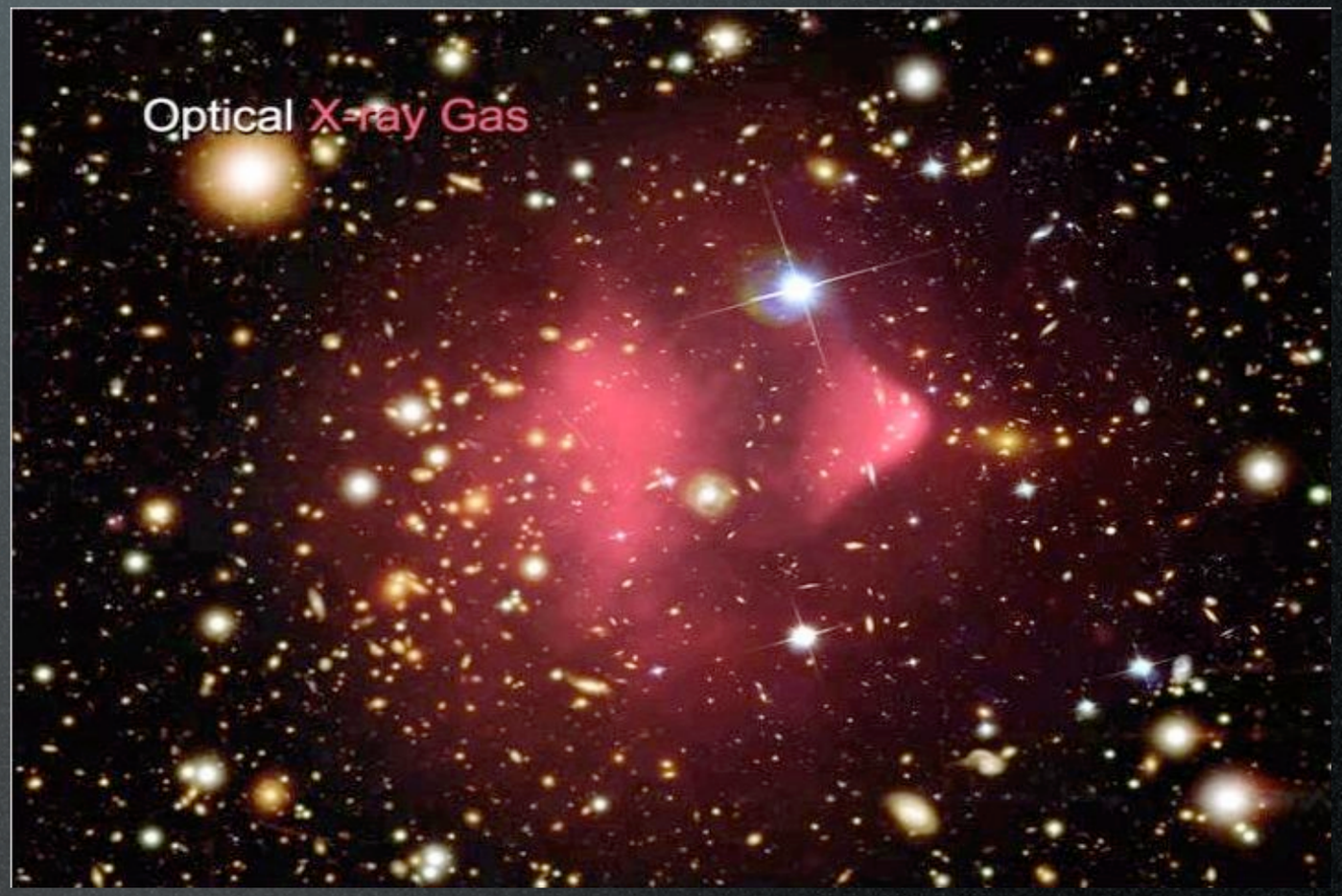

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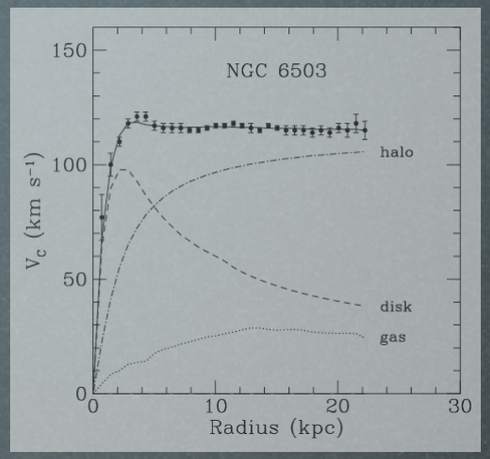

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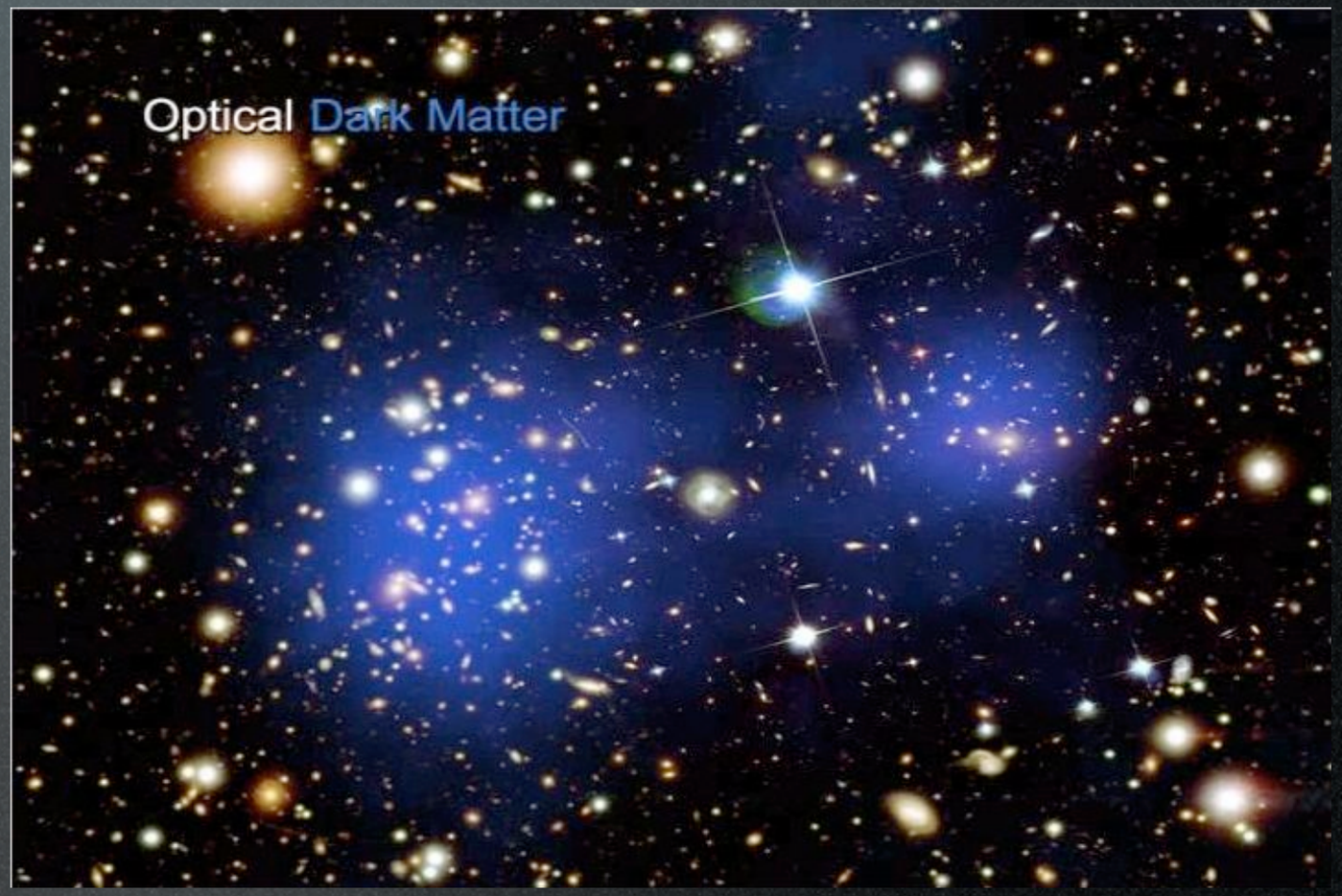

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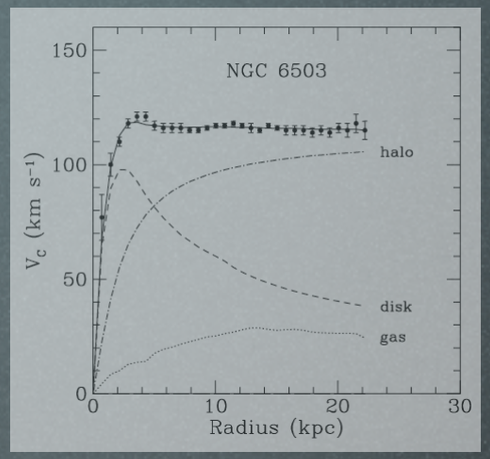

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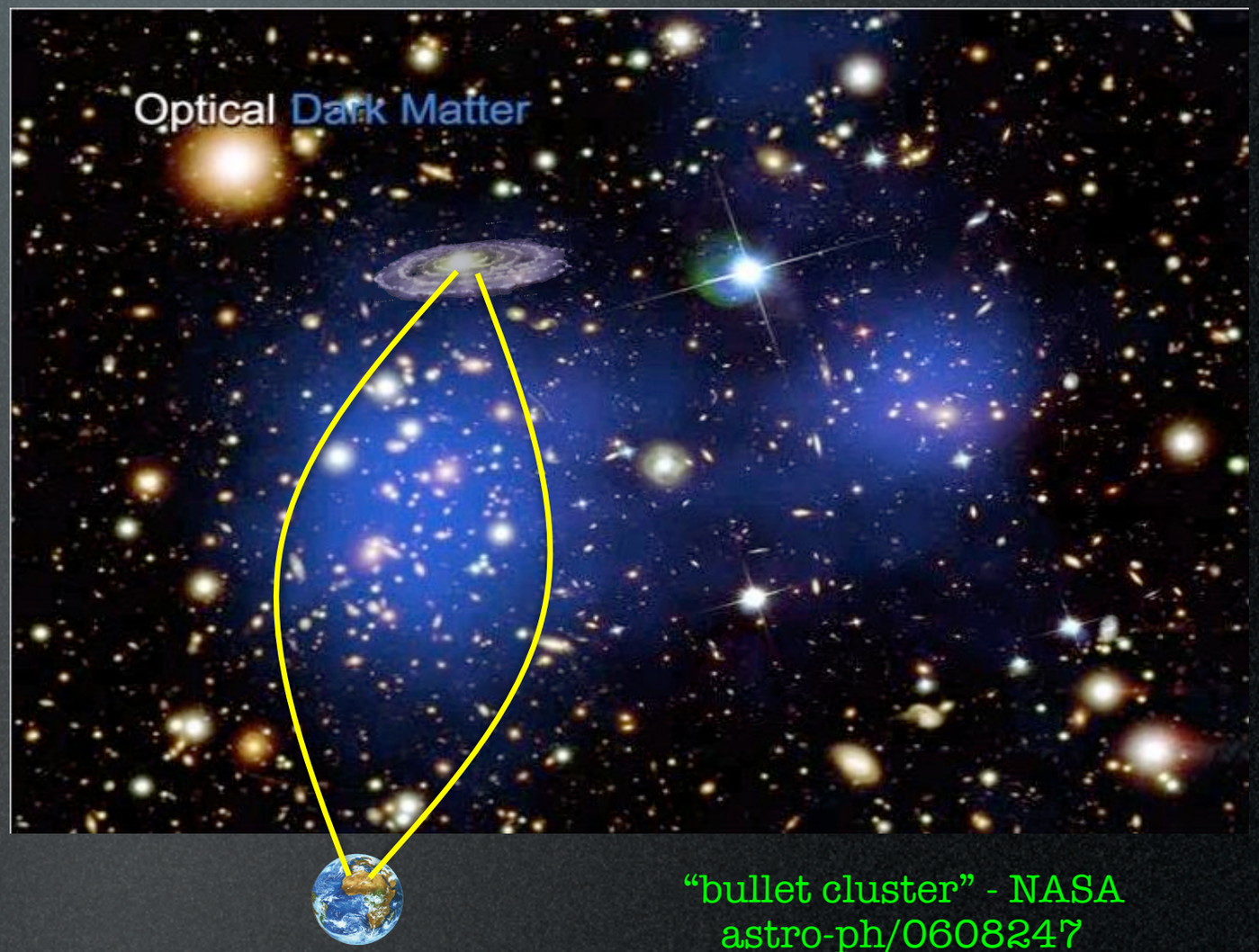

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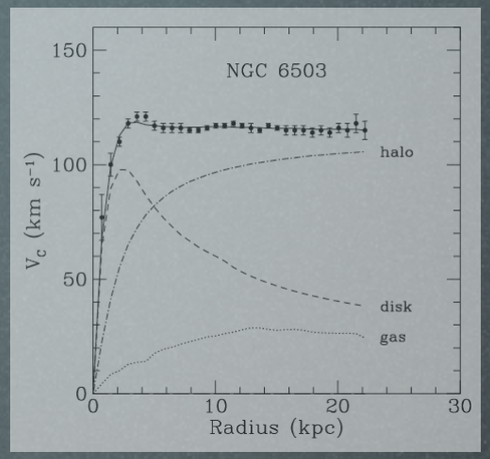

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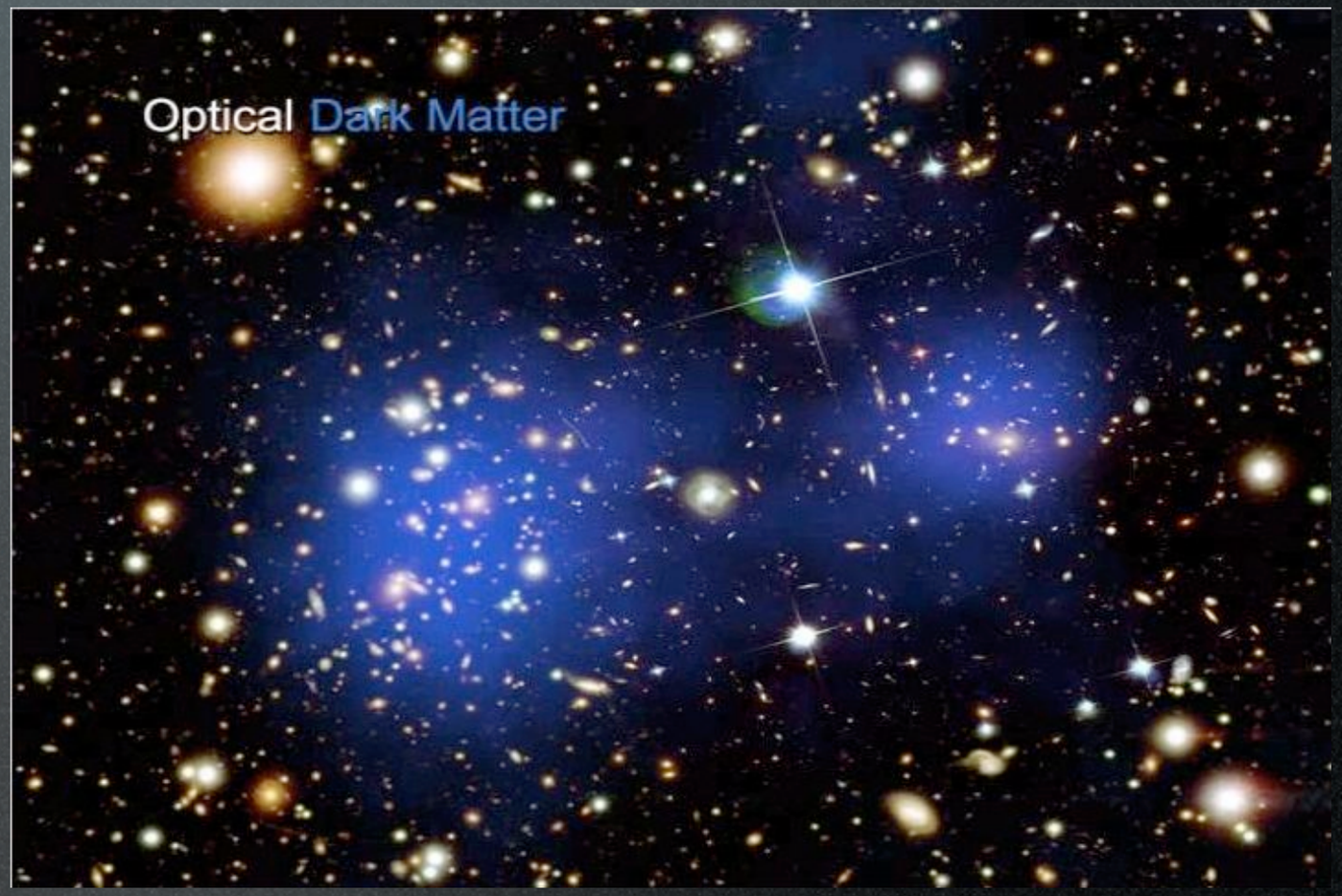

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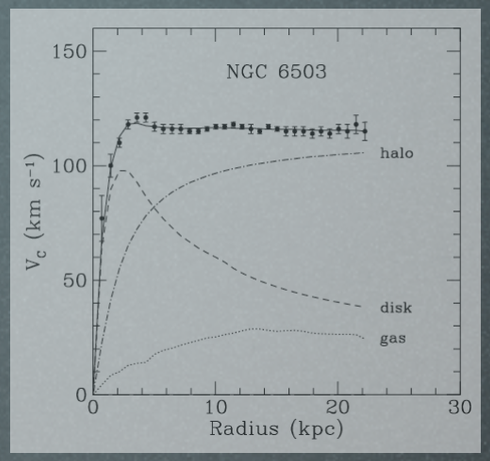

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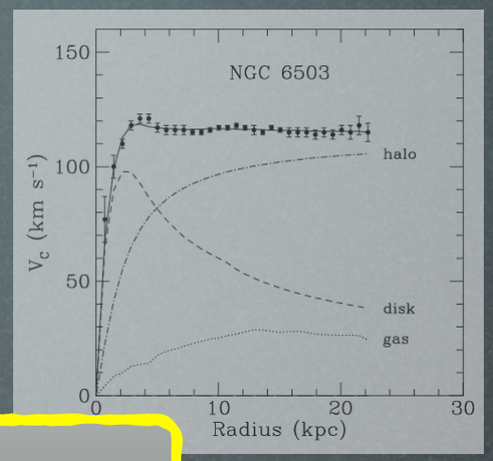

2) ar

- lo

n'émet pas de lumière, elle est 'neutre'

aucune ou très peu d'interaction

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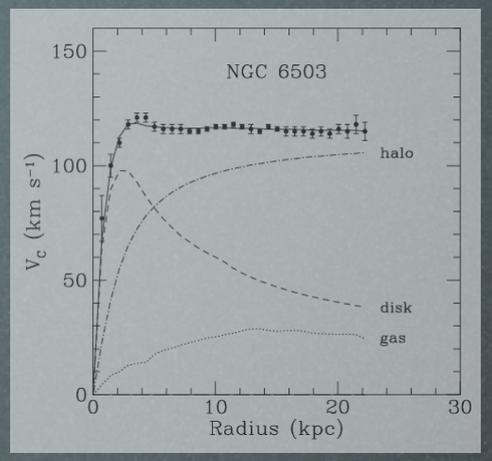

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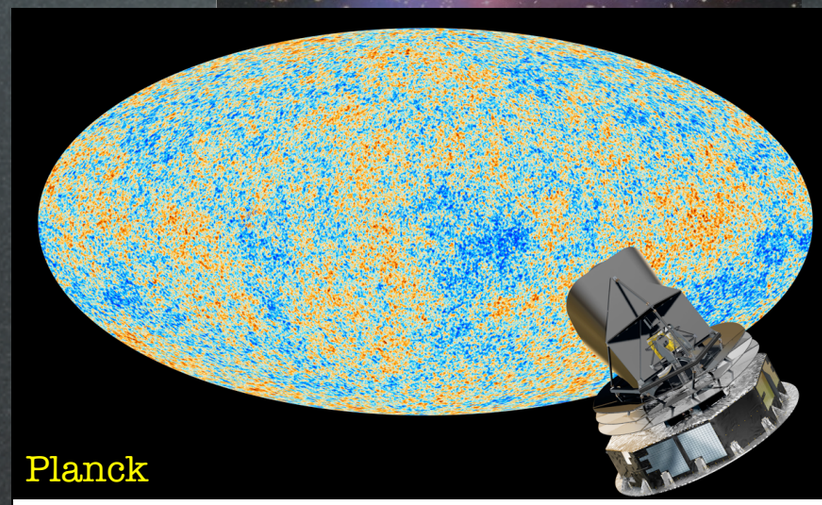

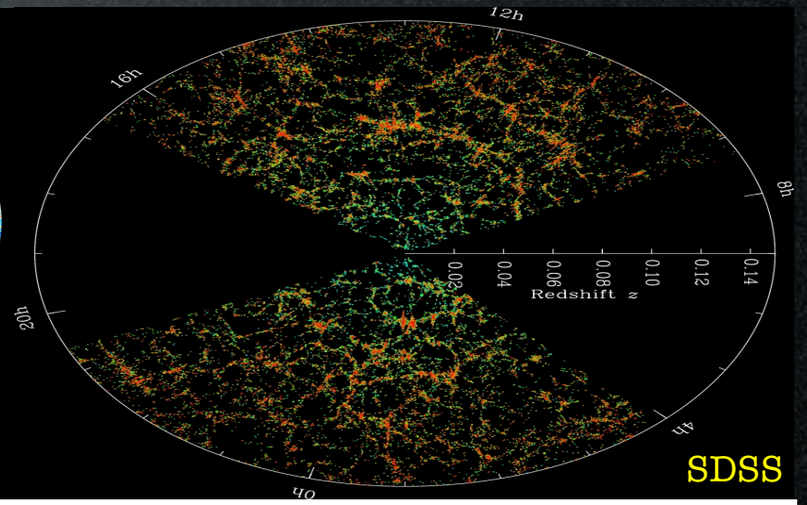

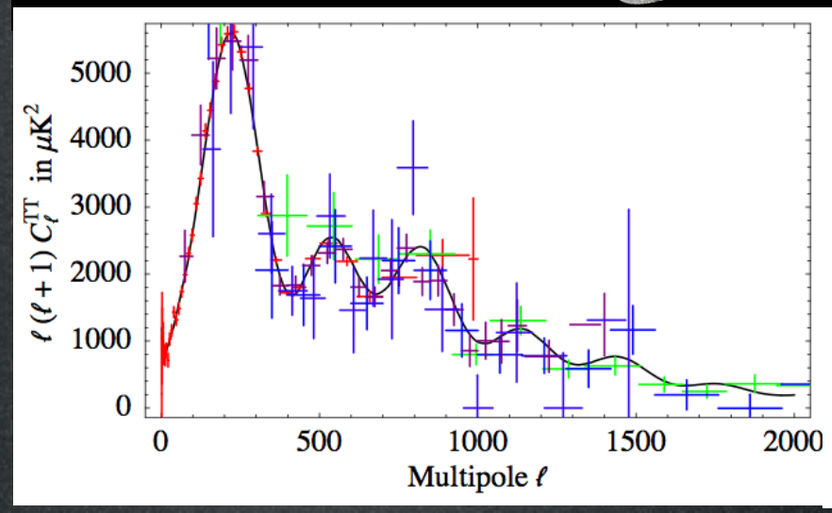

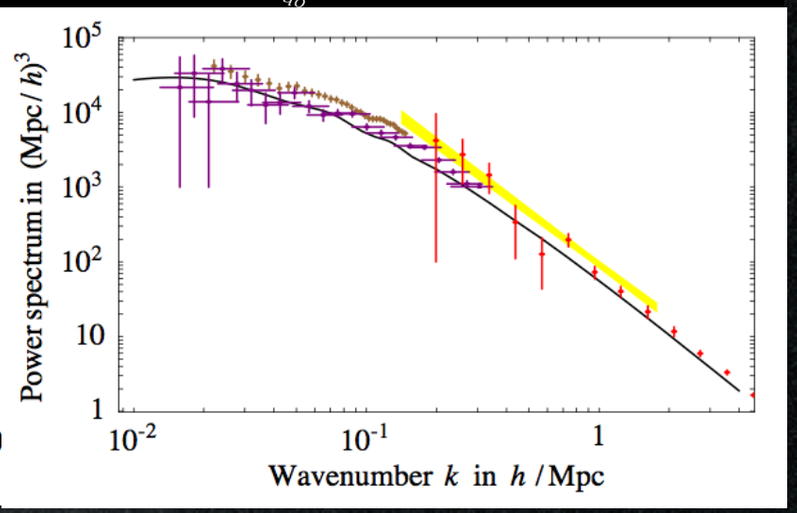

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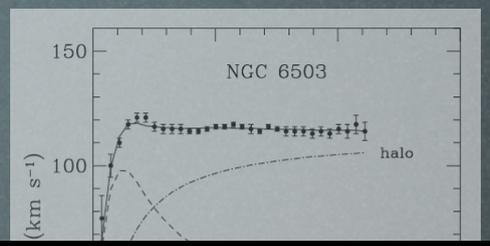
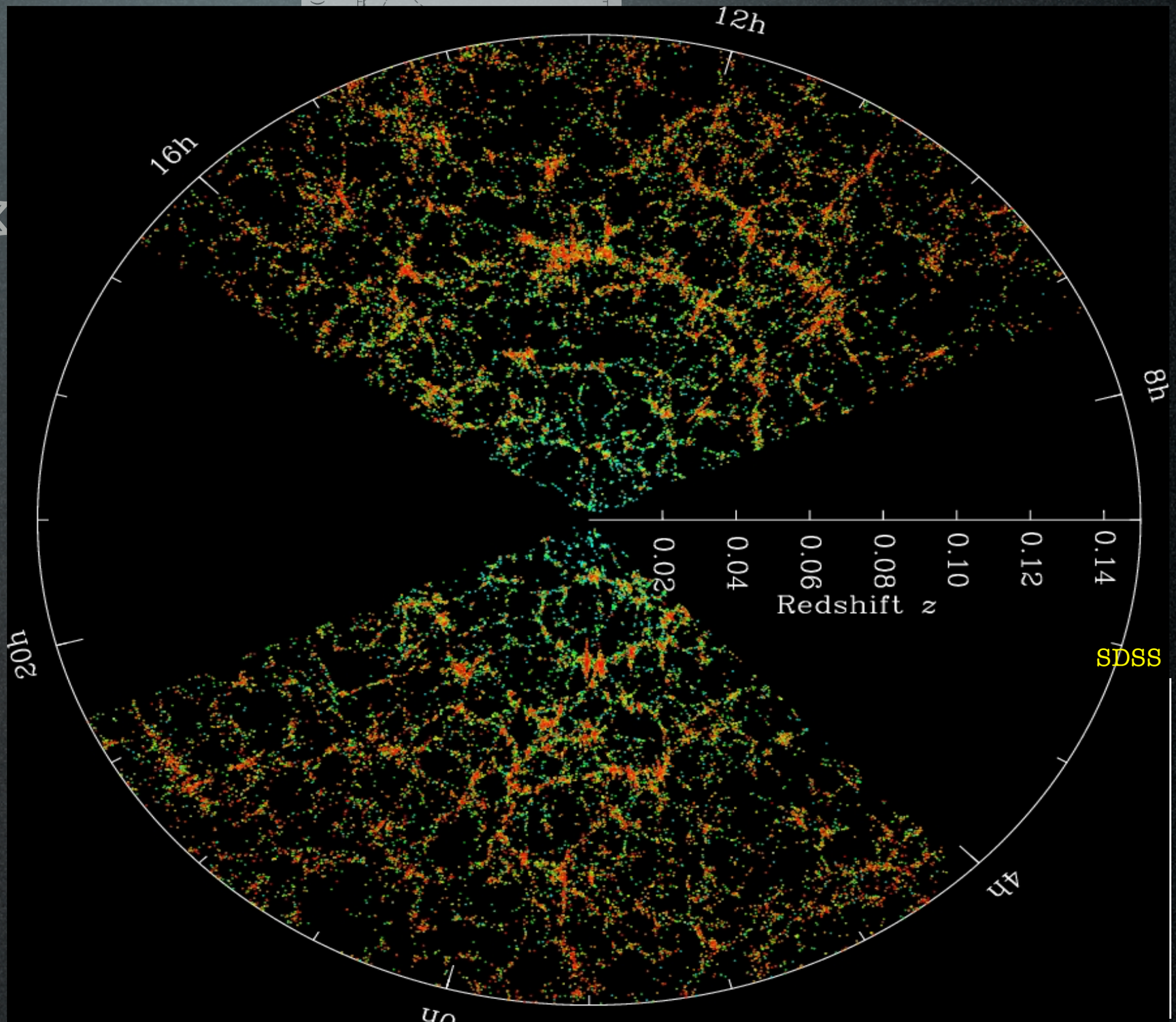


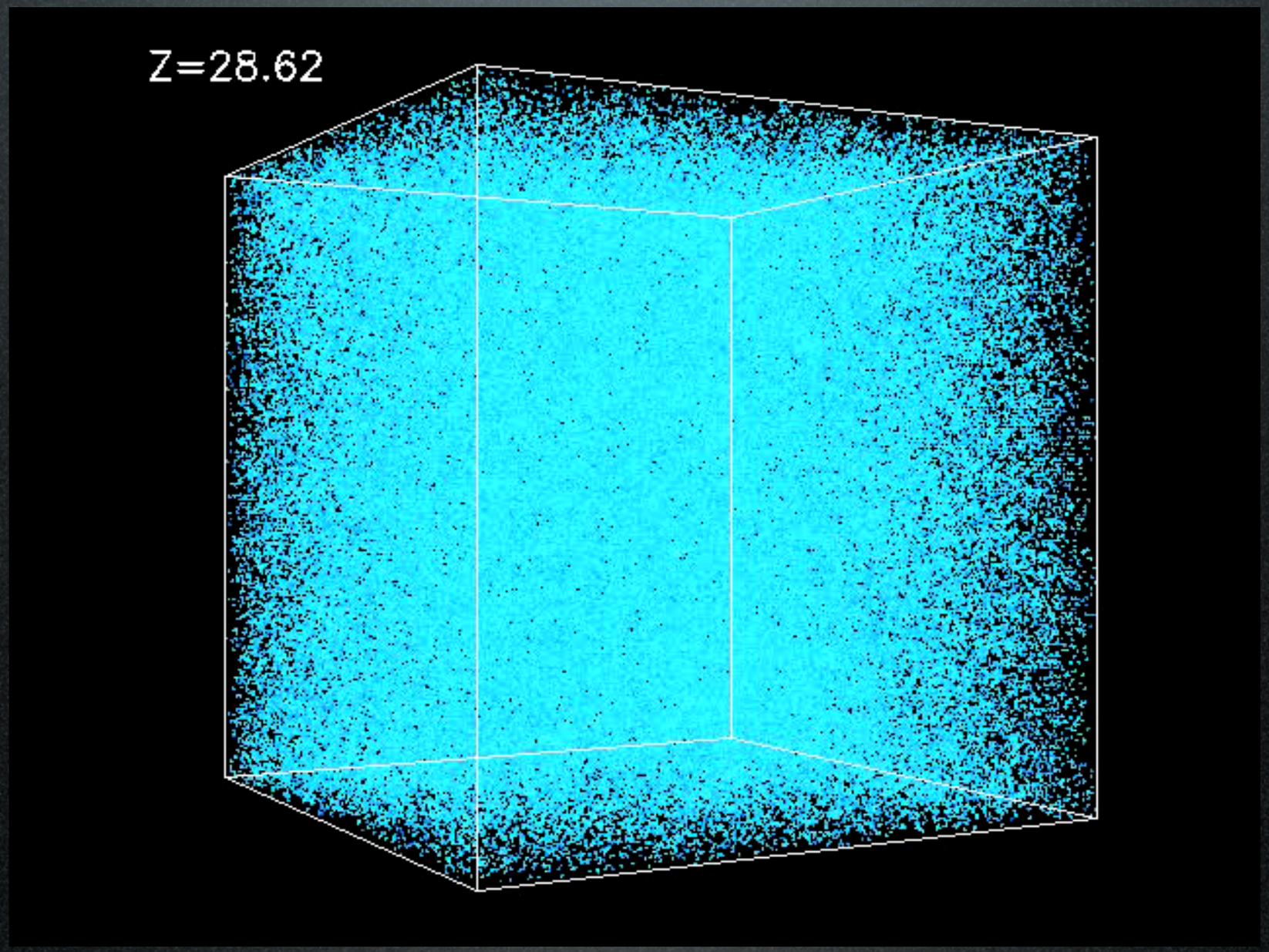
2) amas de galax



3) 'cosmologie de precision'

Preuves d'existence

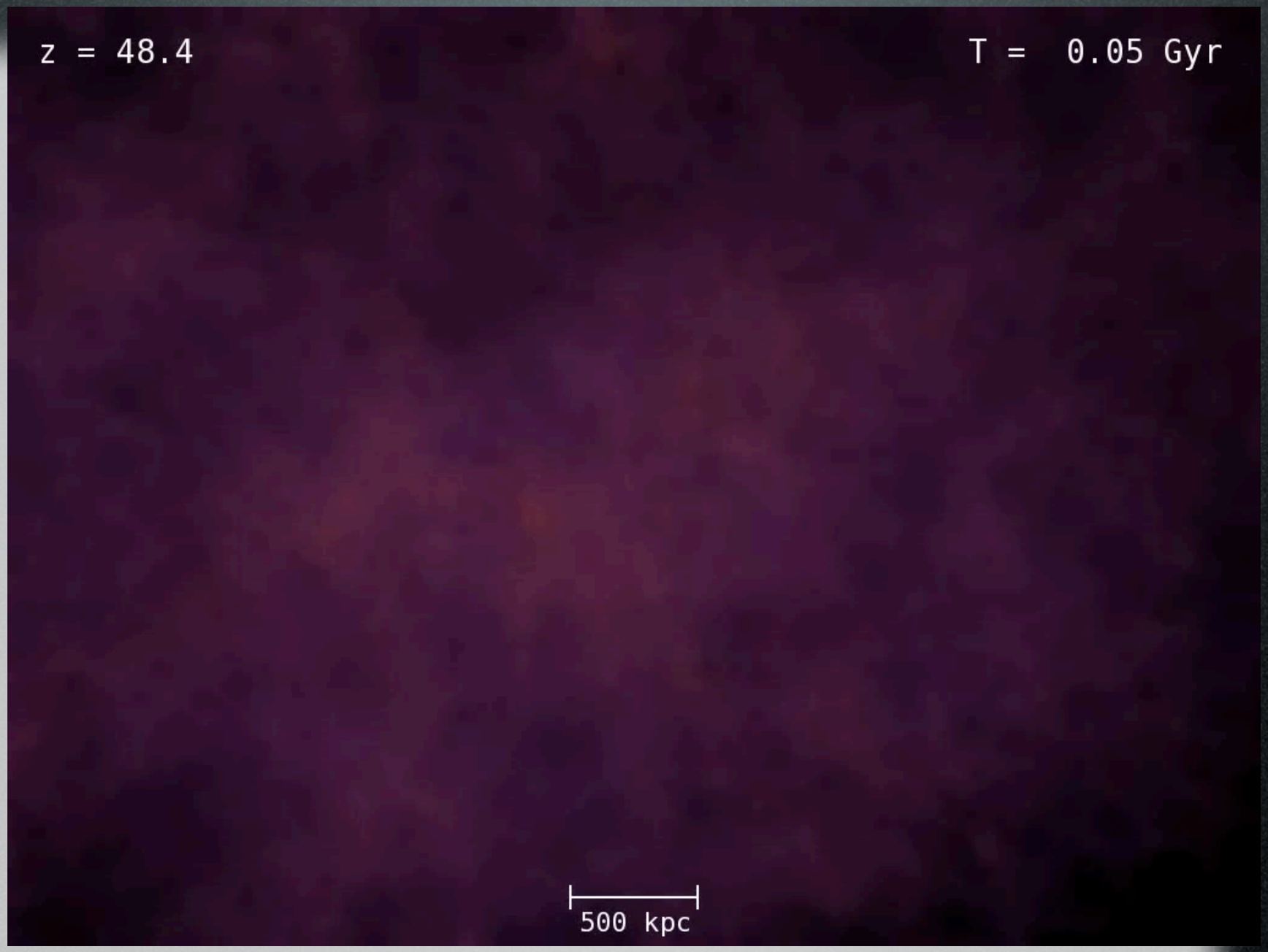
2 10^6 CDM particules, 43 Mpc cubic box



Andrey Kravtsov, cosmicweb.uchicago.edu

Preuves d'existence

Projet Aquarius de la collaboration VIRGO:
1.5 10^9 CDM particules, un seul halo galactique

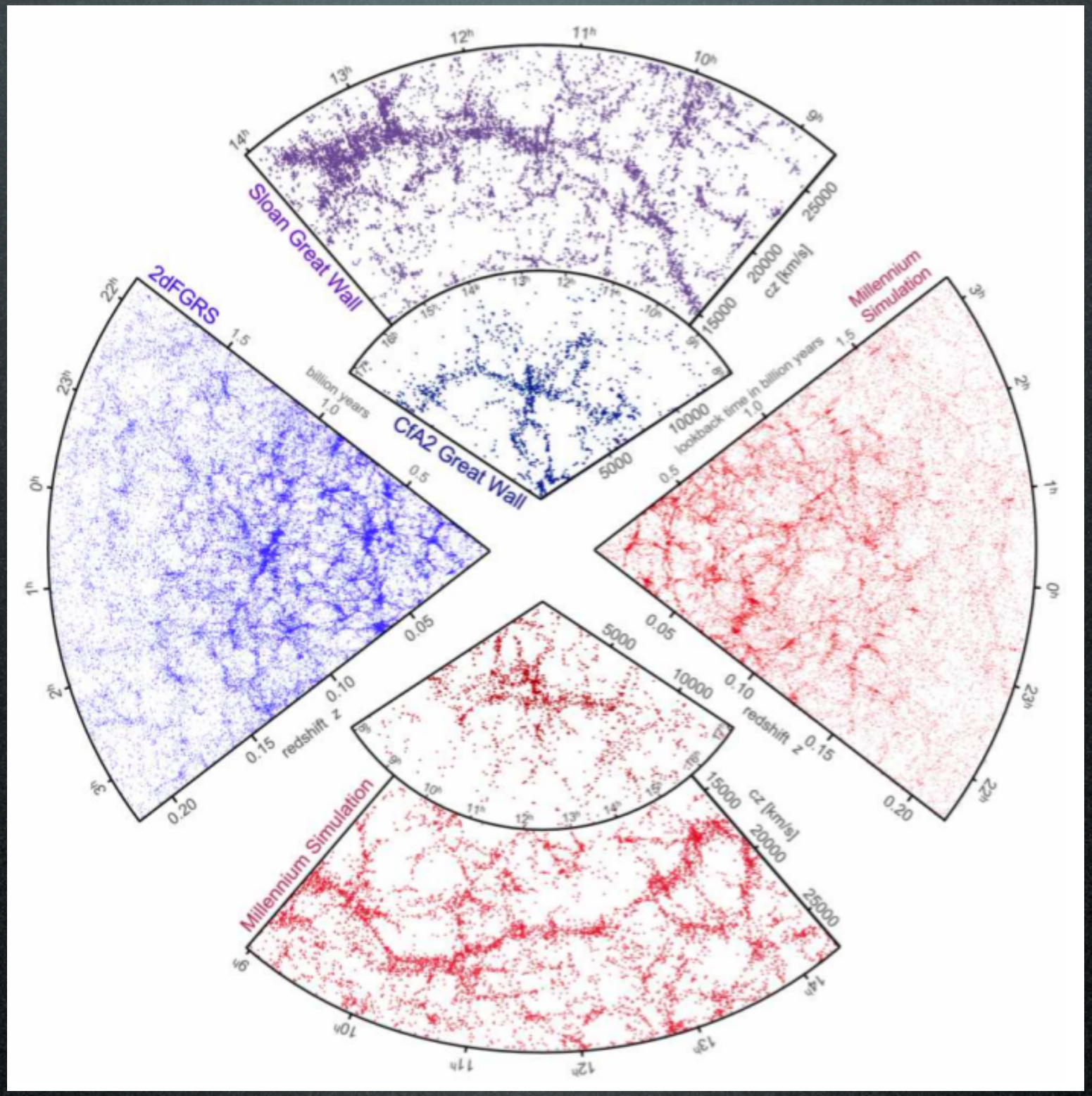


VIRGO coll., Aquarius project, www.mpa-garching.mpg.de/aquarius/

Preuves d'existence

2dF: 2.2 10^5 galaxies

SDSS: 10^6 galaxies,
2 billions
d'années lumière



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

Springel, Frenk, White, Nature 440 (2006)

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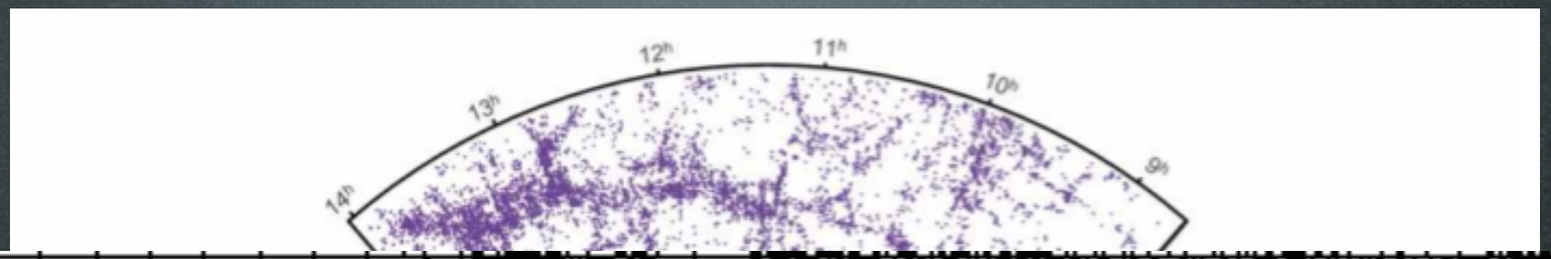
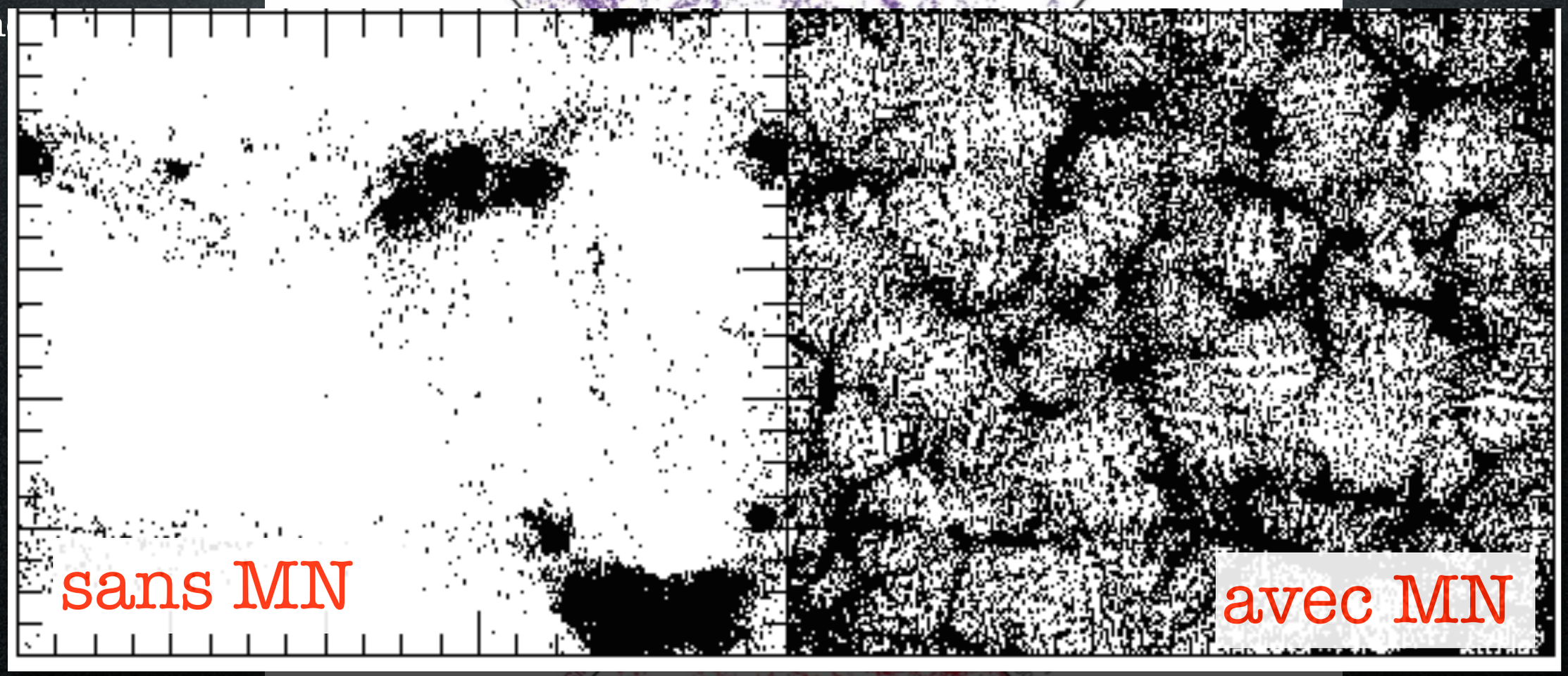
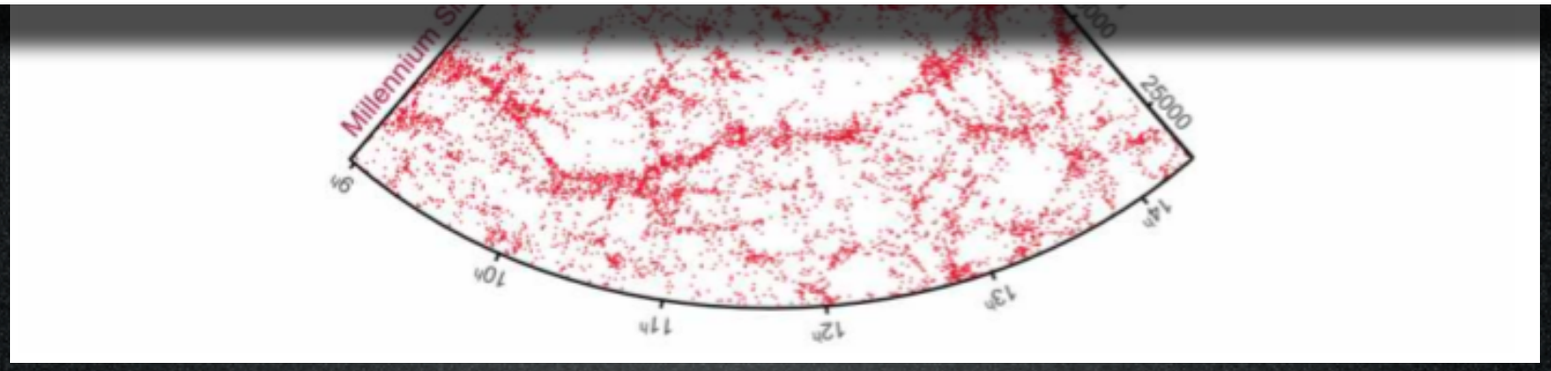




A. Nusser, 0109016, MNRAS 331 (2002)



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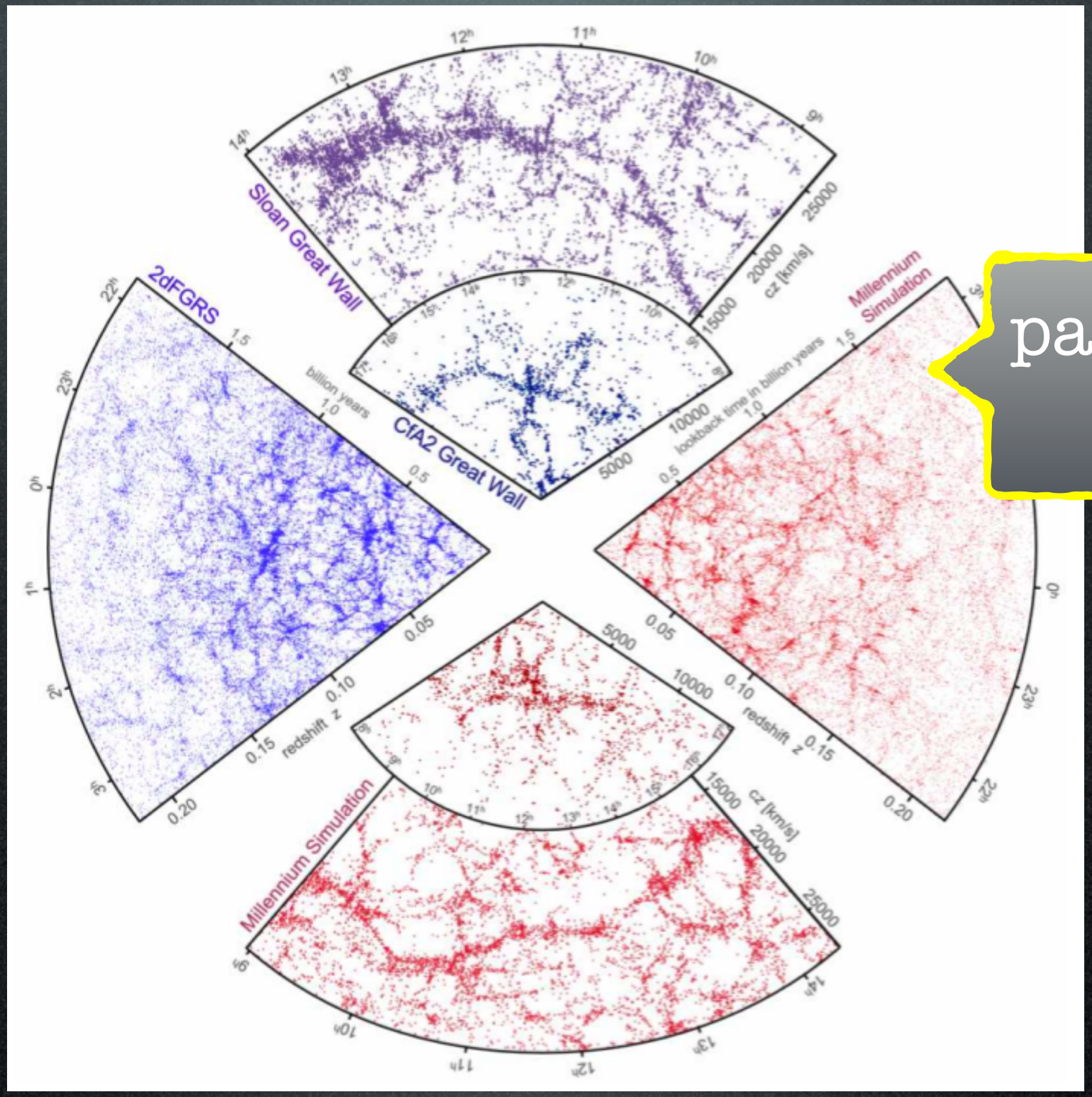

particules

Millennium:
10^{10} particules,
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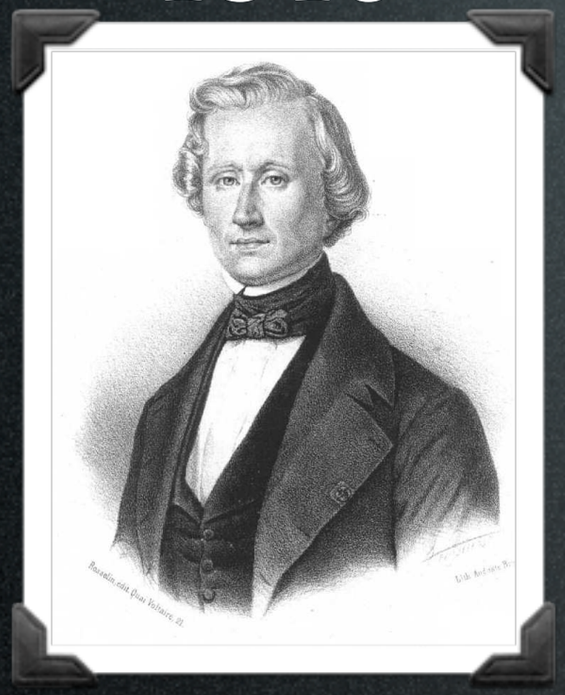
Springel, Frenk, White, Nature 440 (2006)

DETOUR

Modifier la loi de gravité ?

Modifier la loi de gravité ?

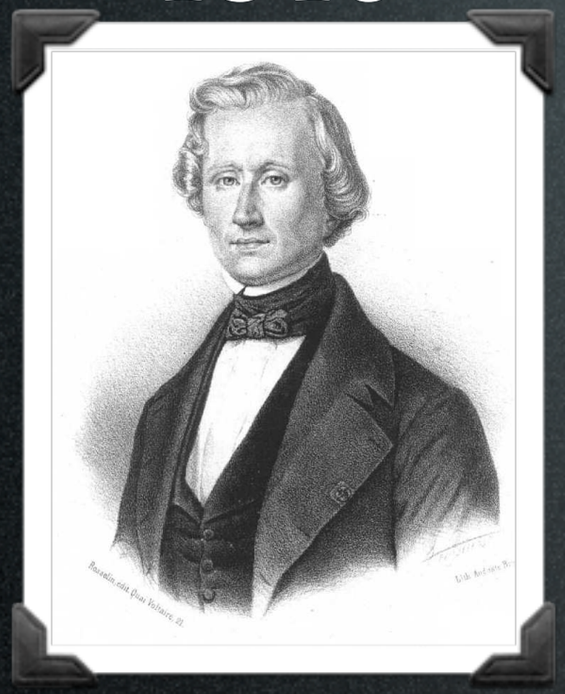
1846



Urbain Le Verrier

Modifier la loi de gravité ?

1846



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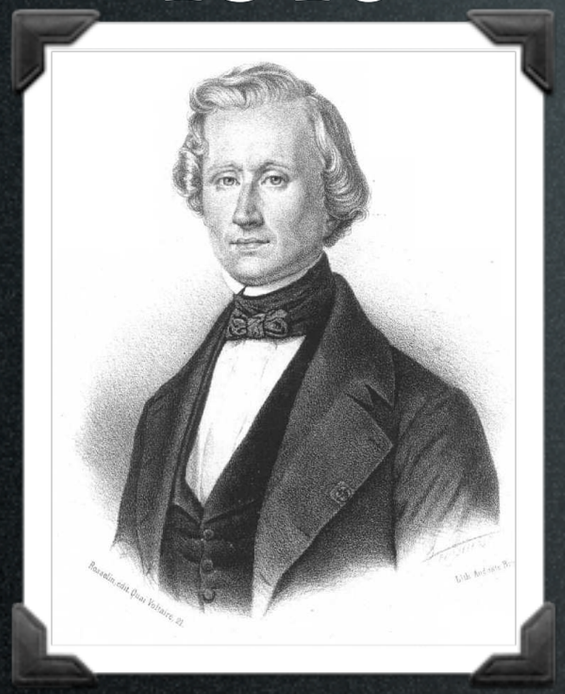

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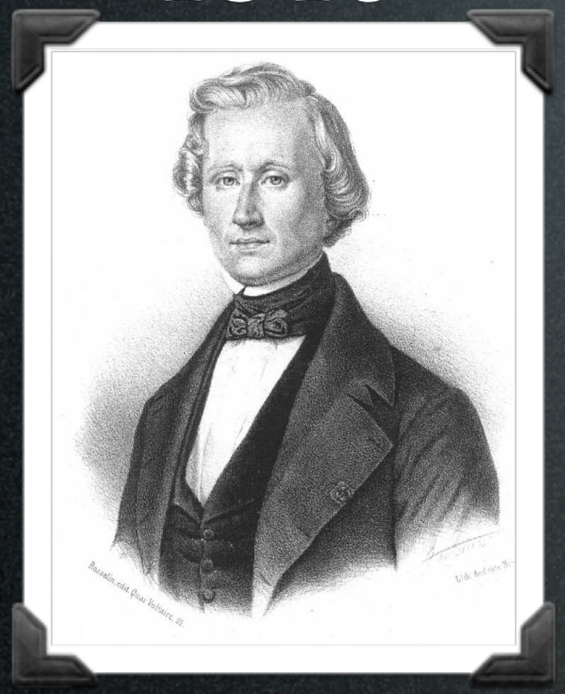

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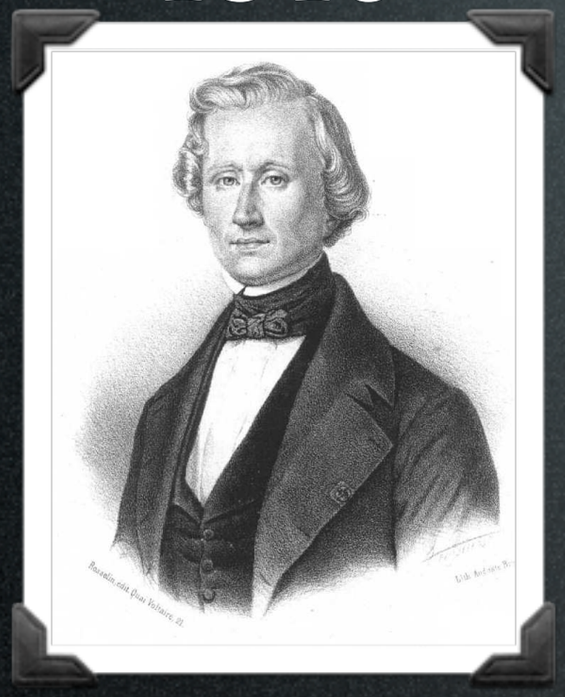
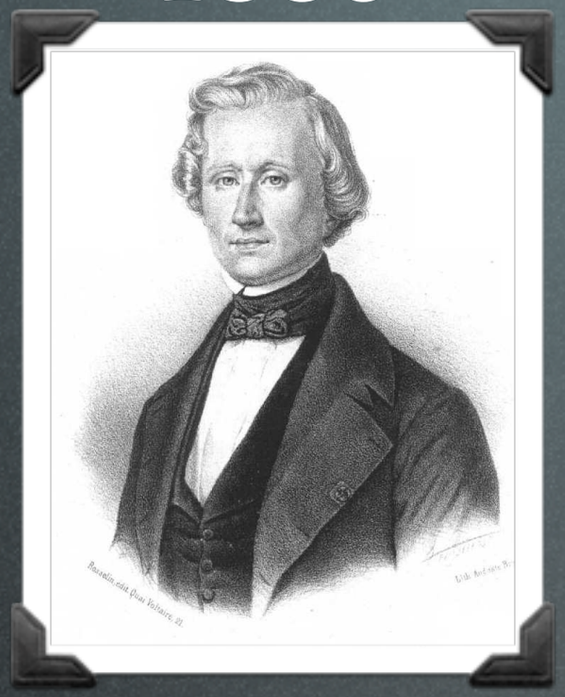


Urbain Le Verrier

1859



Urbain Le Verrier

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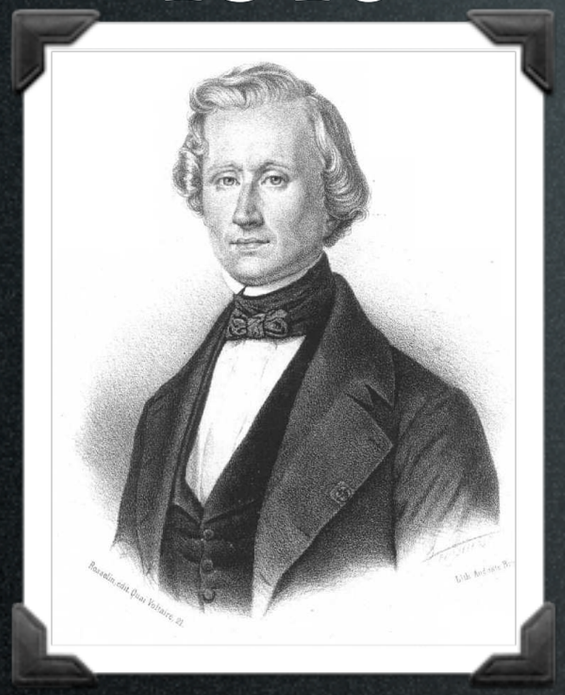
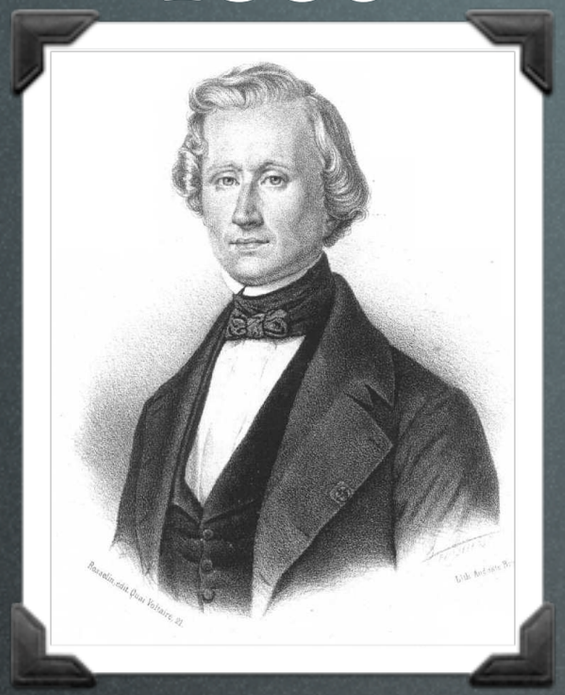


Urbain Le Verrier

1859



Urbain Le Verrier

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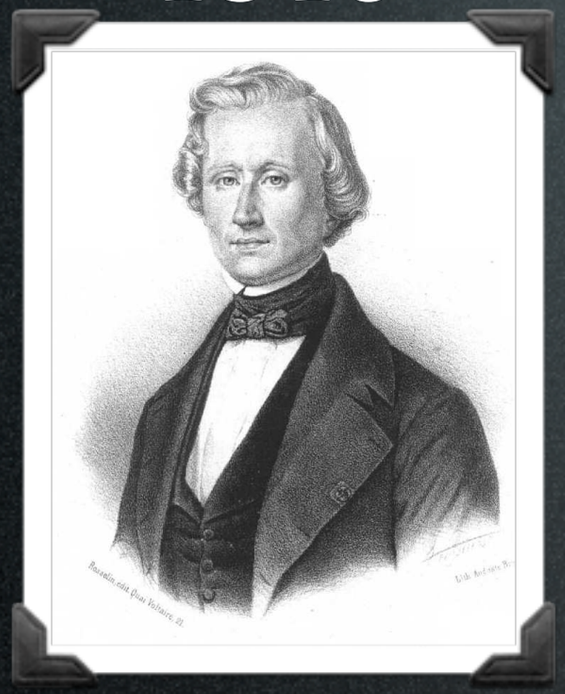
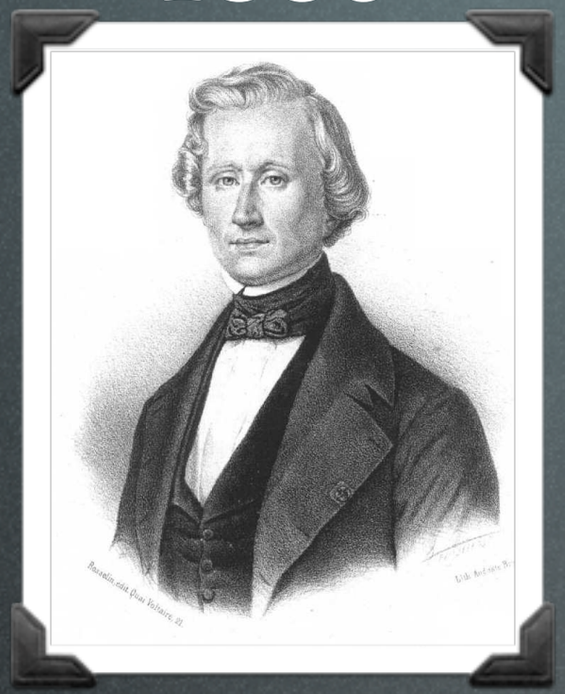
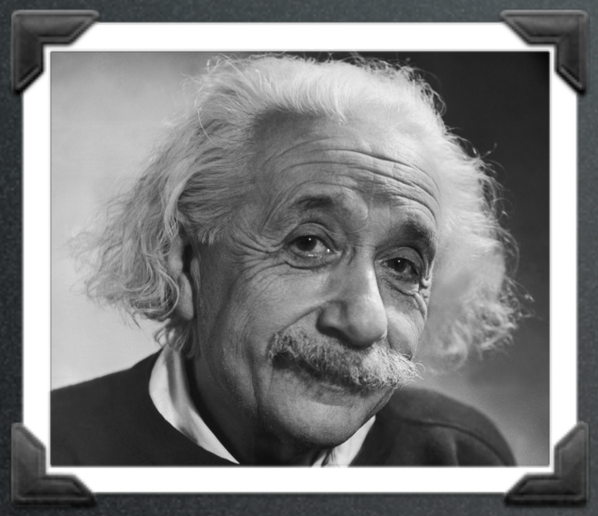


Urbain Le Verrier

1859



Urbain Le Verrier



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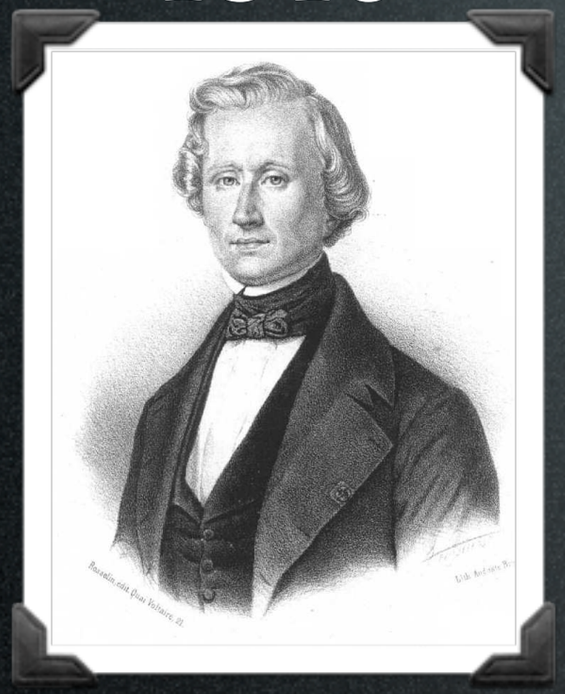

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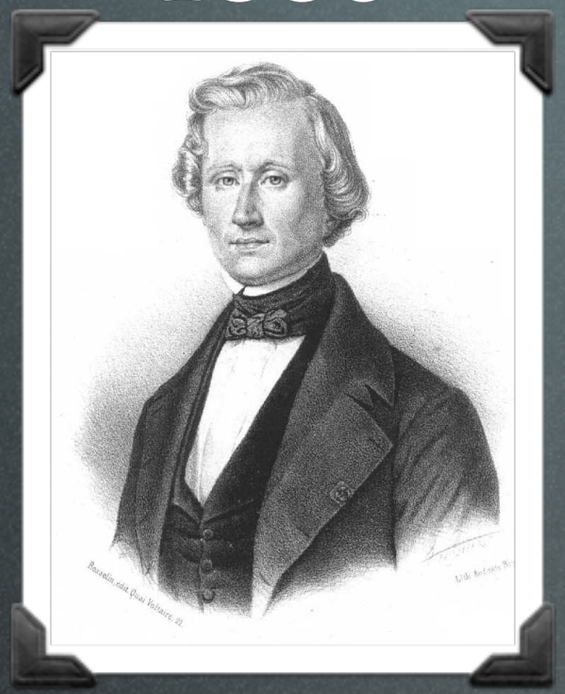

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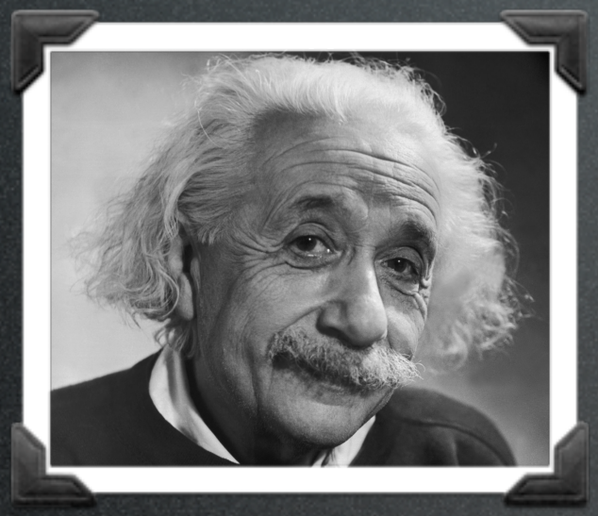

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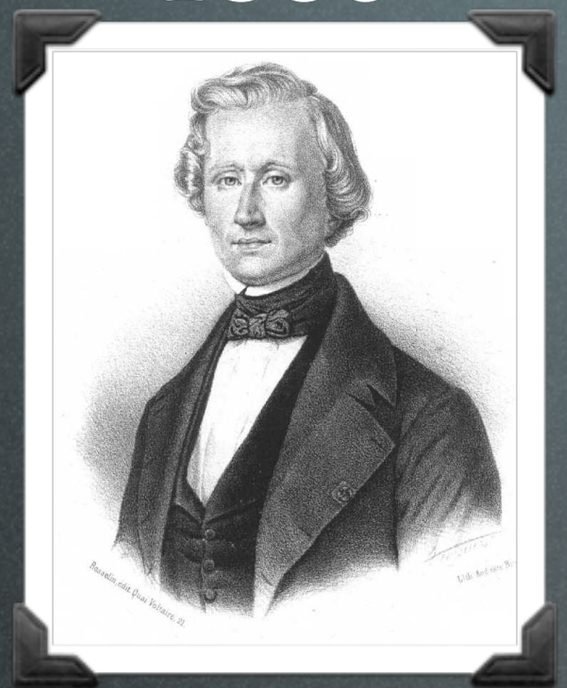
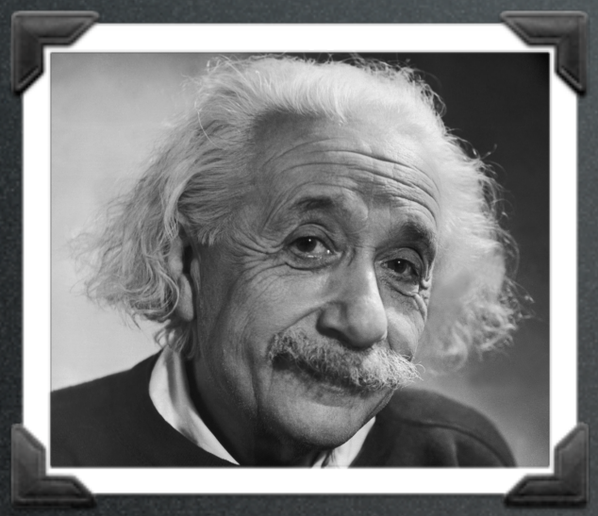


Urbain Le Verrier

1981

Mordehai Milgrom



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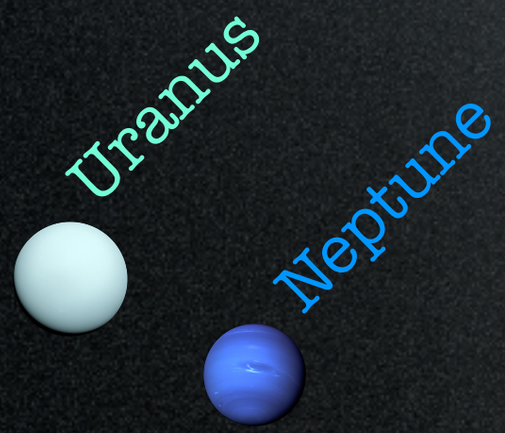
Urbain Le Verrier



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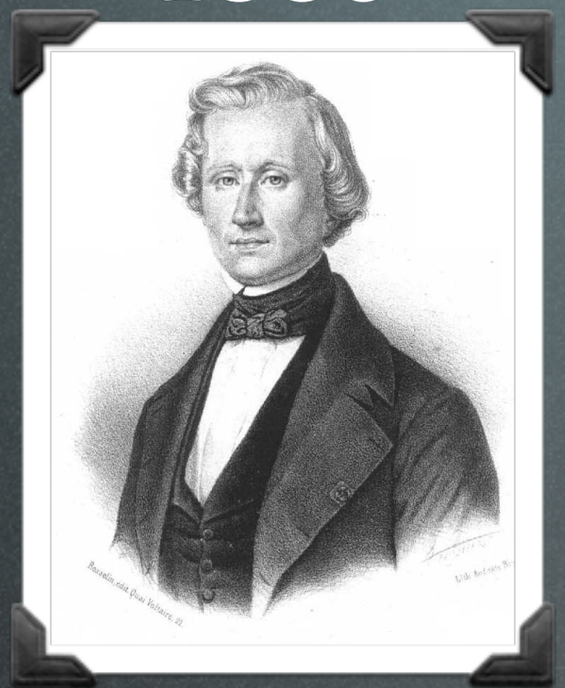
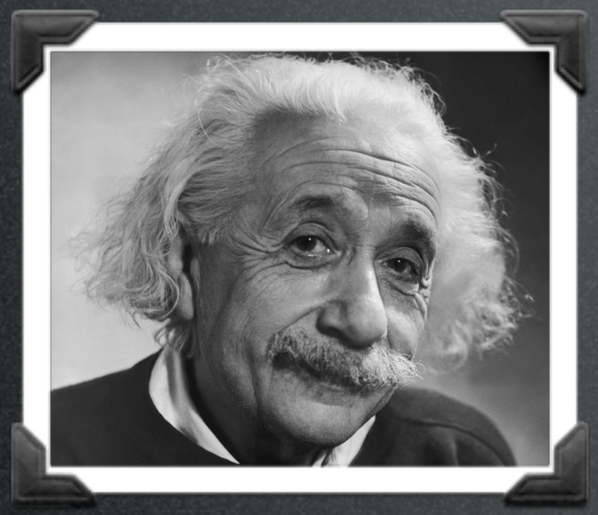


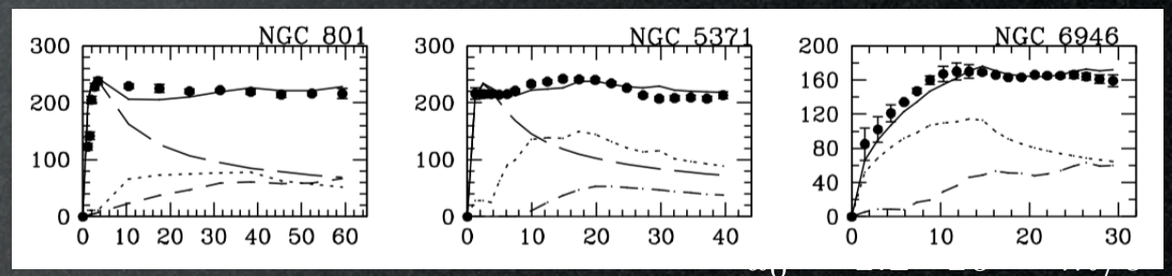
Urbain Le Verrier



1981

Mordehai Milgrom

$$F = m\,a \longrightarrow F = m\,a \cdot \mu(a)$$



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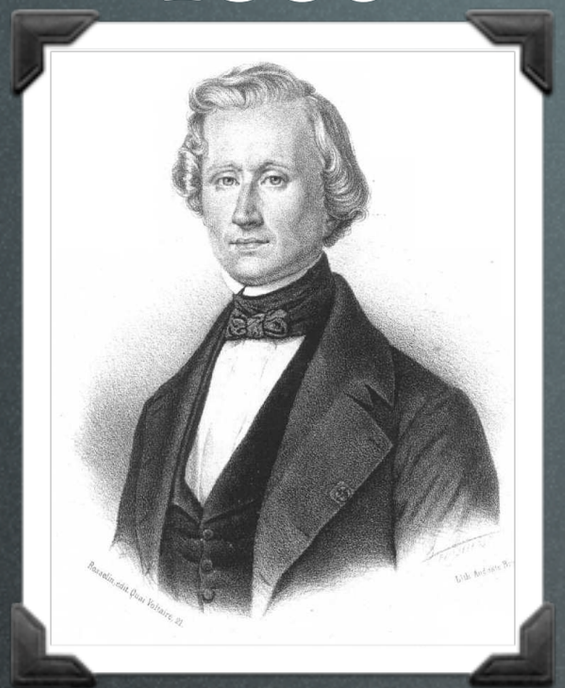

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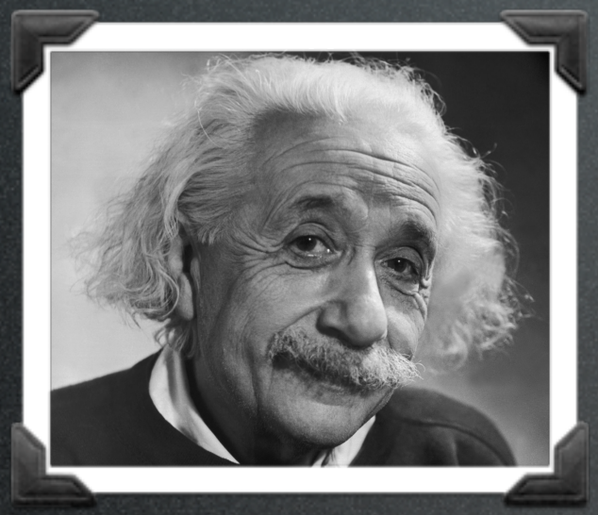

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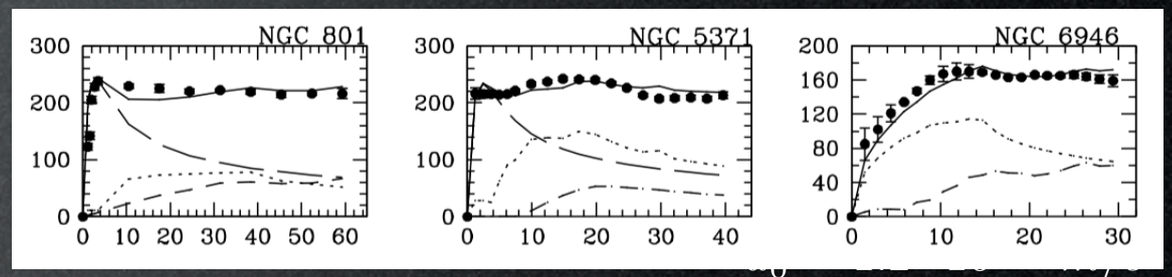

?

DETOUR

Preuves d'existence

2dF: 2.2 10^5 galaxies

SDSS: 10^6 galaxies,
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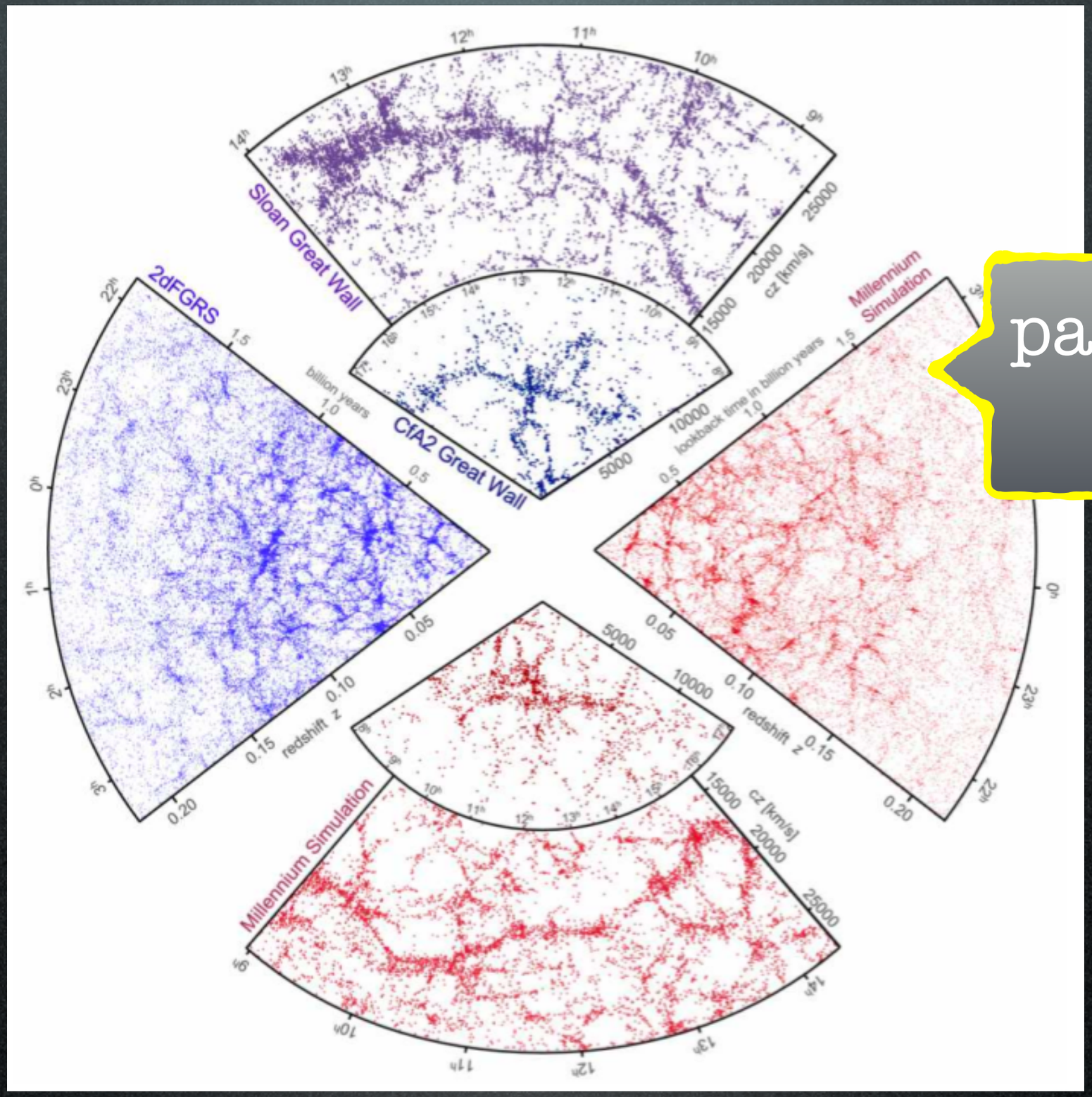
d'années lumière



particules

Millennium:
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Springel, Frenk, White, Nature 440 (2006)

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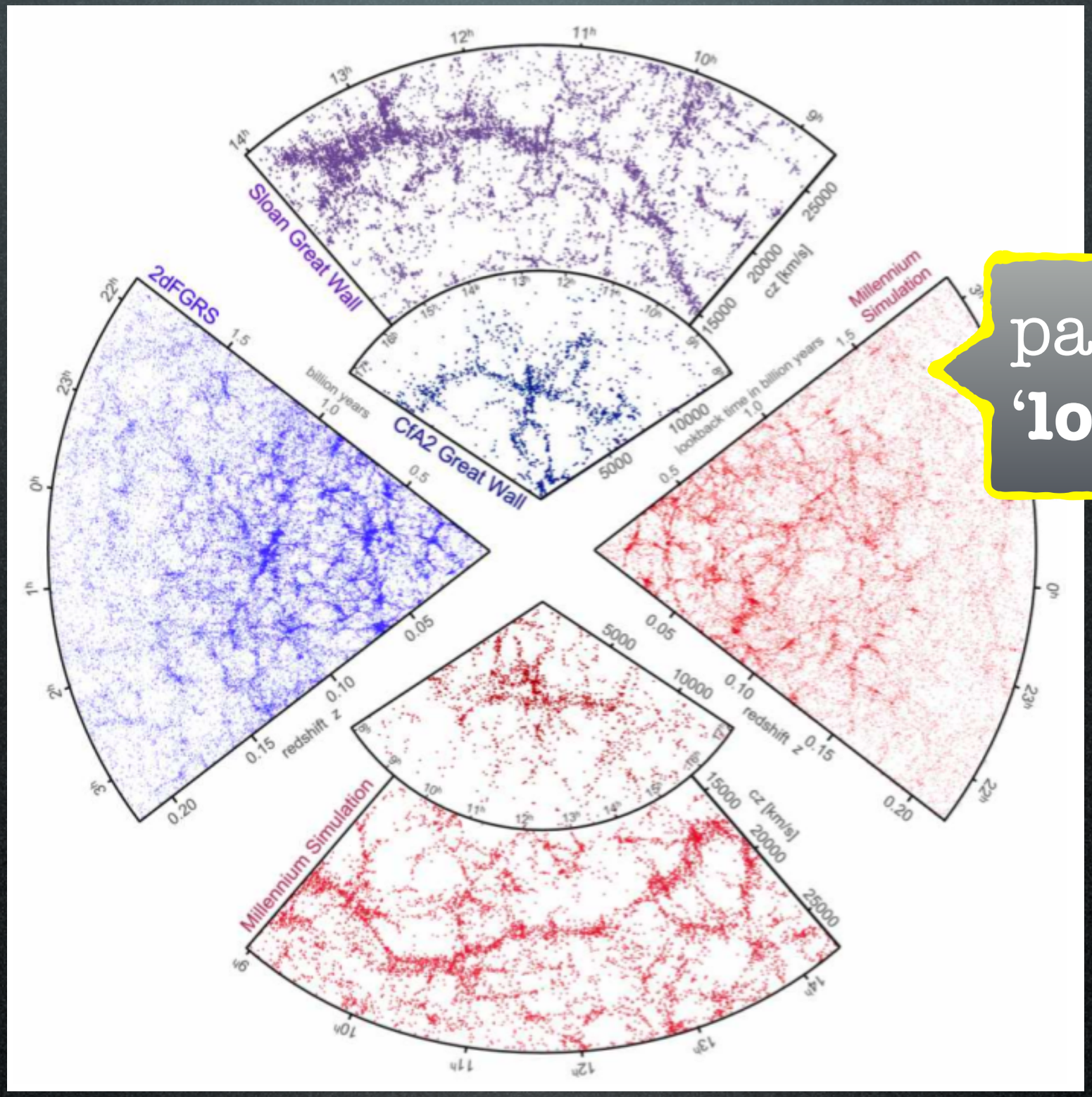

particules
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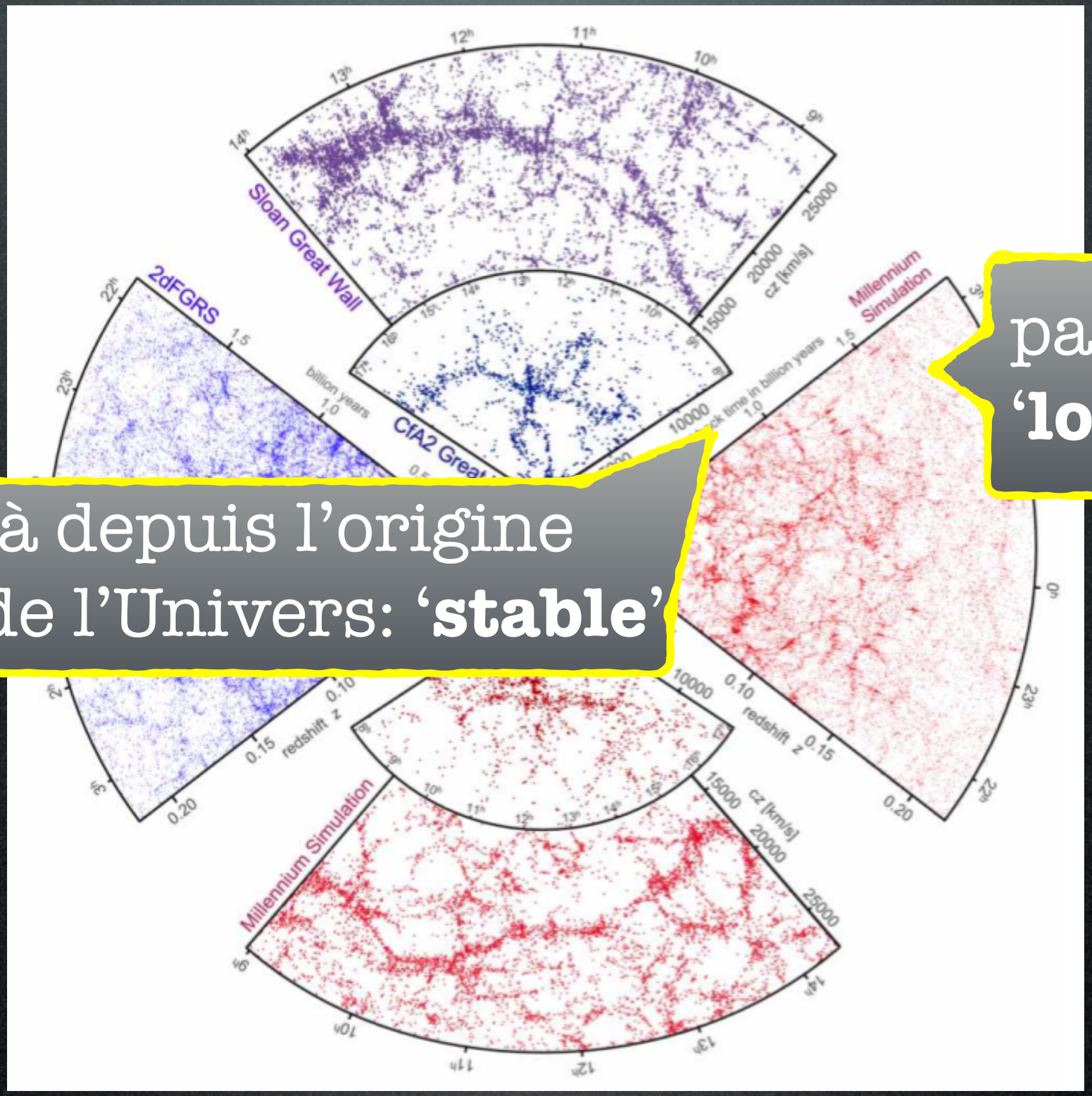

là depuis l'origine
de l'Univers: '**stable**'

particules
'**lourdes**'

Millennium:
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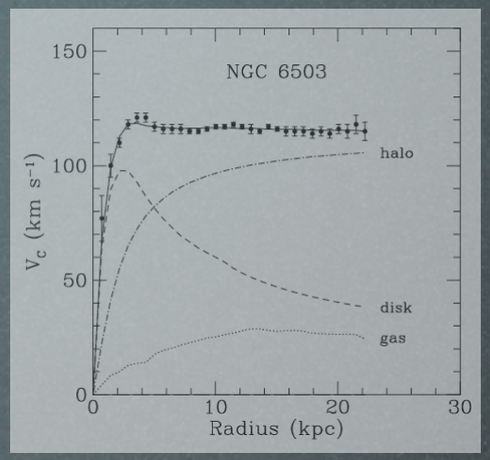
Springel, Frenk, White, Nature 440 (2006)

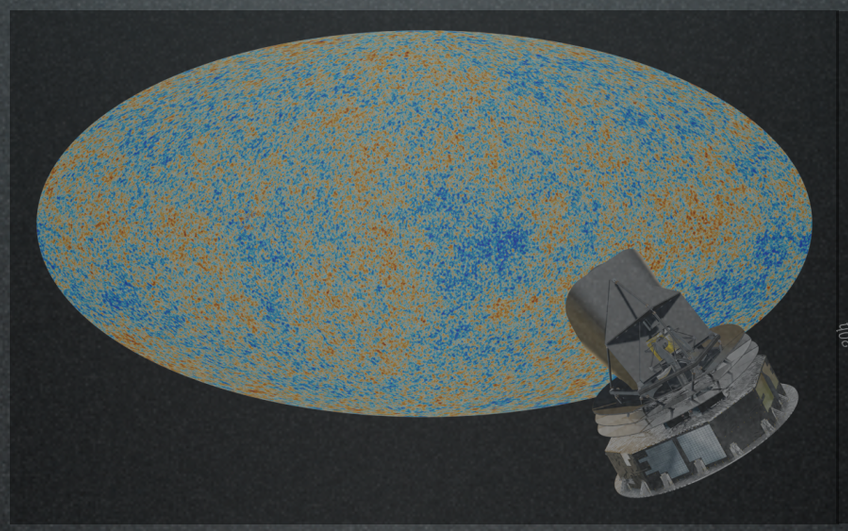
Preuves d'existence

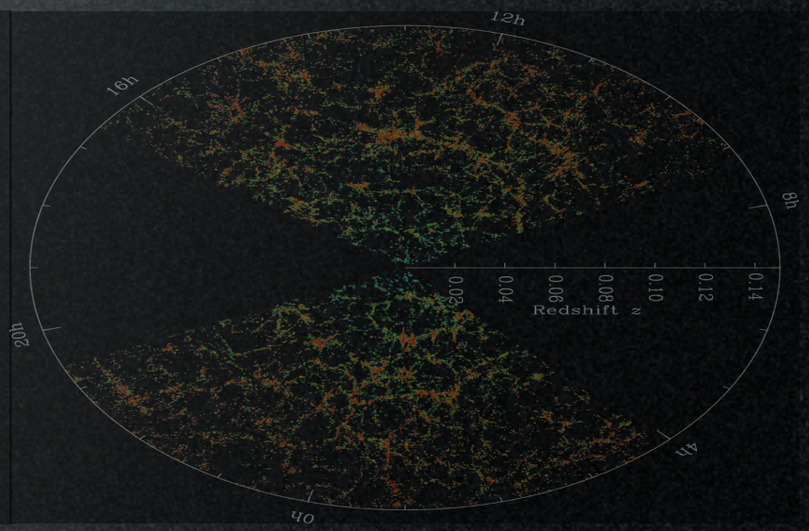
1) courbes de rotation galactiques



2) clusters of galaxies

3) 'cosmologie de précision'





NB: tous effets de force de gravité

Que savons-nous de ses **propriétés** ?

Propriétés et nature

n'émet pas de lumière, elle est '**neutre**'

particules '**lourdes**'

là depuis l'origine de l'Univers: '**stable**'

plus abondante que la matière ordinaire

aucune ou très peu d'interaction

Propriétés et nature

particules
‘**lourdes**’

‘**neutre**’

‘**stable**’

presque sans
interactions

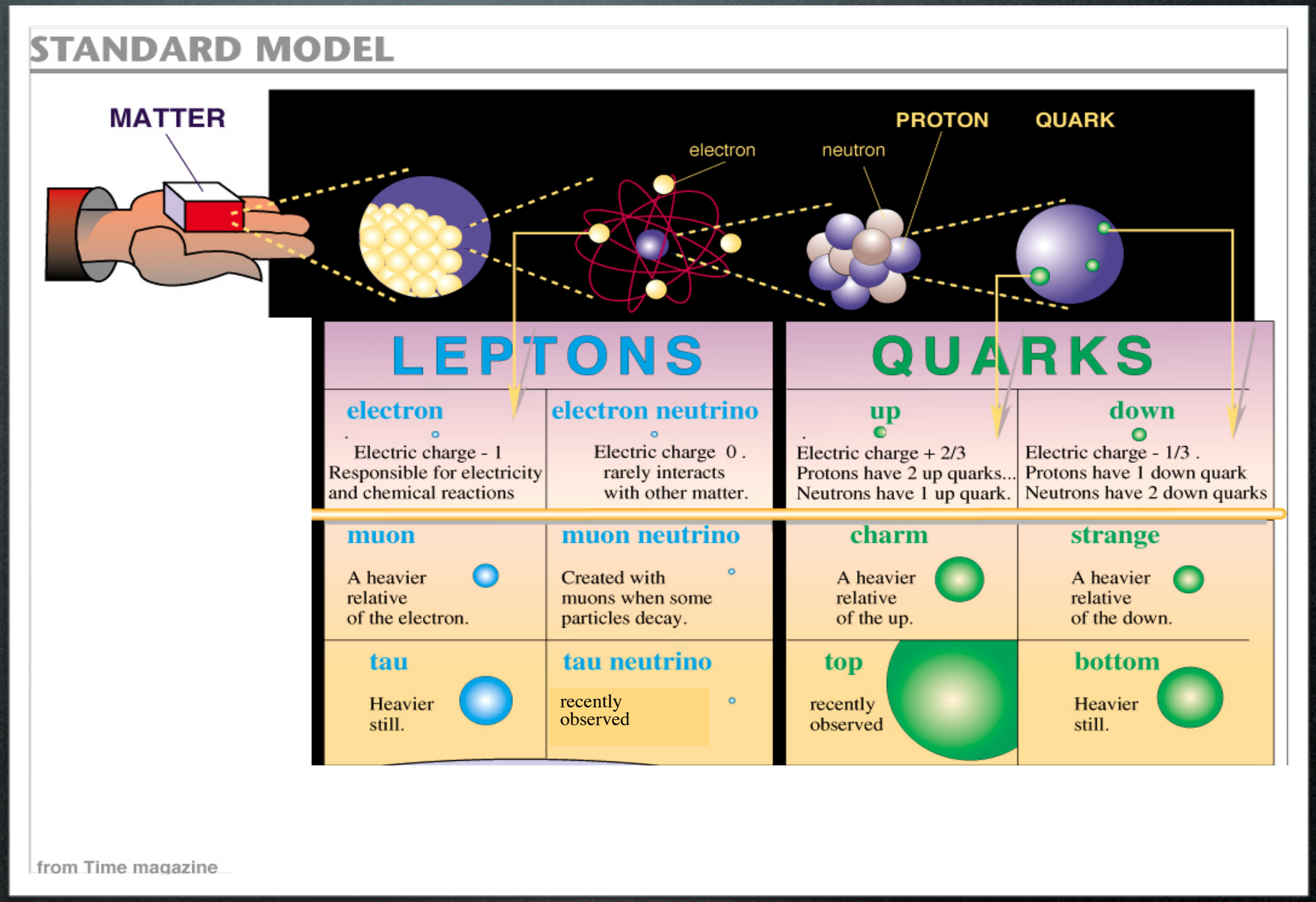
Propriétés et nature

particules **'lourdes'**

'neutre'

'stable'

presque sans interactions



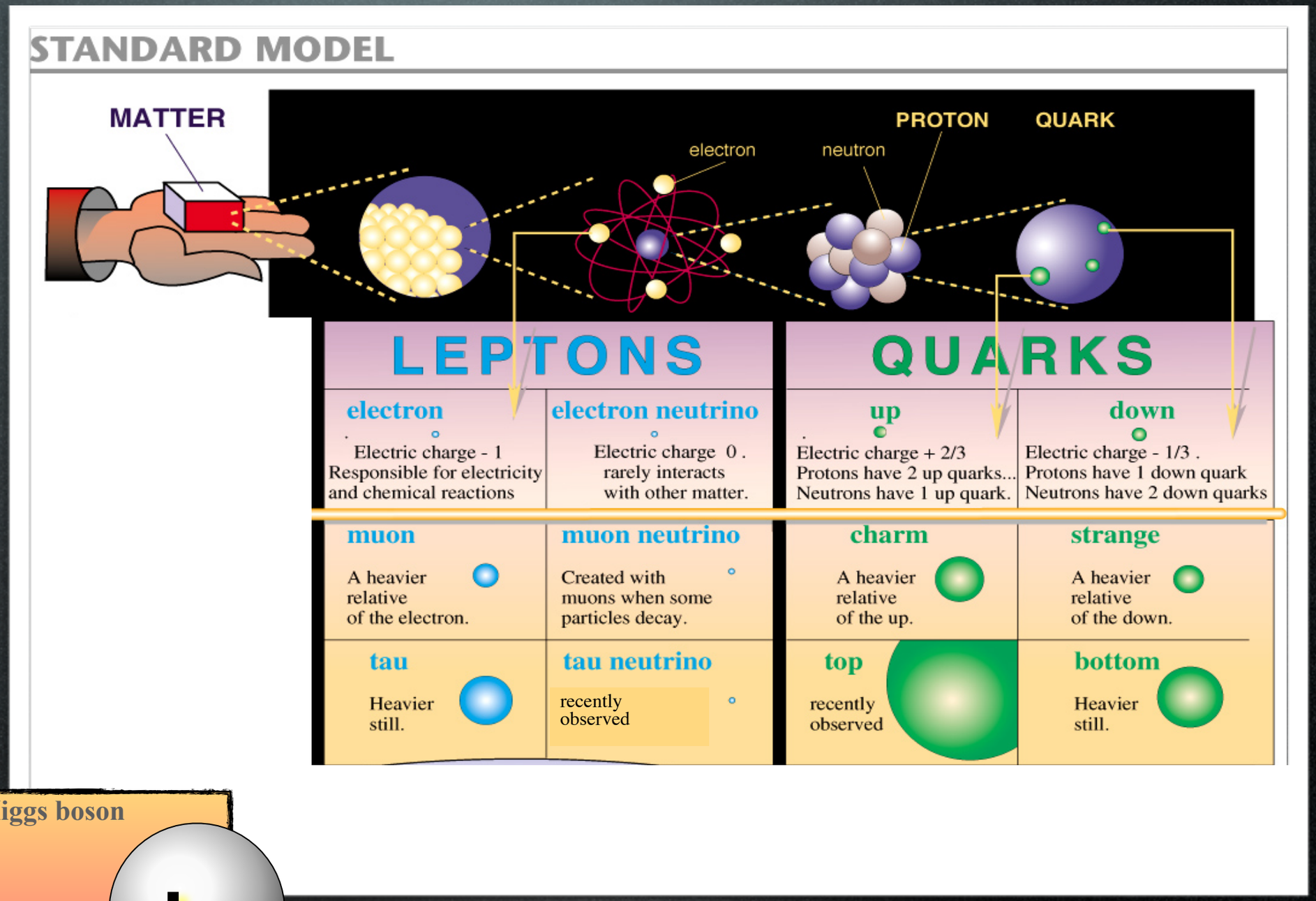
Propriétés et nature

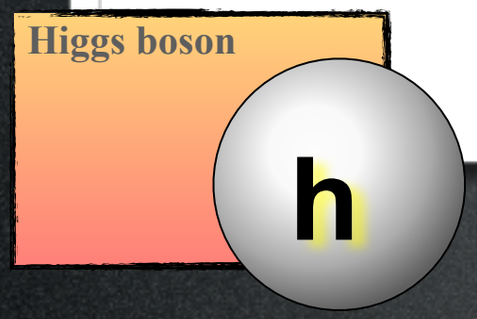
particules **'lourdes'**

'neutre'

'stable'

presque sans interactions





Propriétés et nature

particules **'lourdes'**

'neutre'

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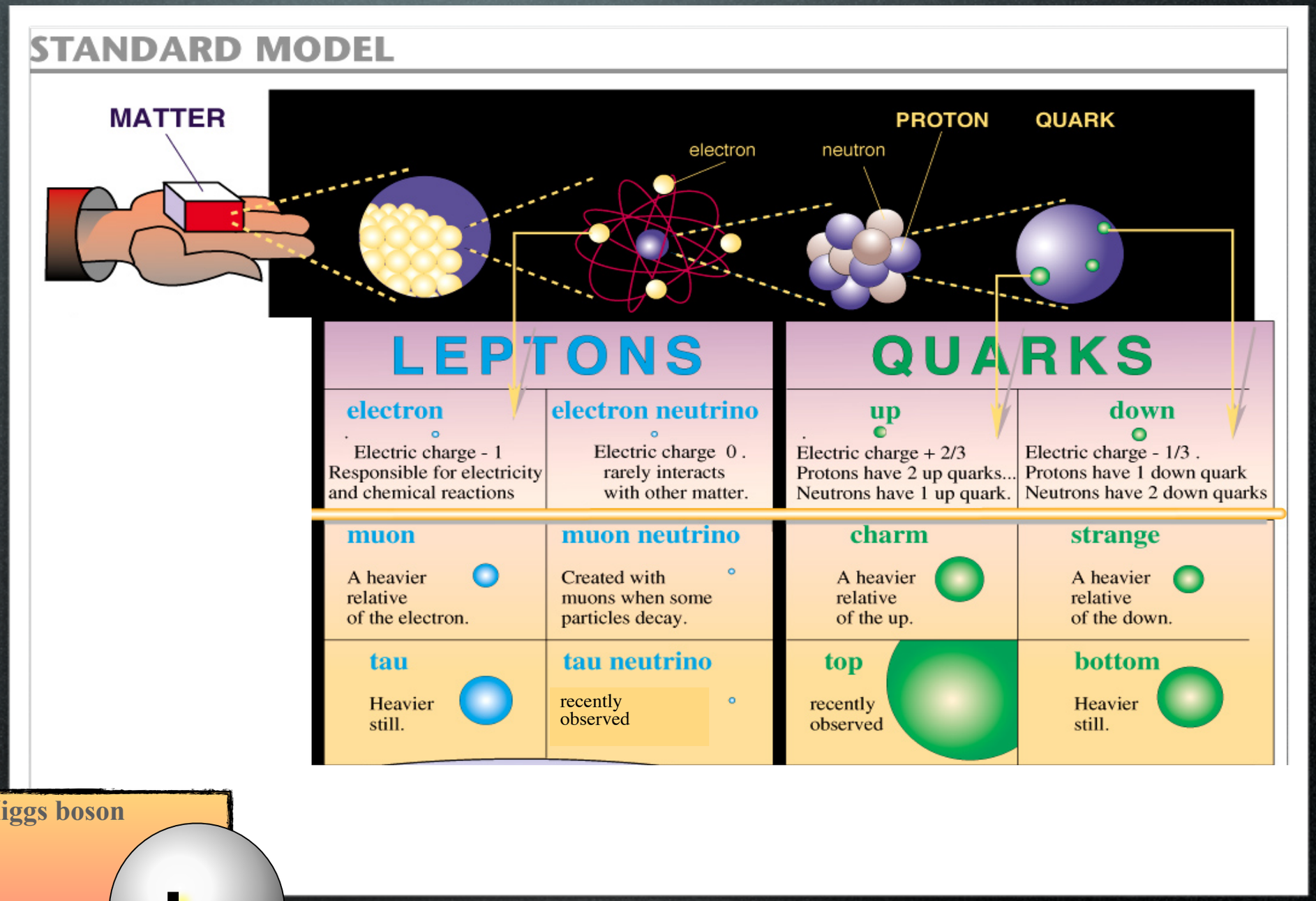
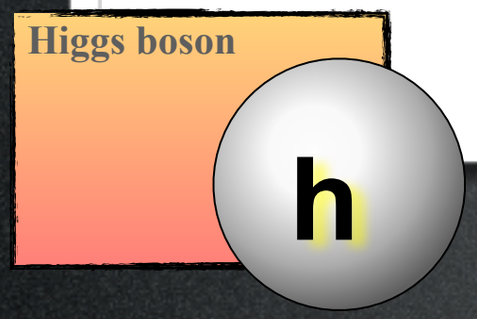
presque sans interactions





Propriétés et nature

particules **'lourdes'**

'neutre'

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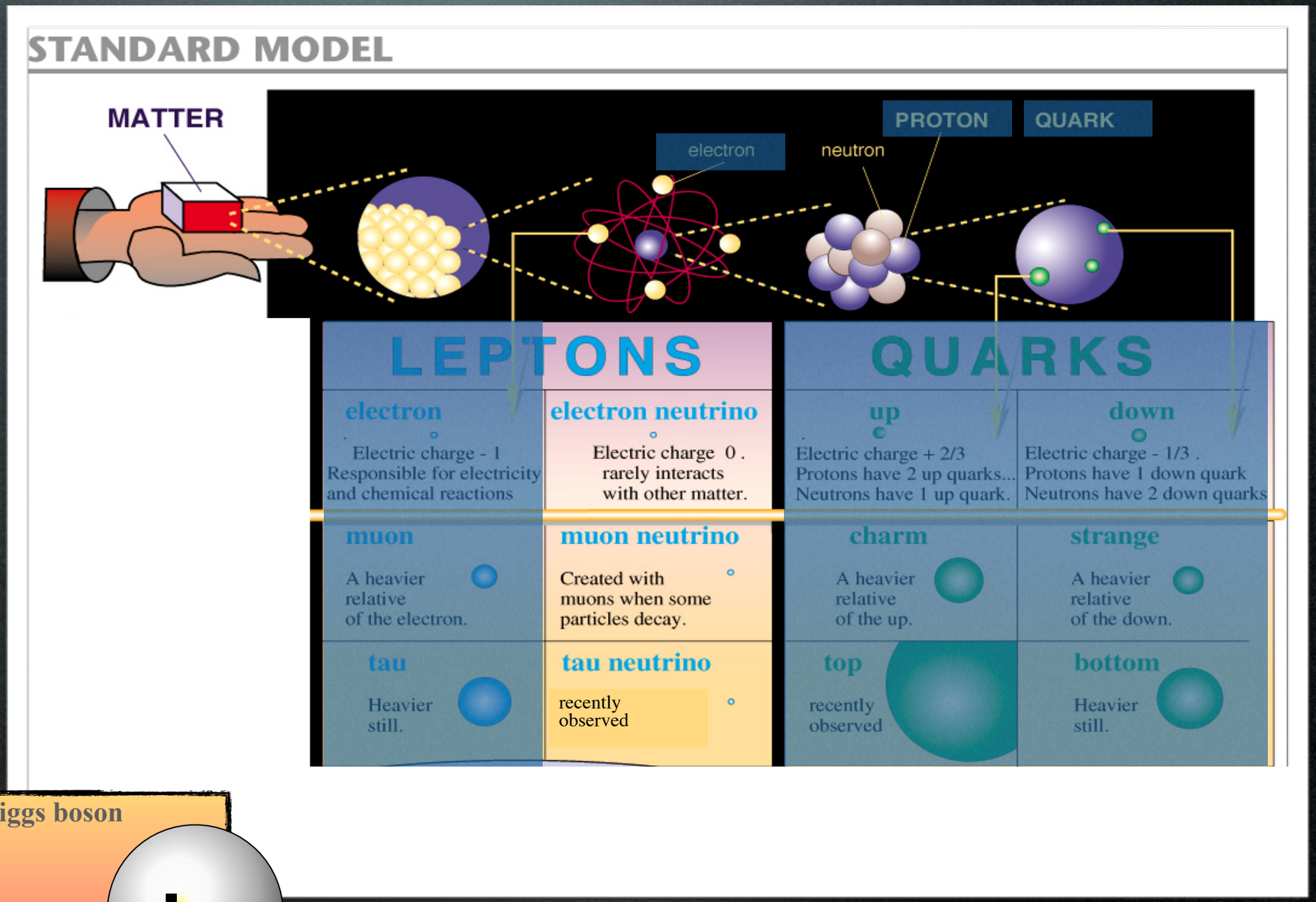
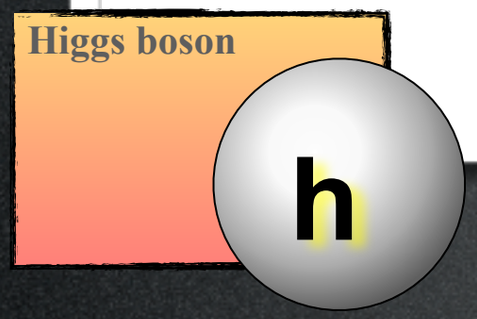
presque sans interactions





Propriétés et nature

particules **'lourdes'**

'neutre'

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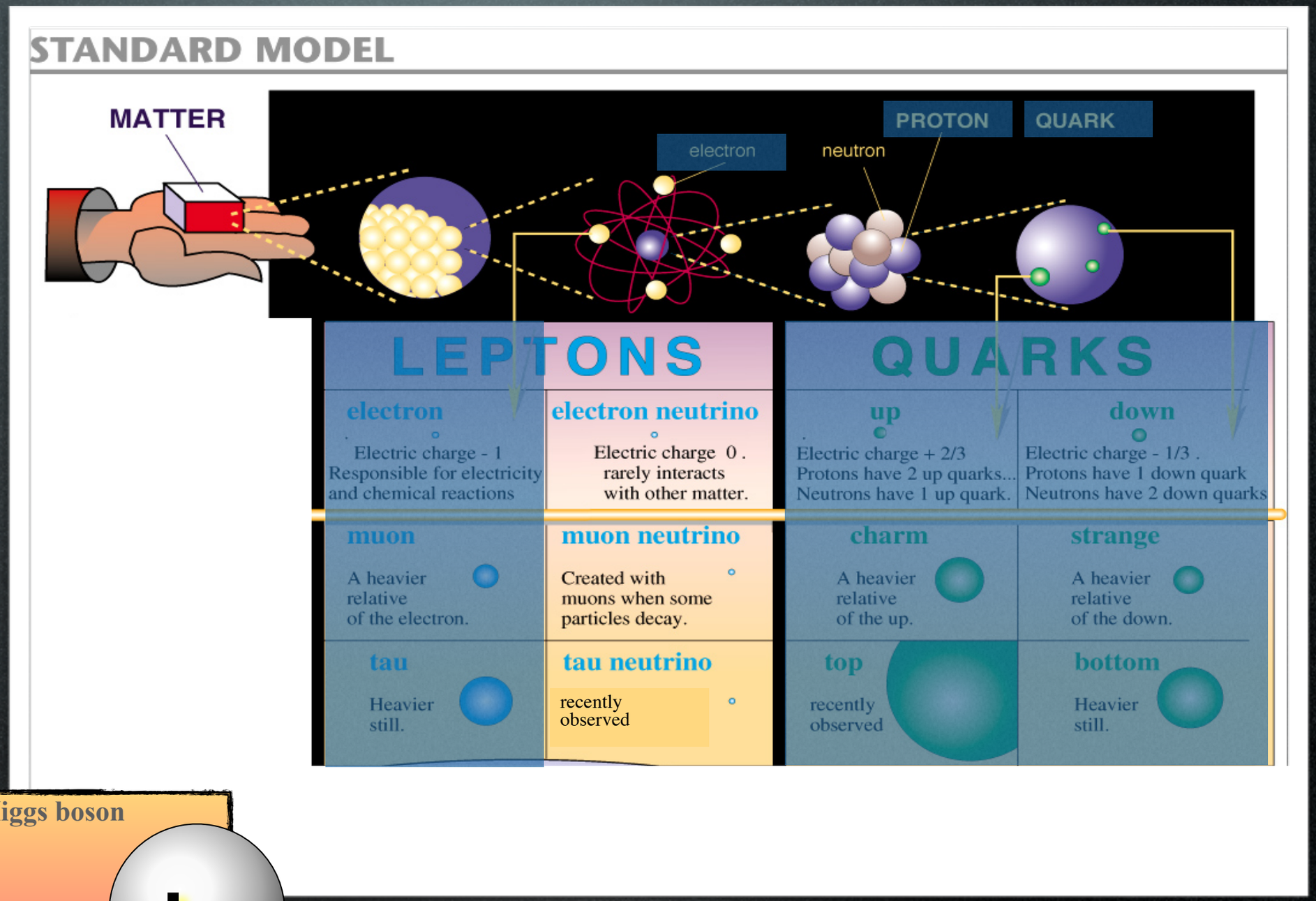
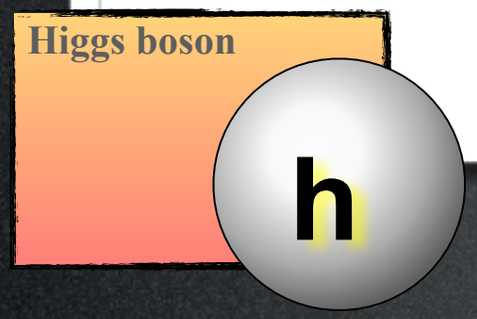
presque sans interactions





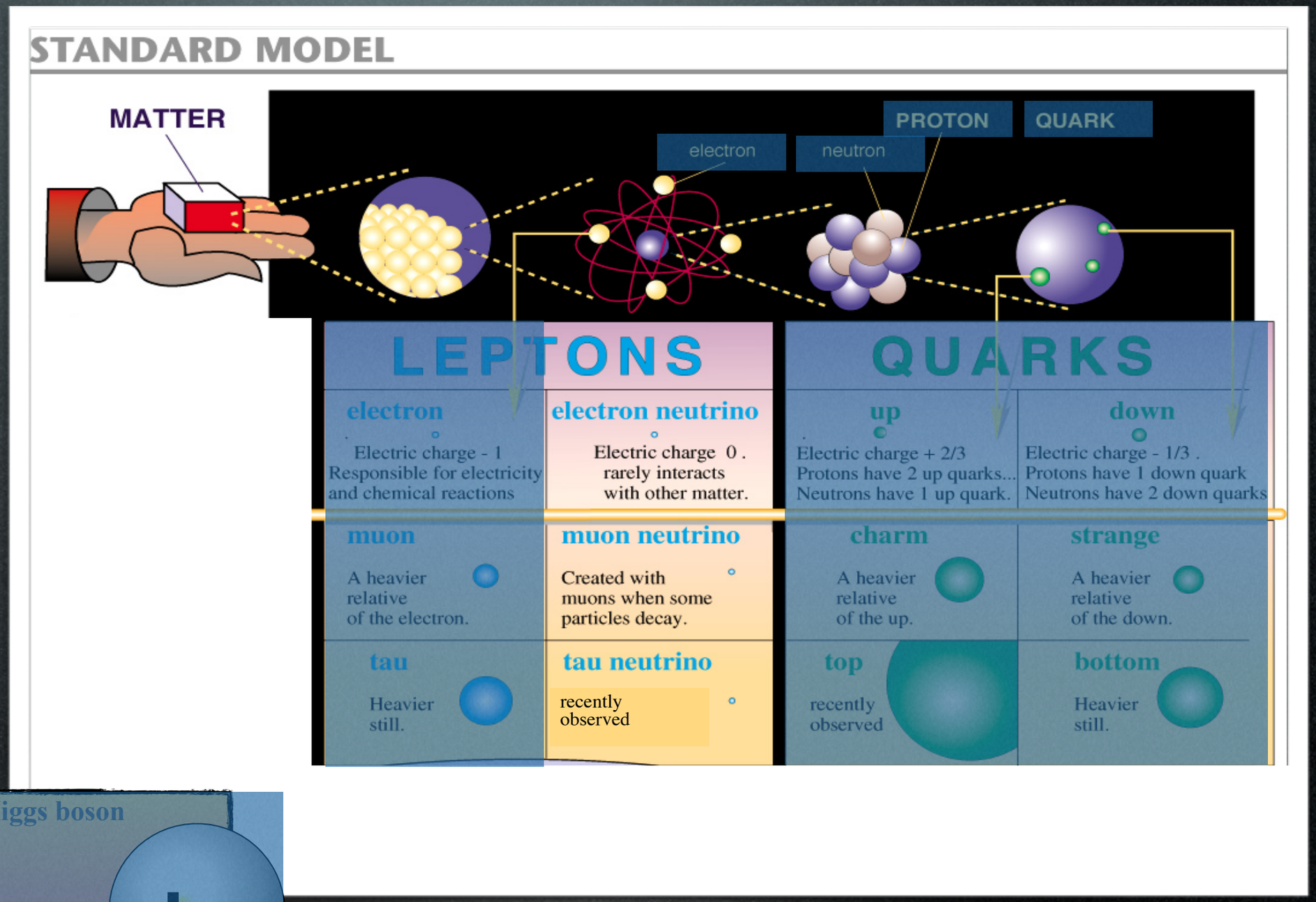
Propriétés et nature

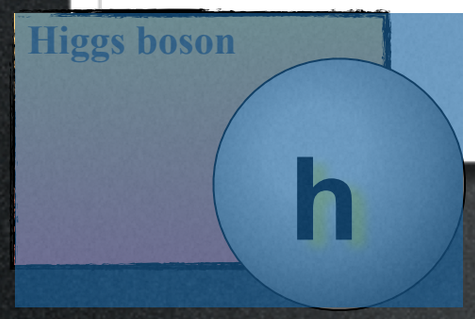
particules **'lourdes'**

'neutre'

'stable'

presque sans interactions





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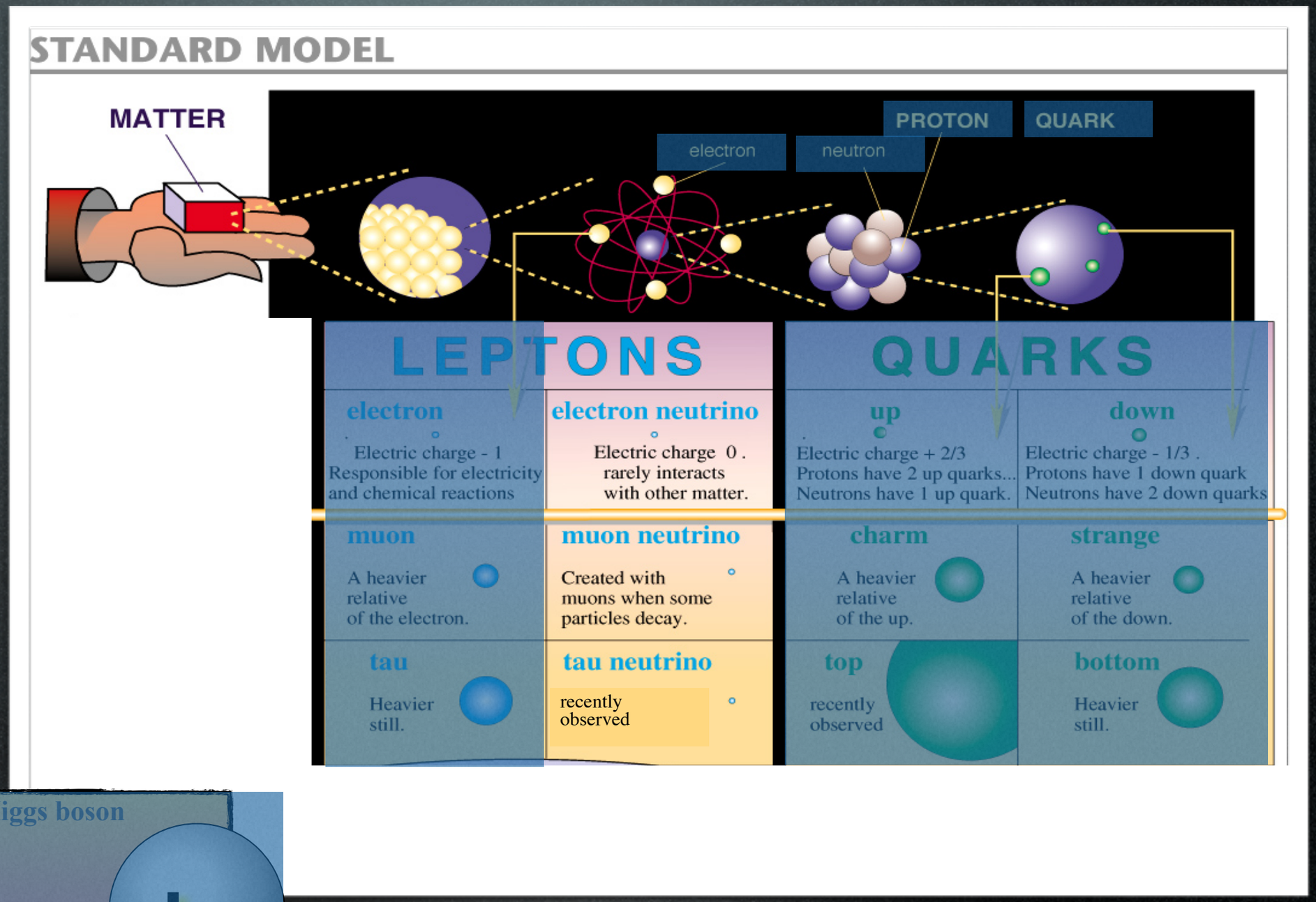

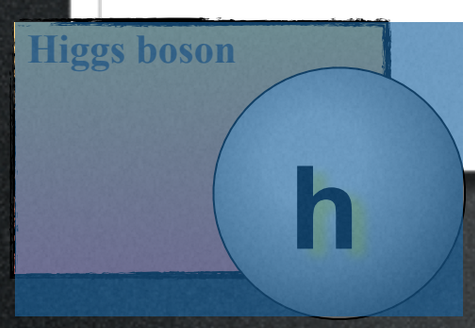

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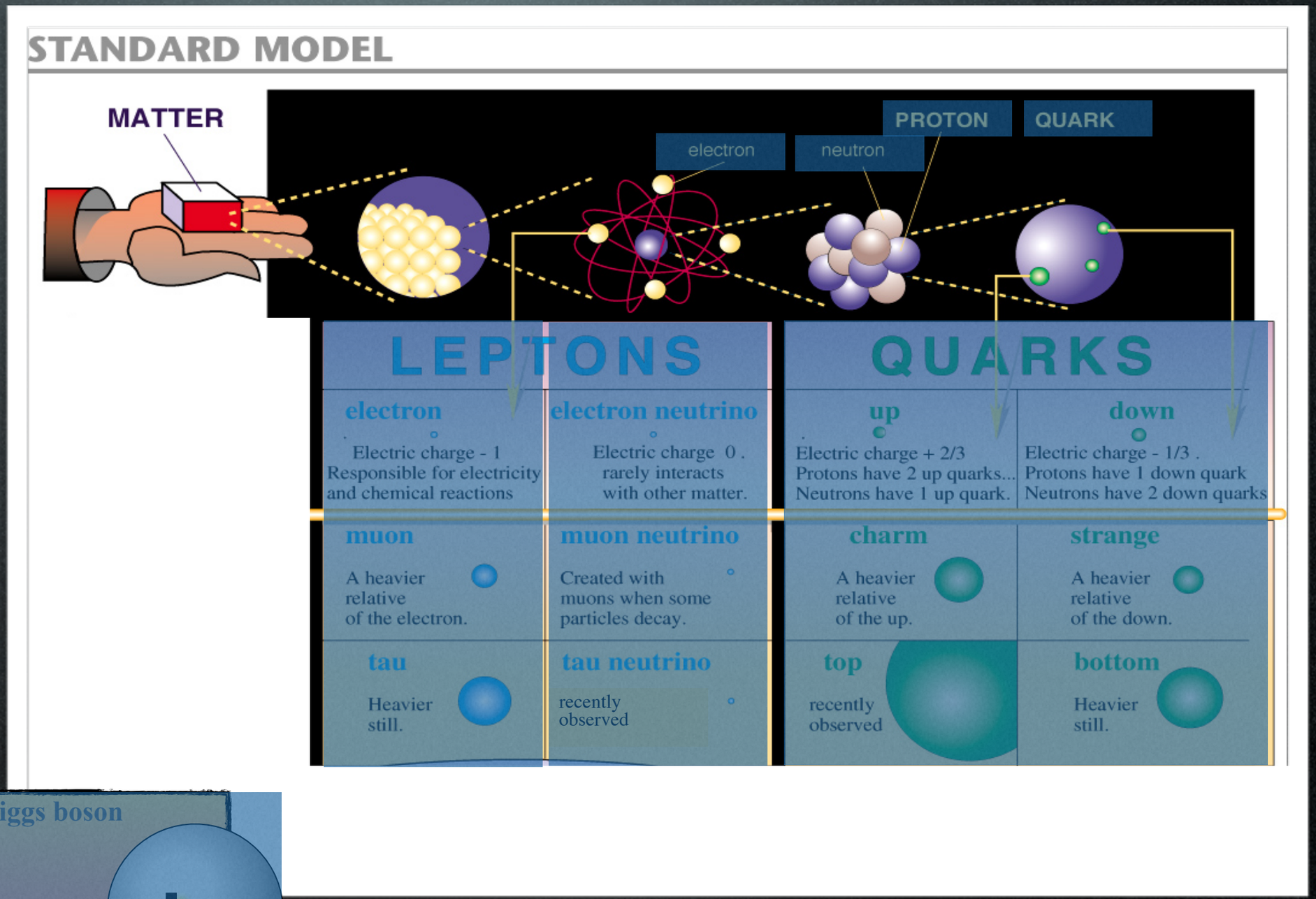

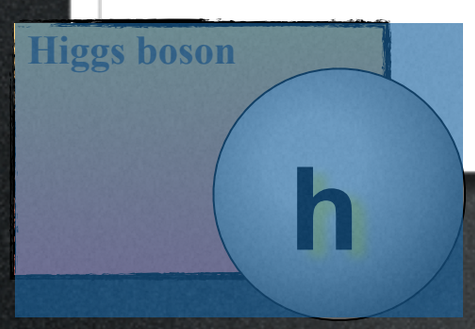

Propriétés et nature

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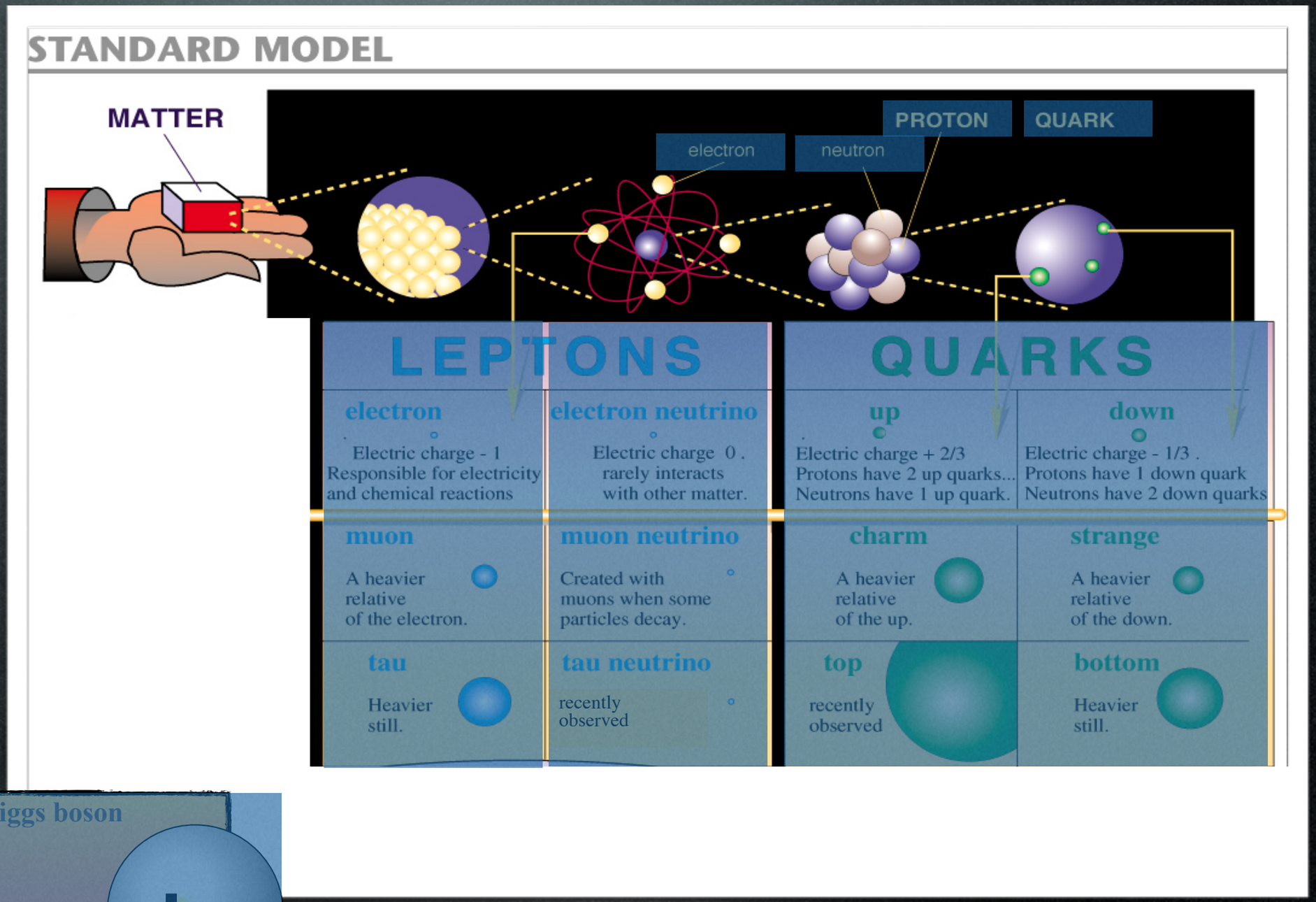
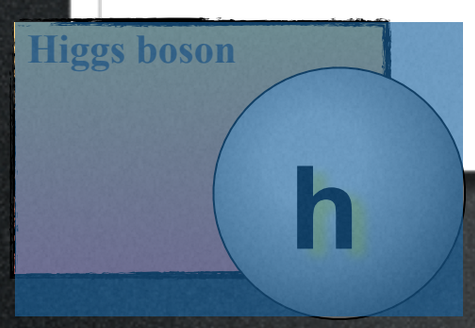
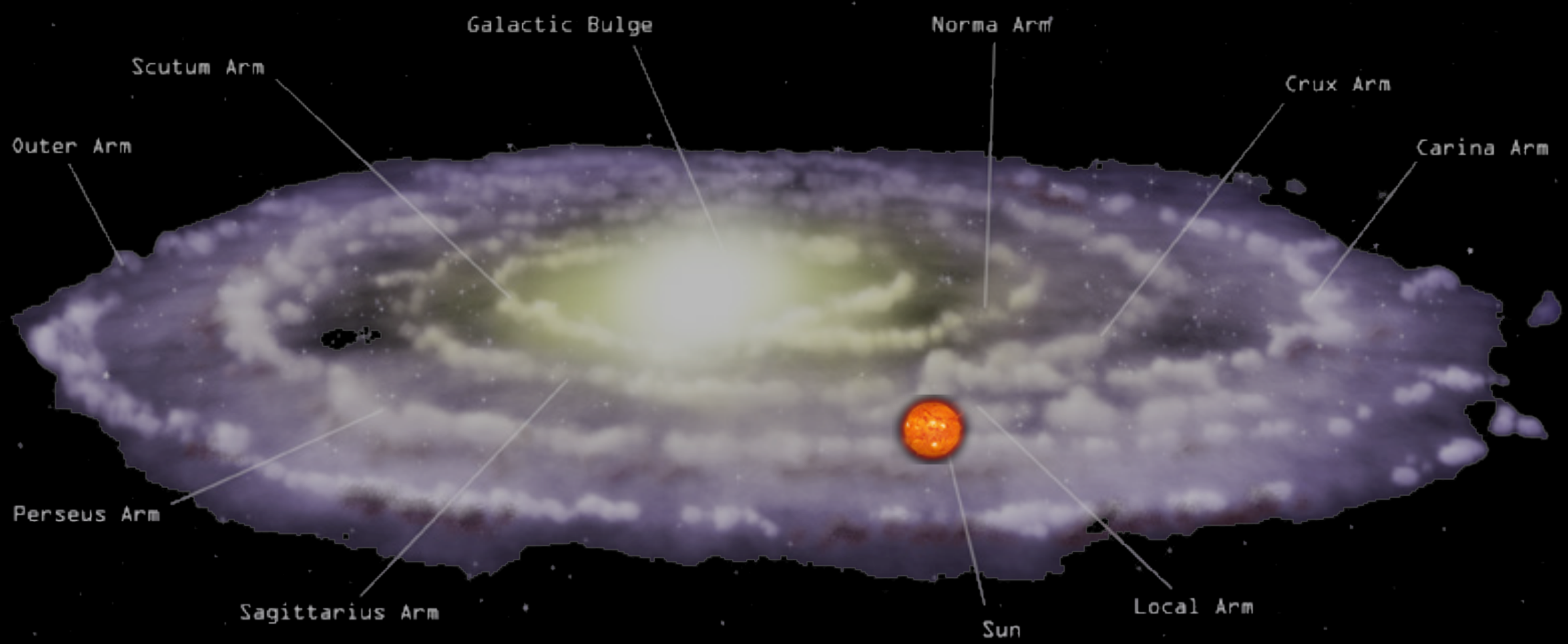




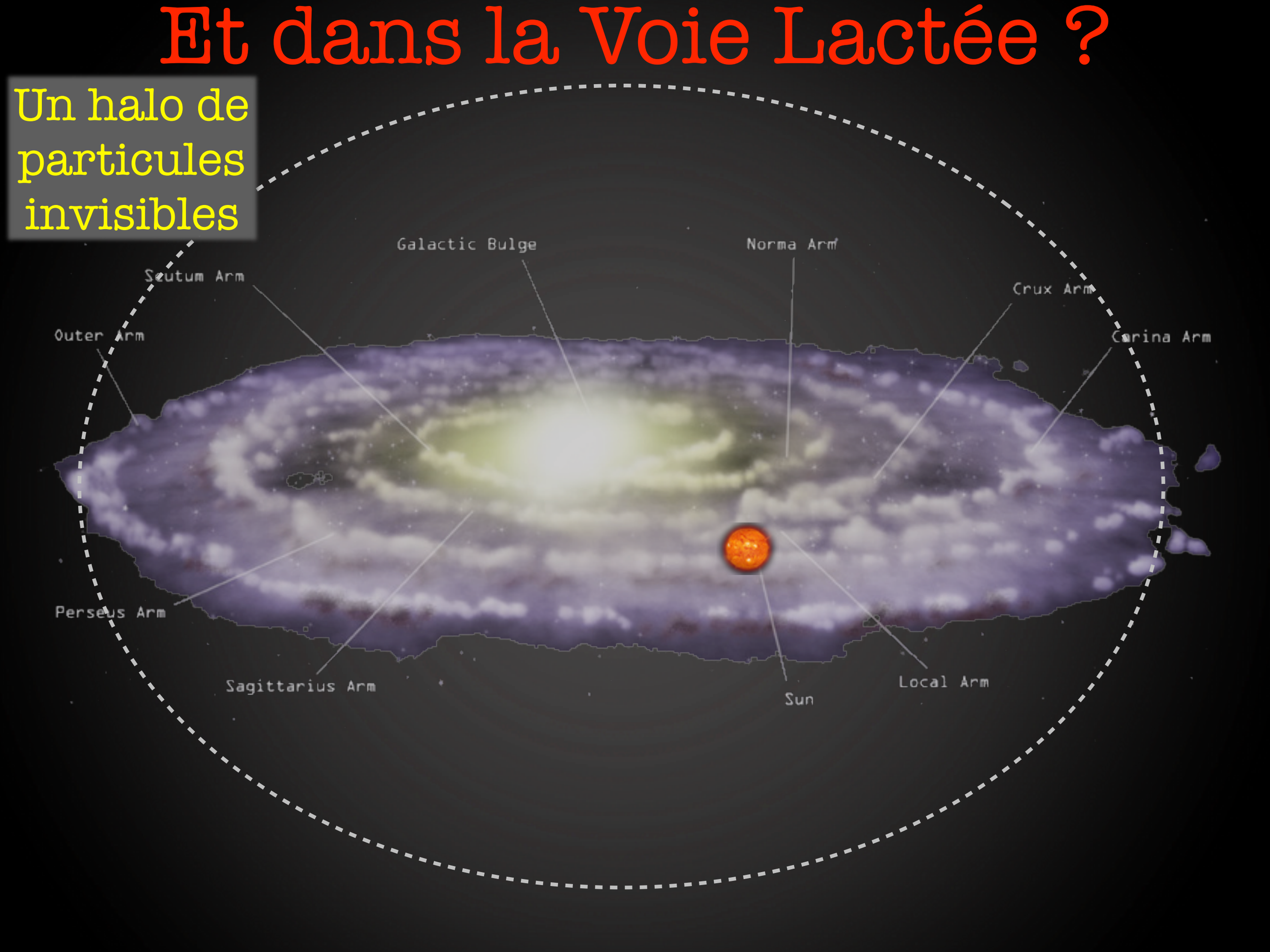
une **nouvelle** particule, encore **inconnue**

Et dans la Voie Lactée ?



Et dans la Voie Lactée ?

Un halo de particules invisibles



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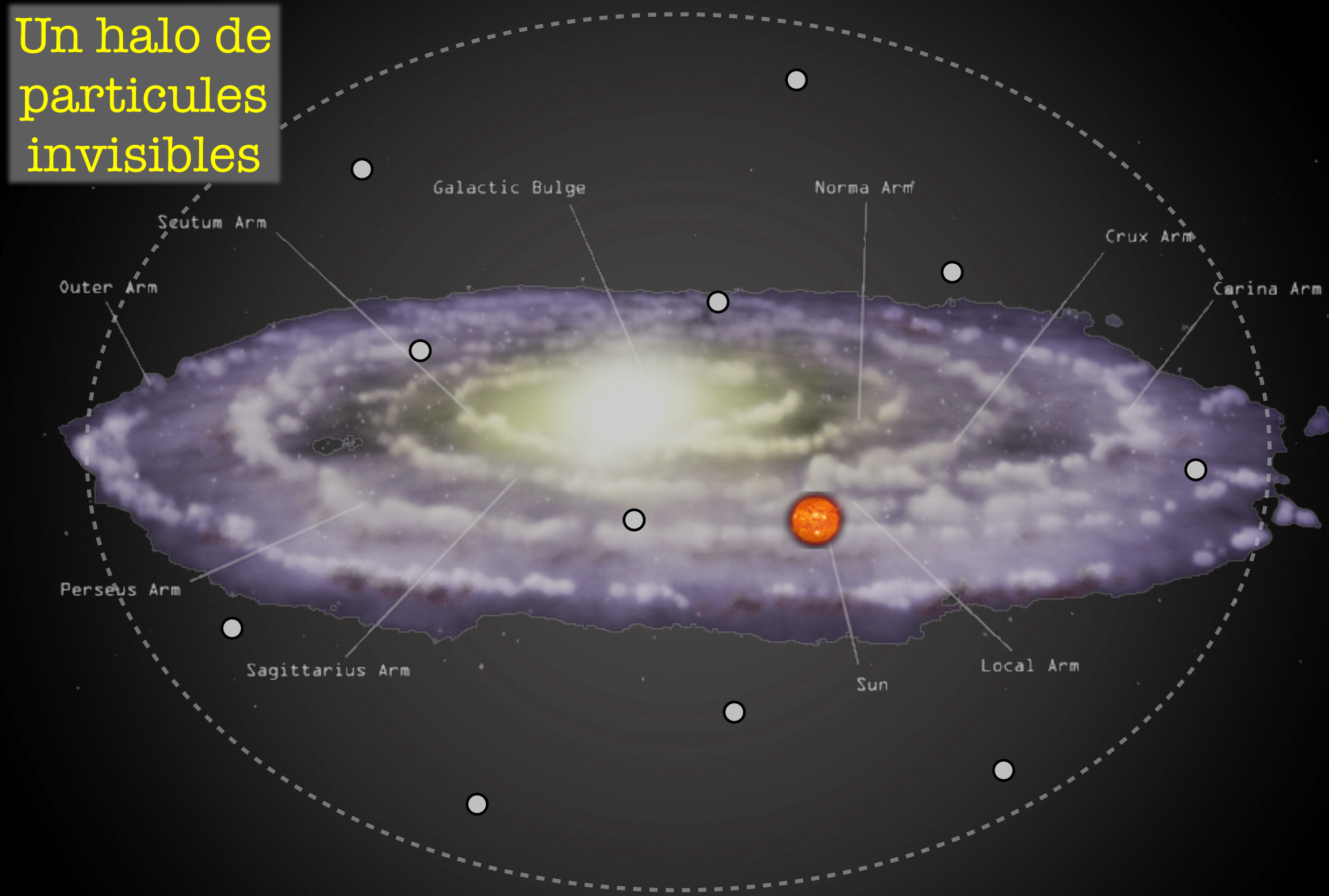

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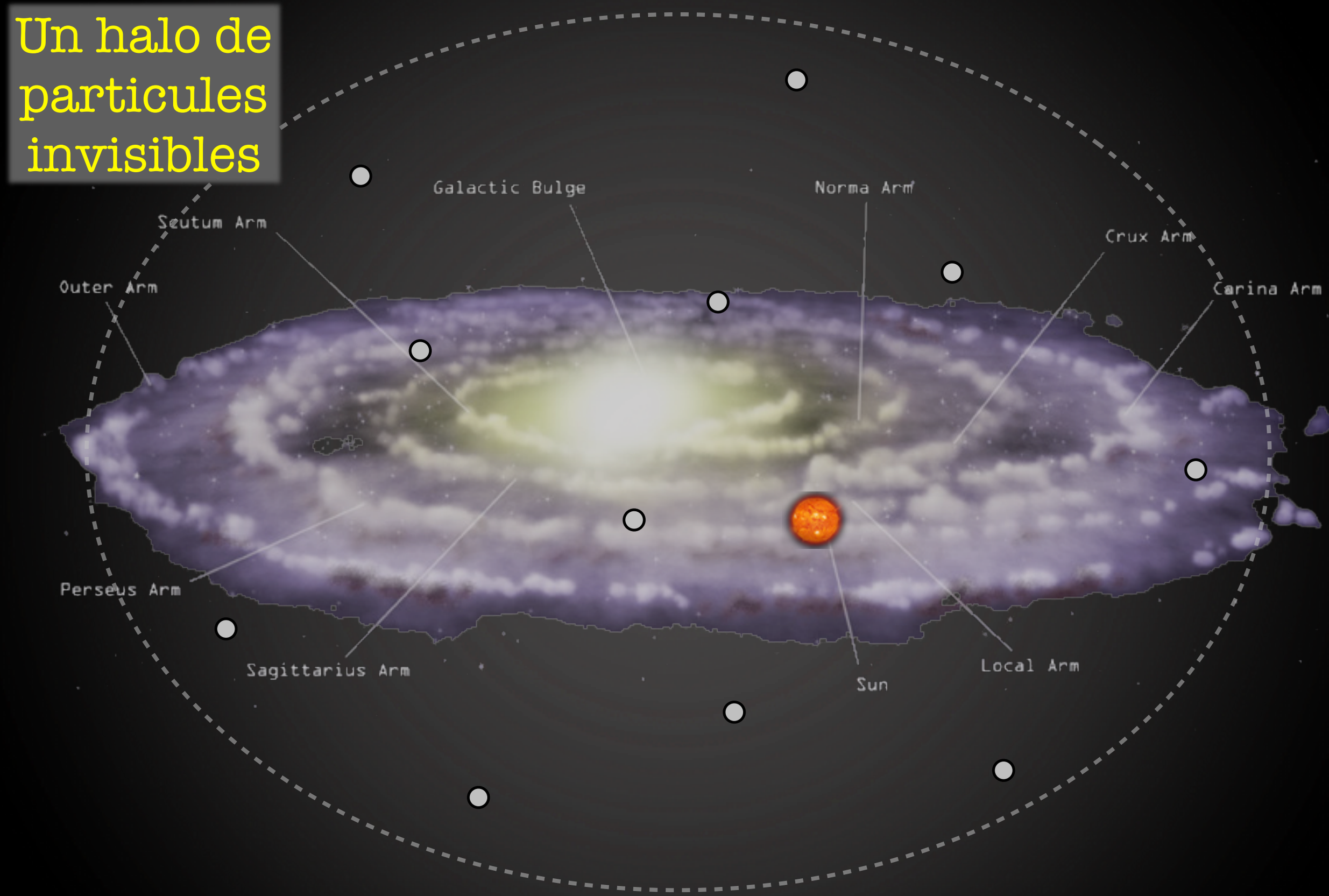

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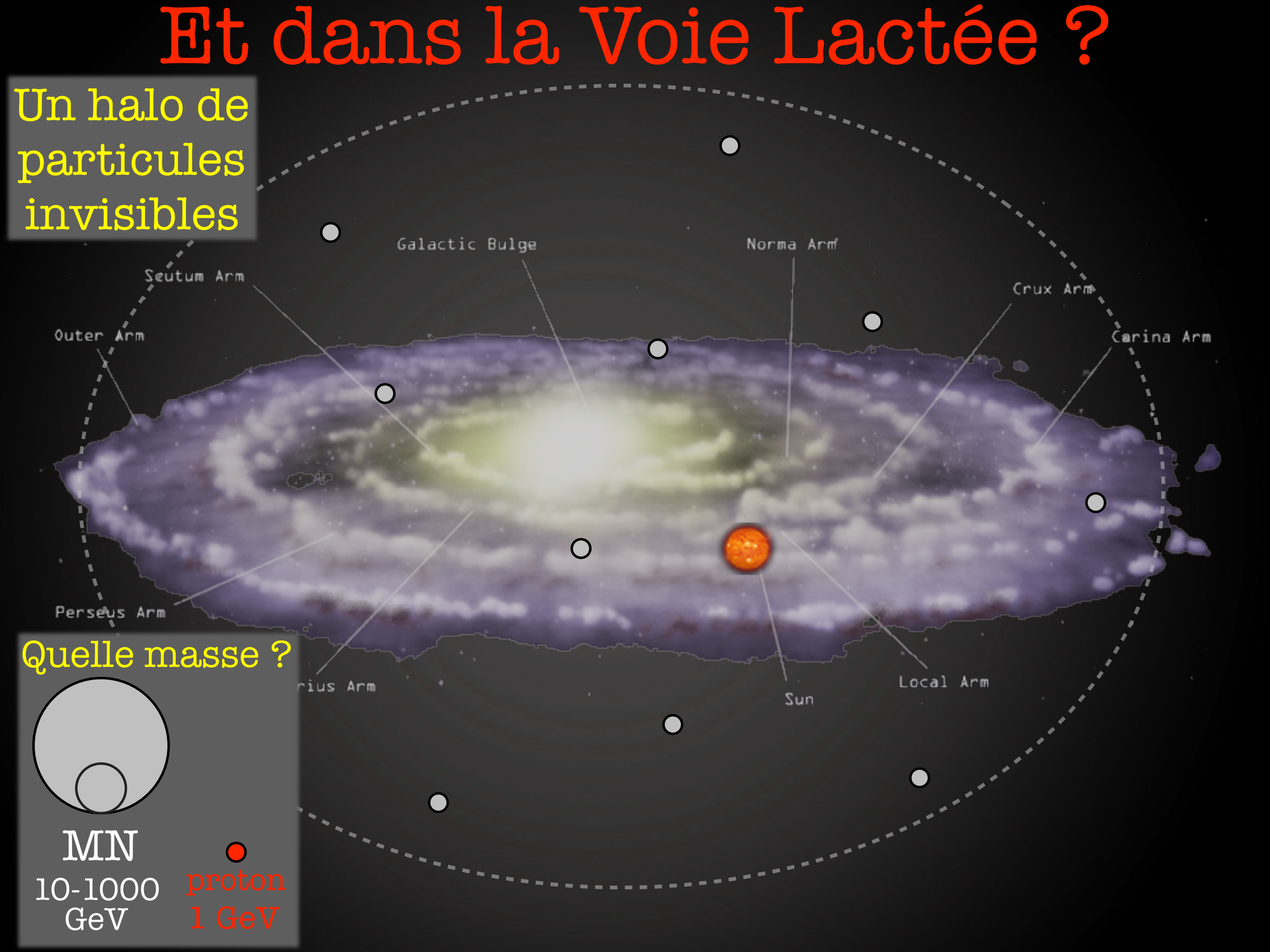


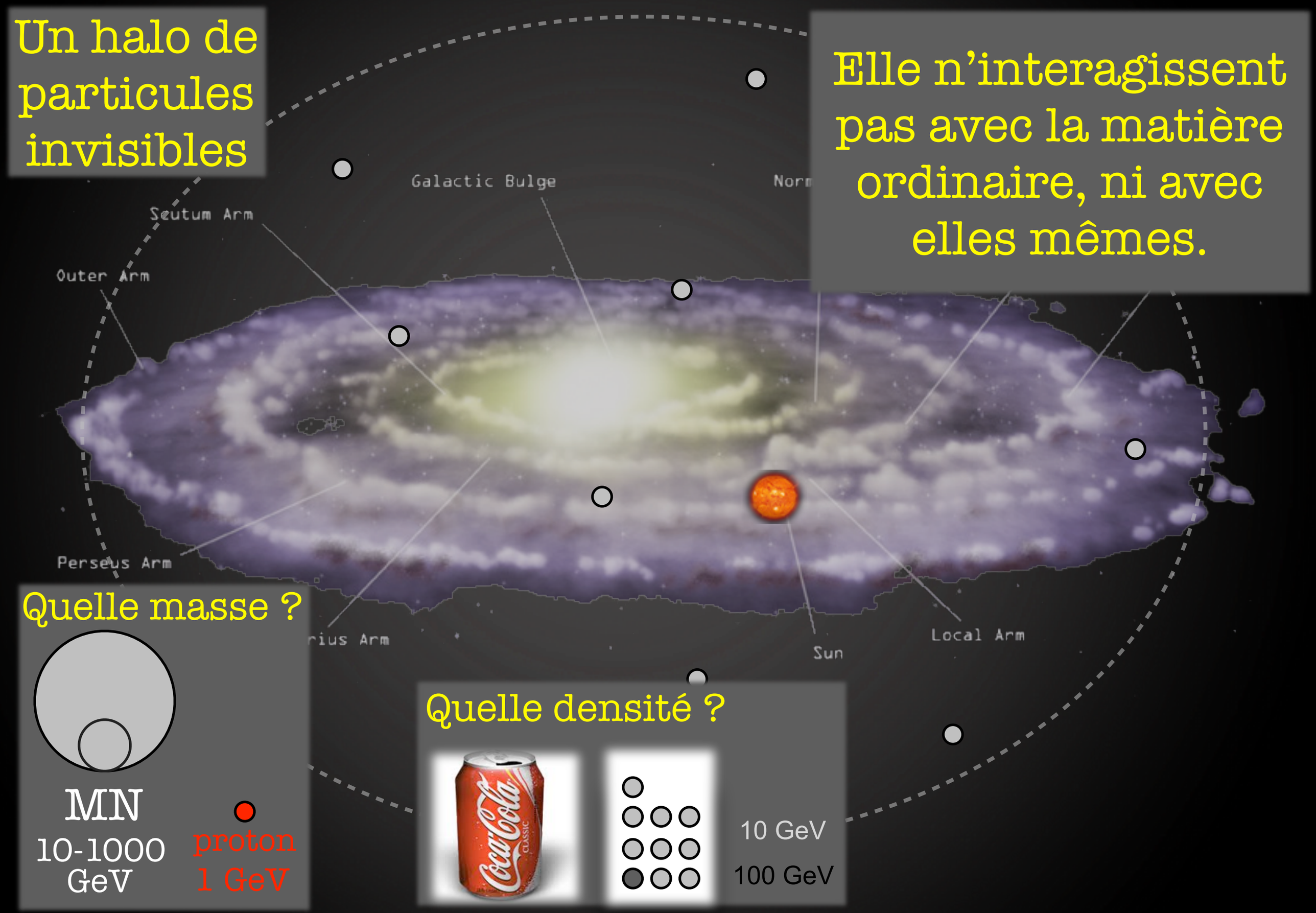
Et dans la Voie Lactée ?

Un halo de particules invisibles

Et dans la Voie Lactée ?

Un halo de particules invisibles

Elle n'interagissent pas avec la matière ordinaire, ni avec elles mêmes.



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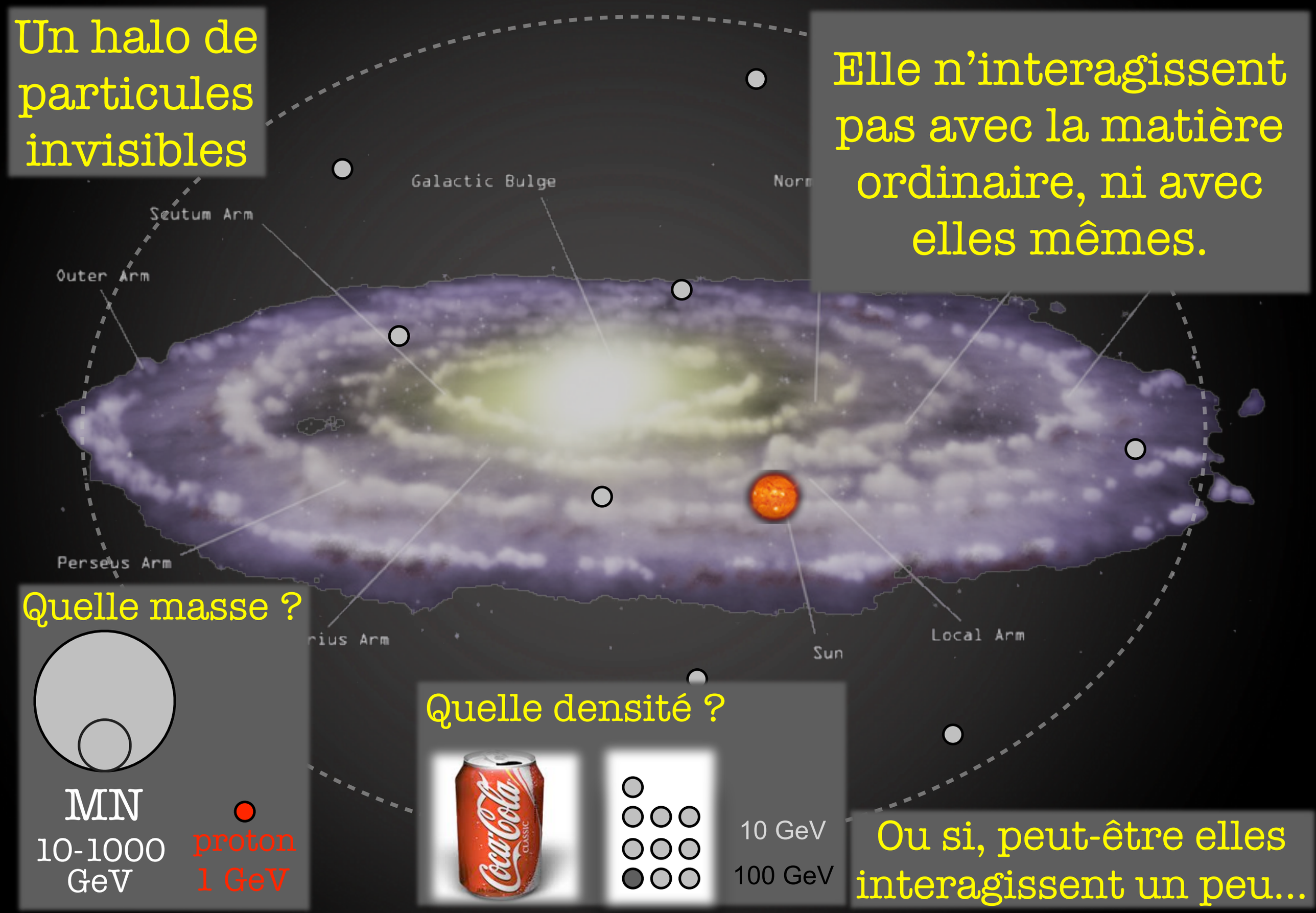


Ou si, peut-être elles interagissent un peu...

Comment
détecter
la Matière Noire ?

Matière
Noire
?

Matière
Noire

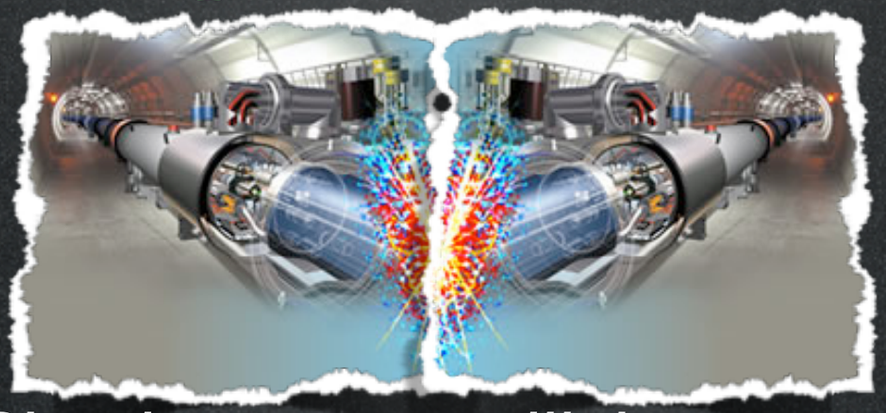
Physique souterraine

'détection directe'

Physique souterraine

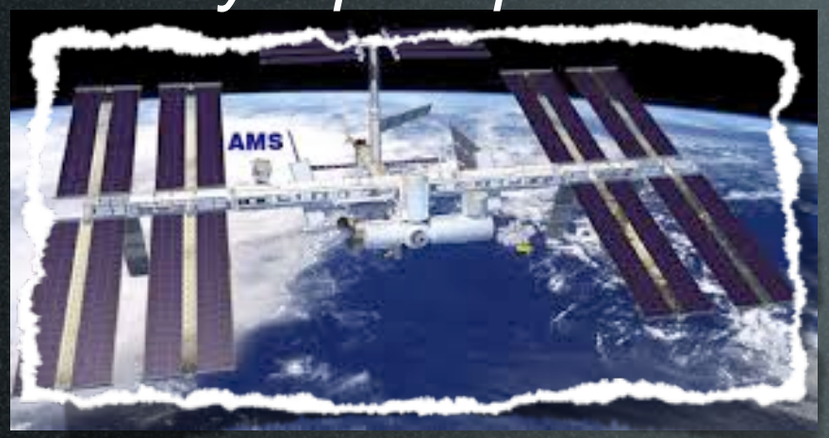
'détection directe'

'production'



Physique aux collisionneurs

Physique spatiale



'détection indirecte'

Physique souterraine

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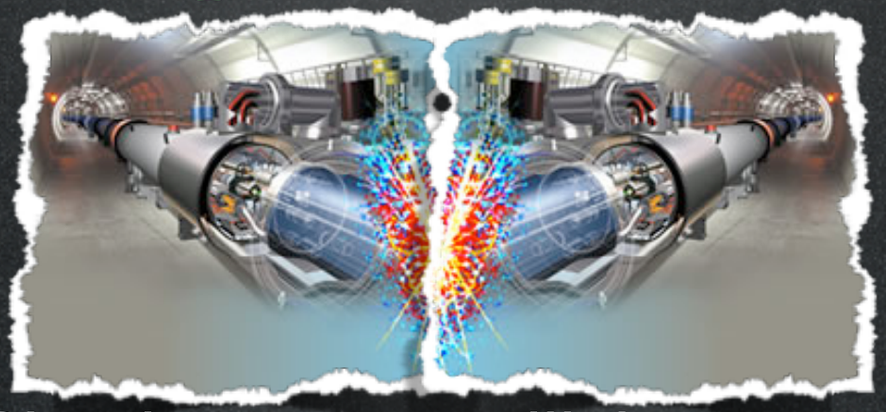
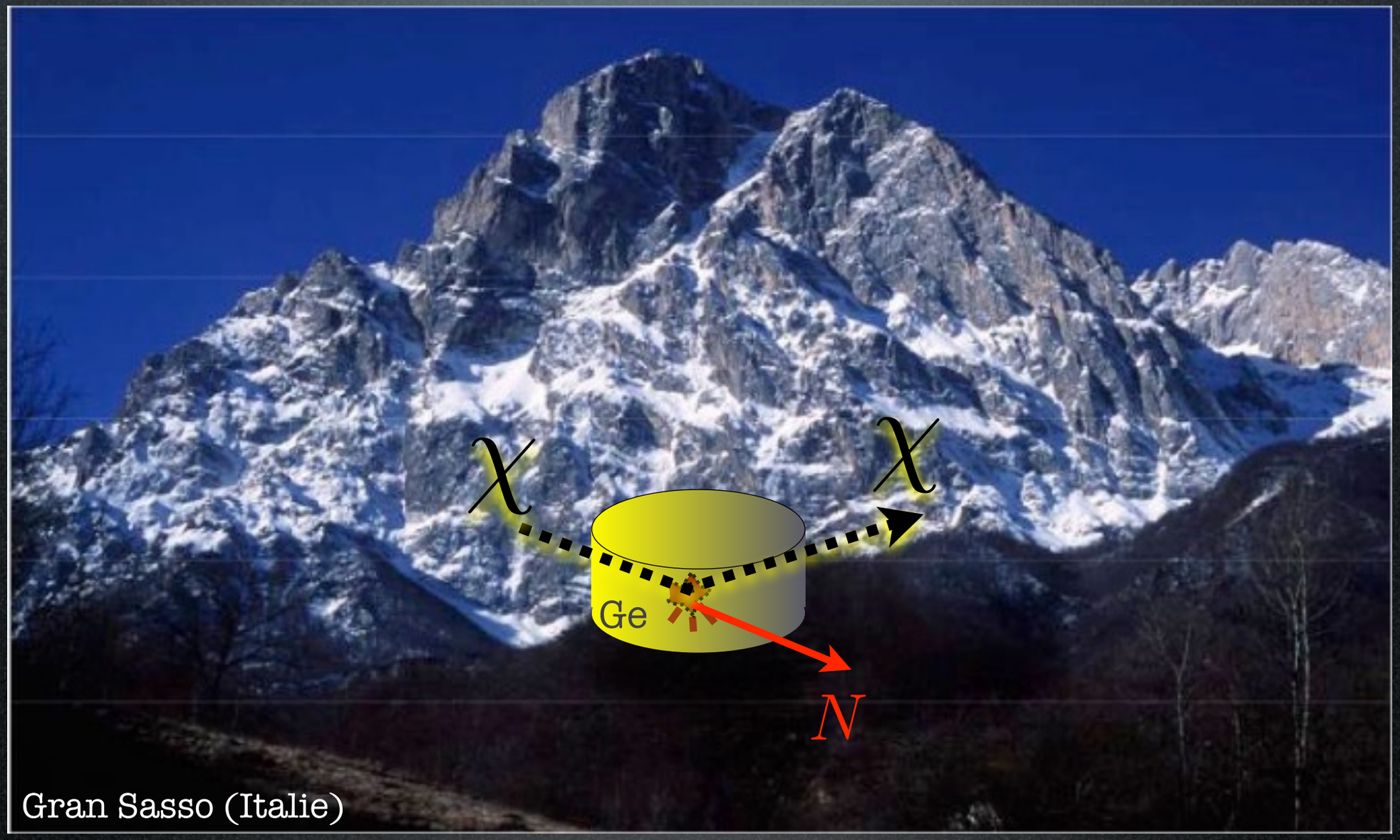


Physique aux collisionneurs

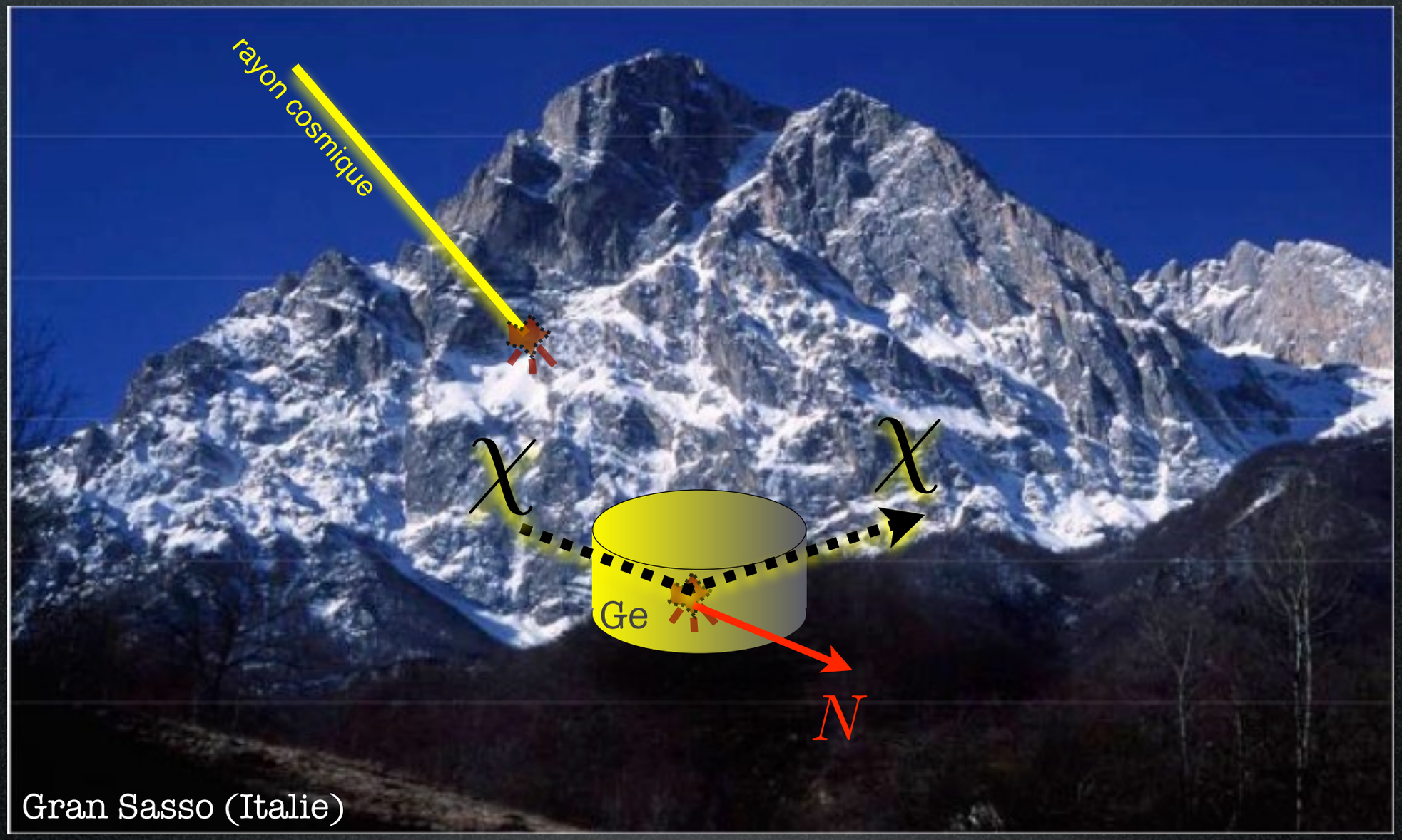
Détection directe

Détection directe

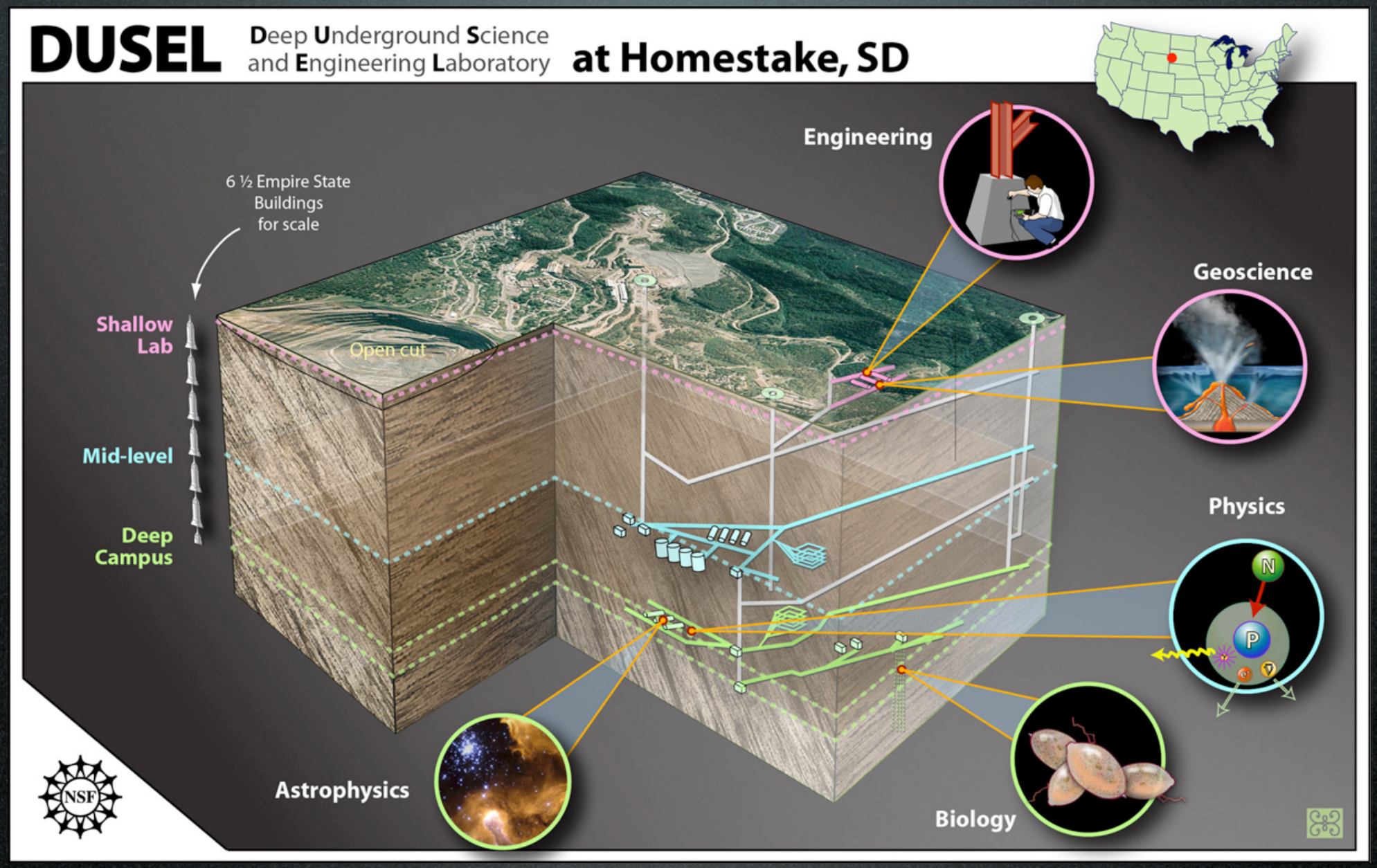
Détection directe



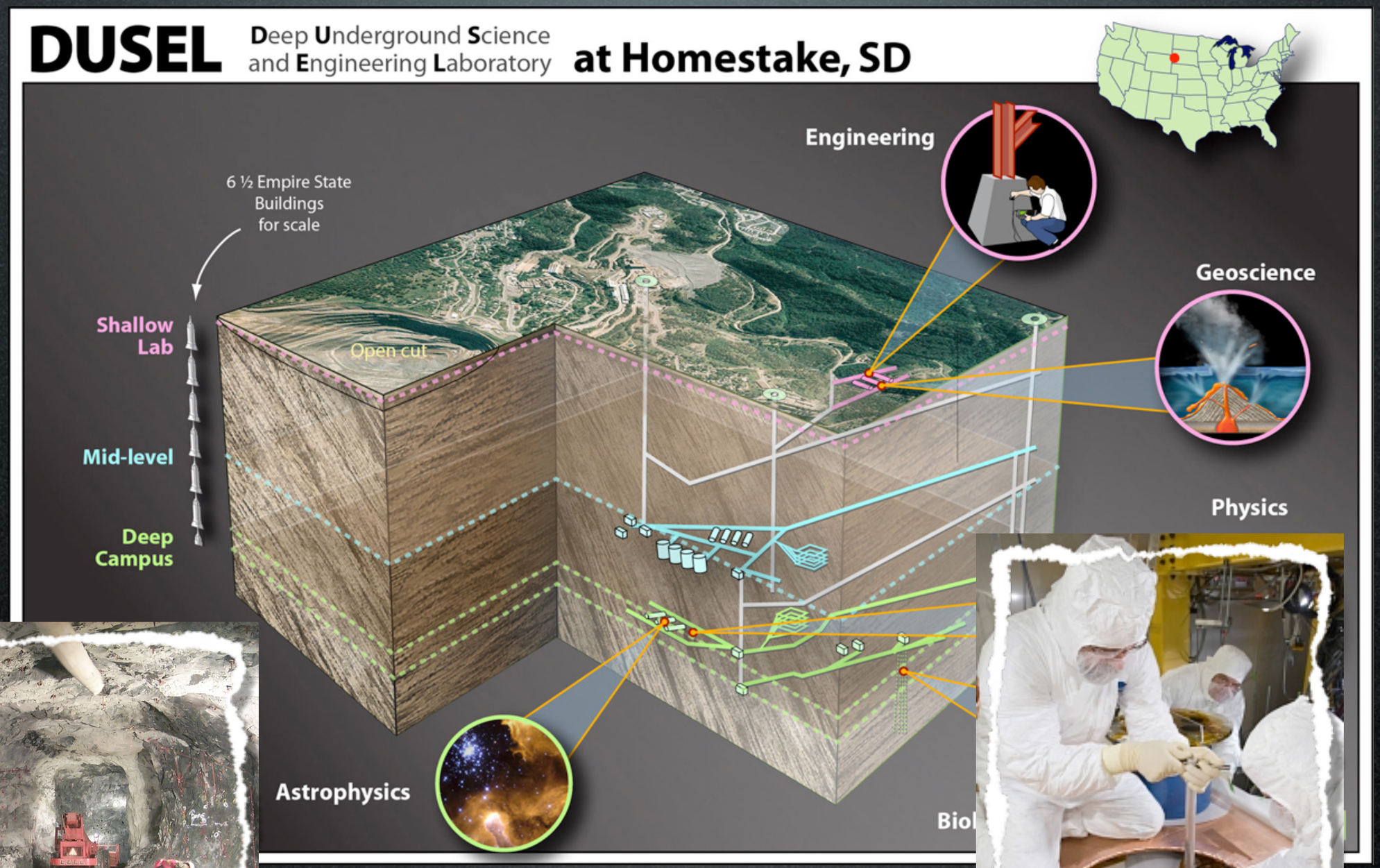
Détection directe



Détection directe



Détection directe



Détection directe

Stratégie n.1: faire taire l'Univers

Détection directe

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mesurer deux quantités pour distinguer le Signal du Bruit, pour chaque événement

Détection directe

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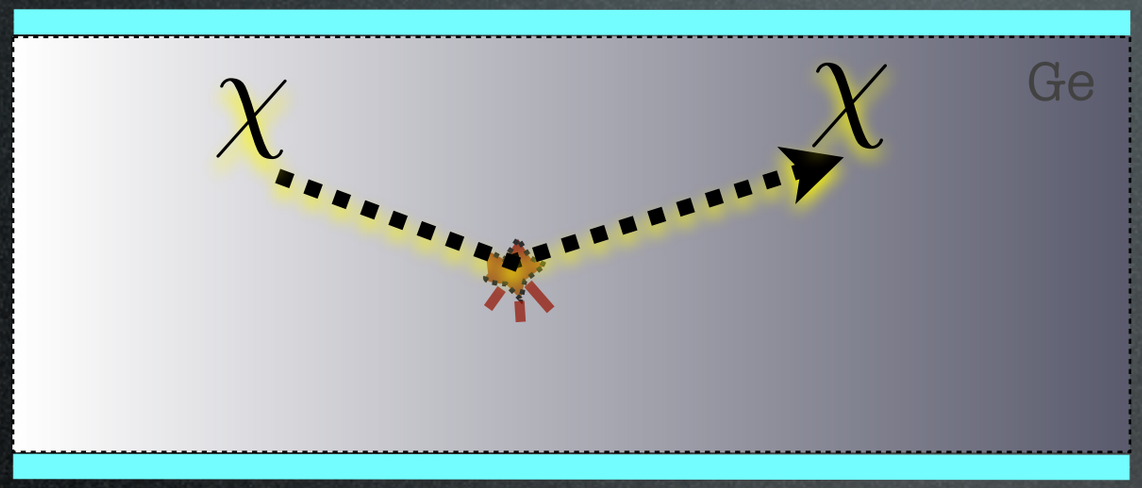

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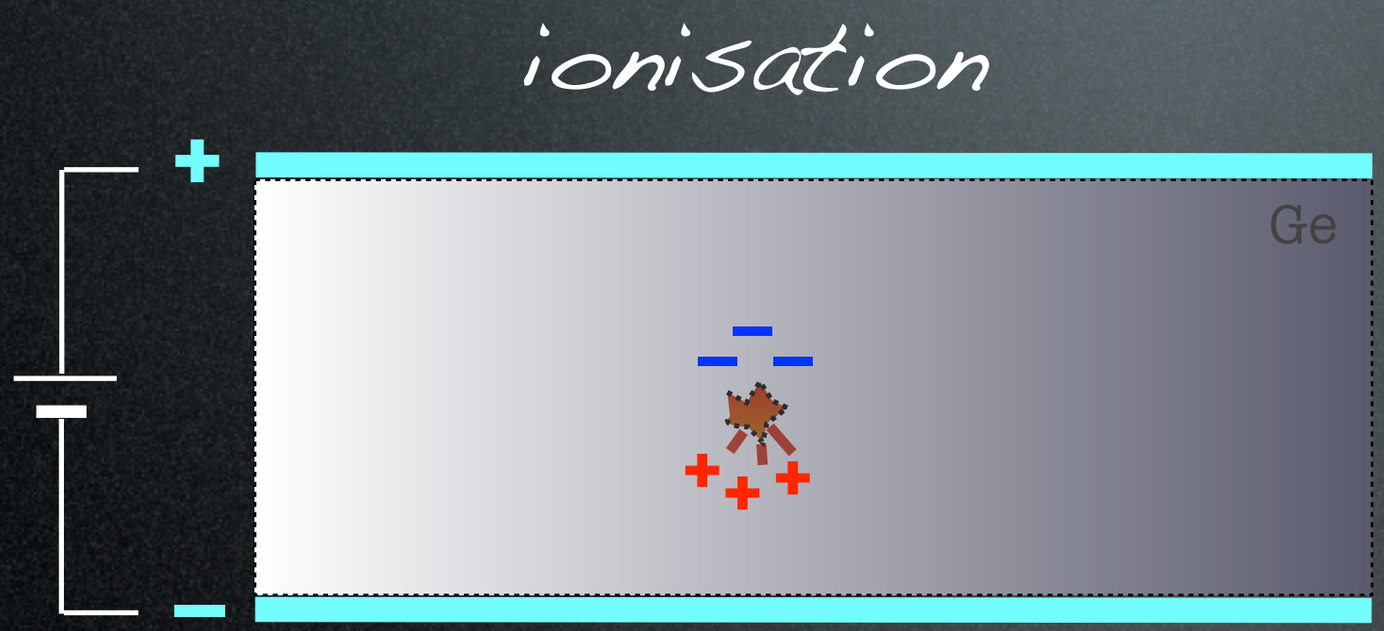

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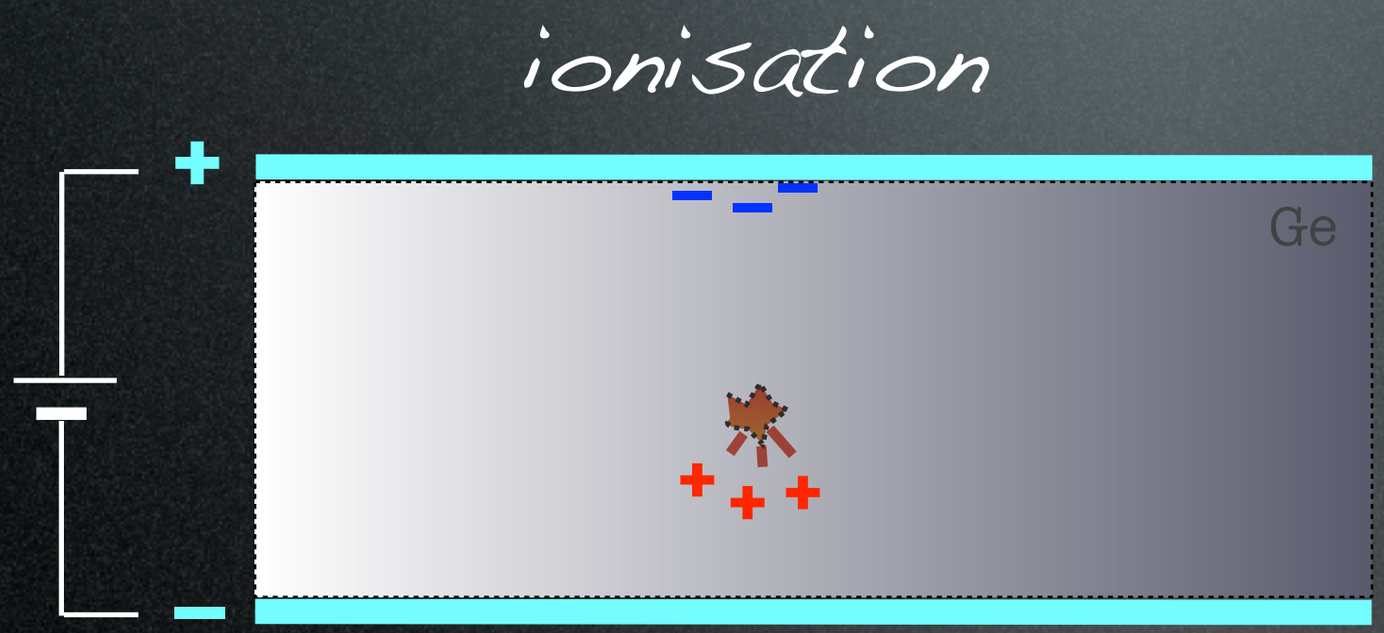

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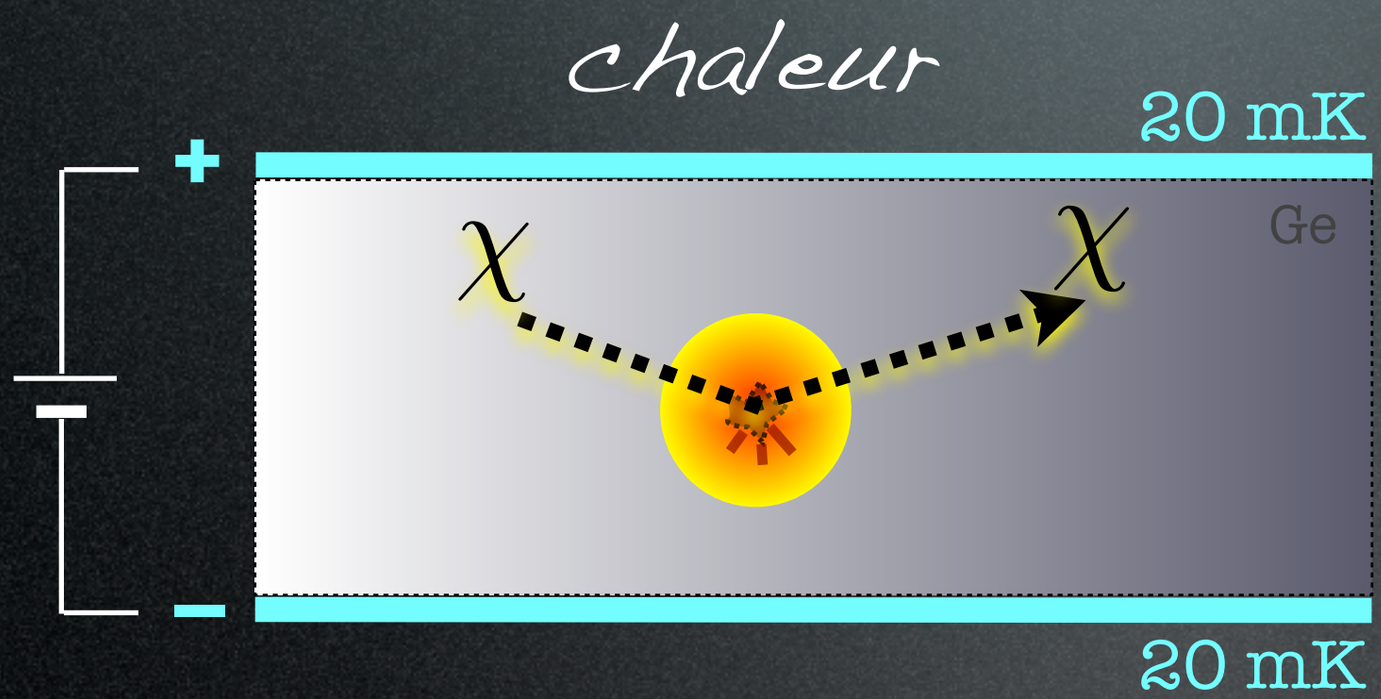

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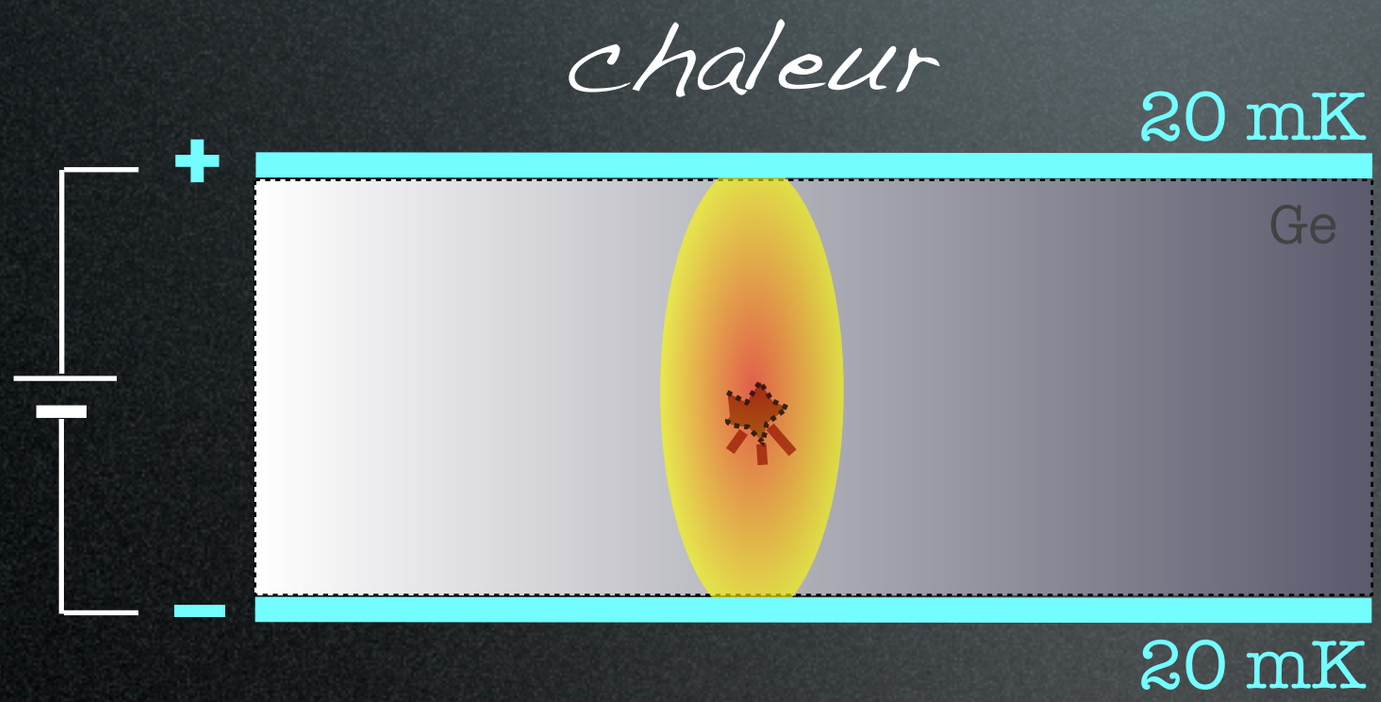

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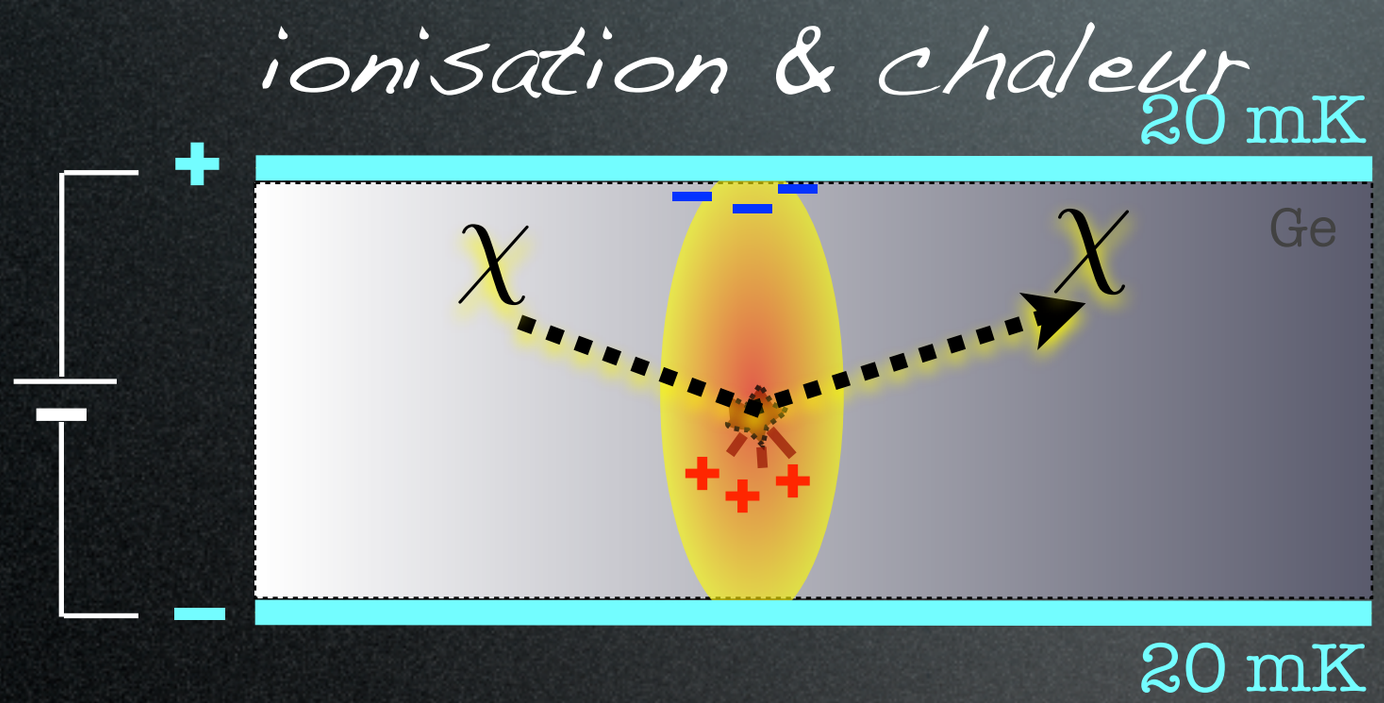

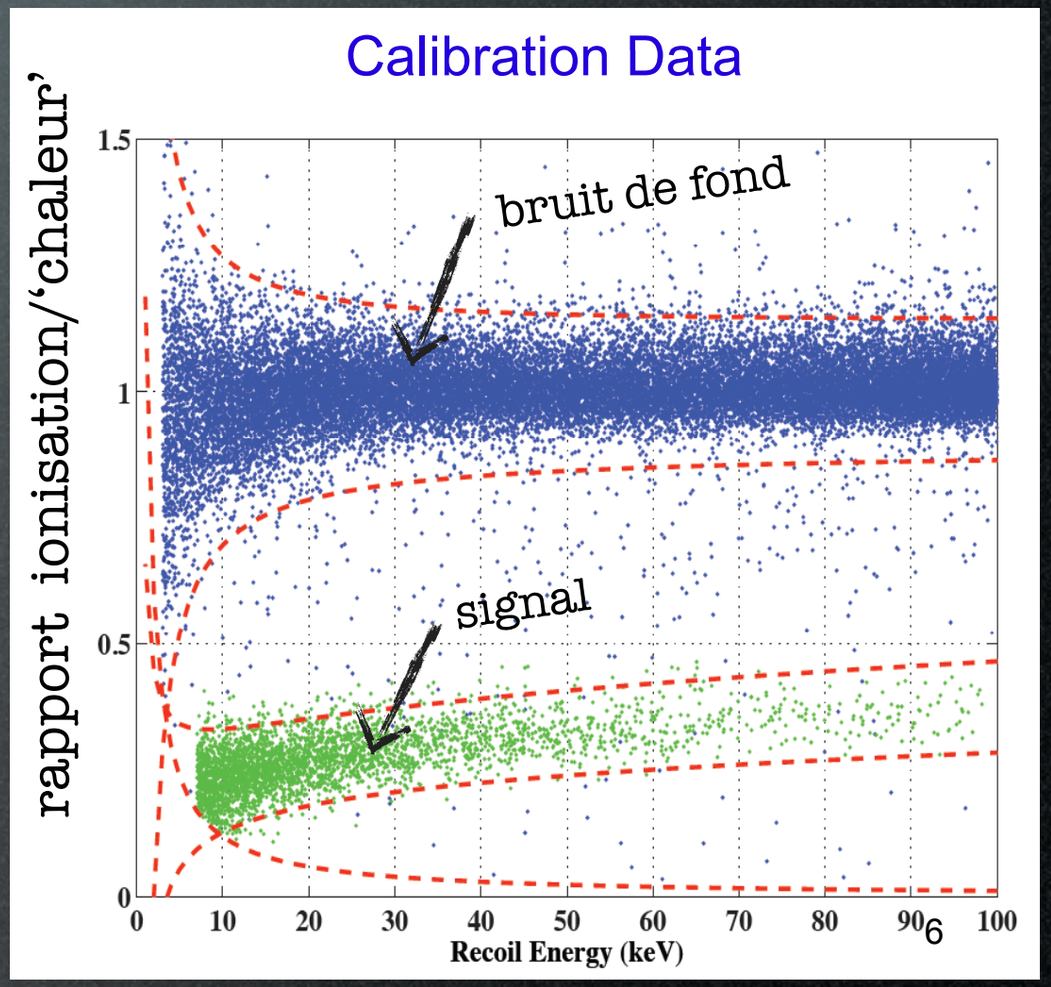

CDMS coll.

Détection directe

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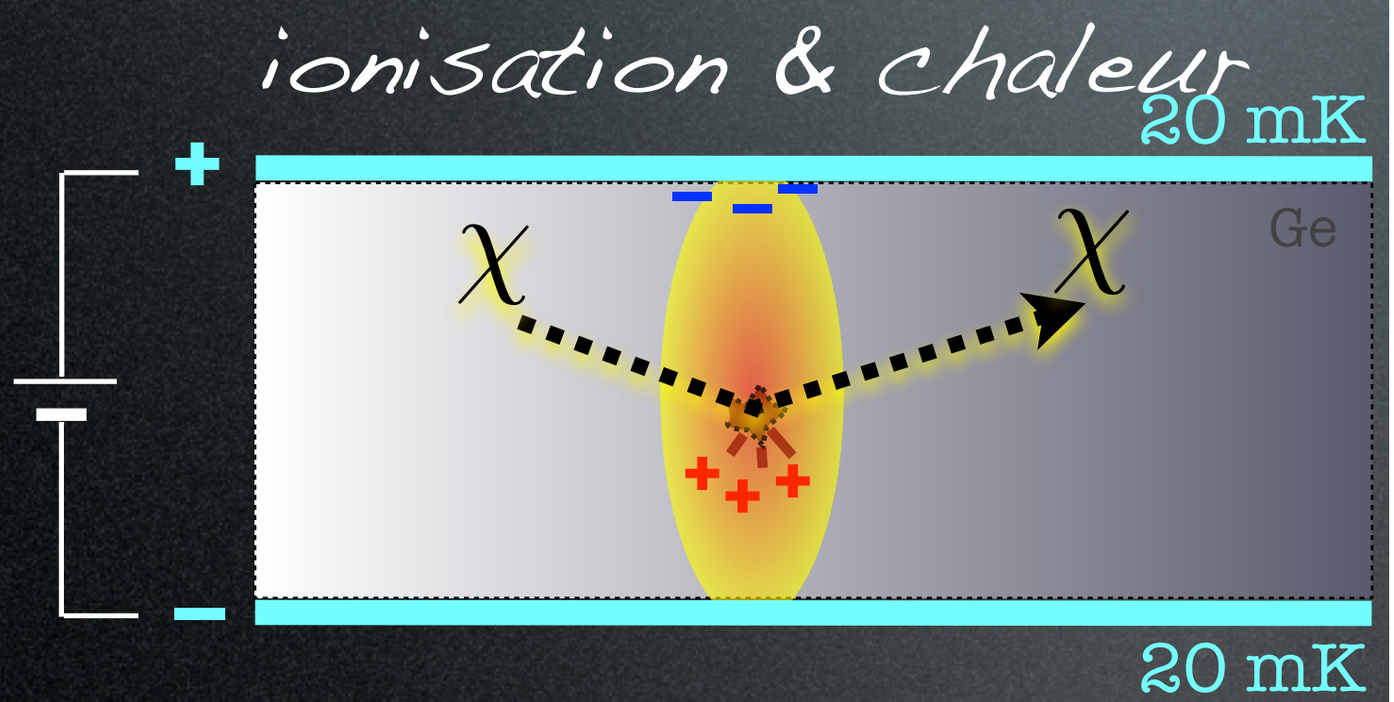

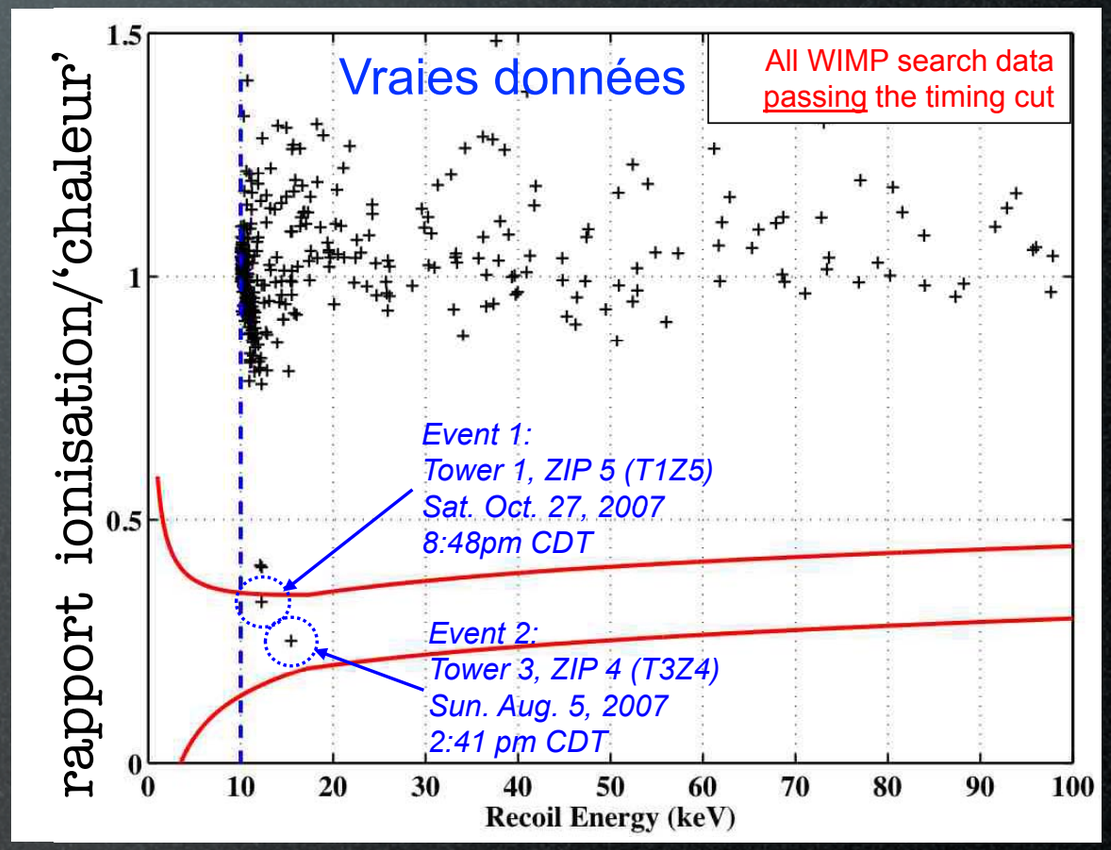

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Détection directe

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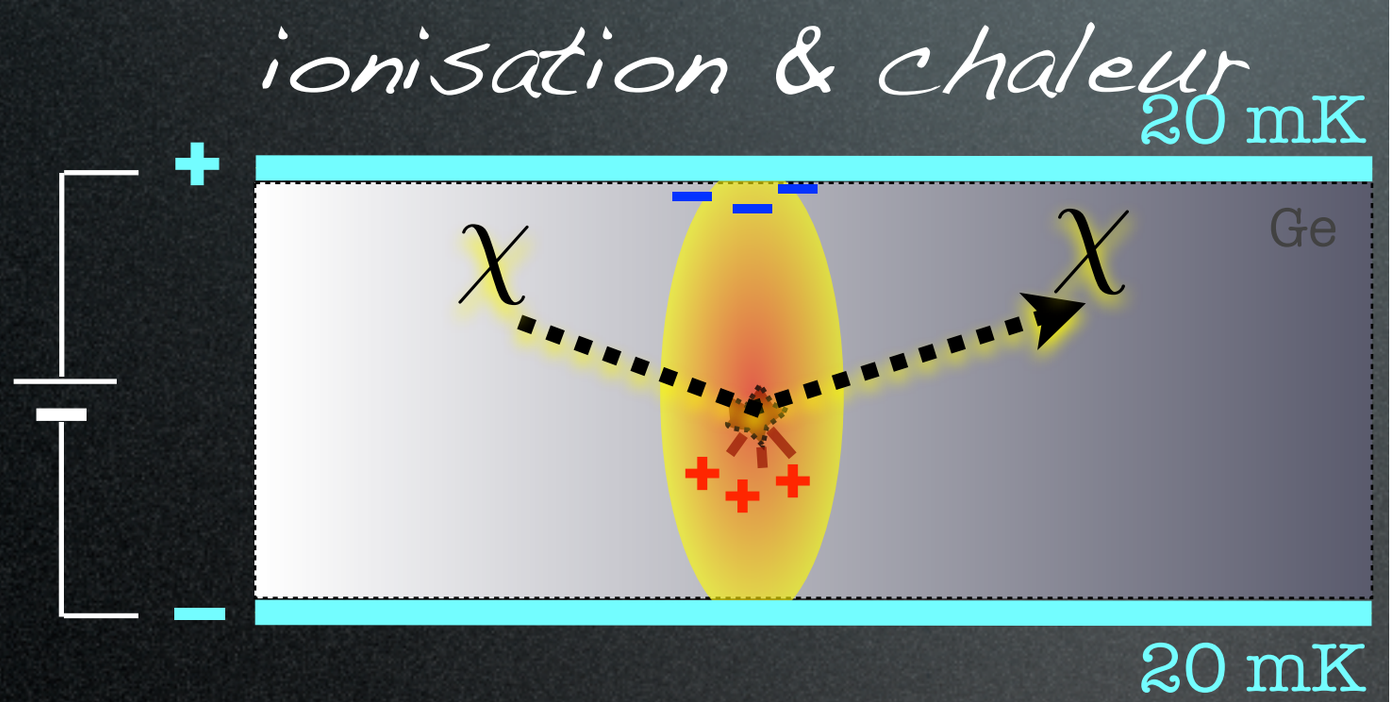

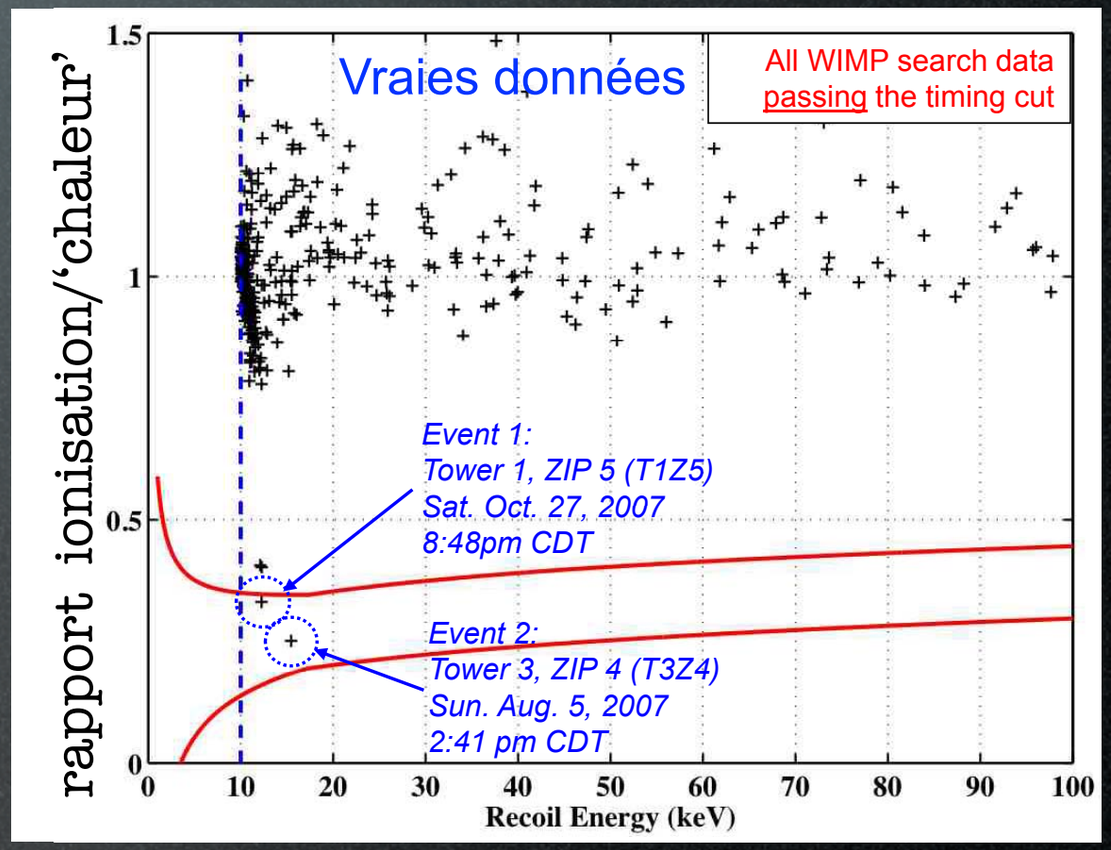

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NB: 1 évènement/kg/an!

Détection directe

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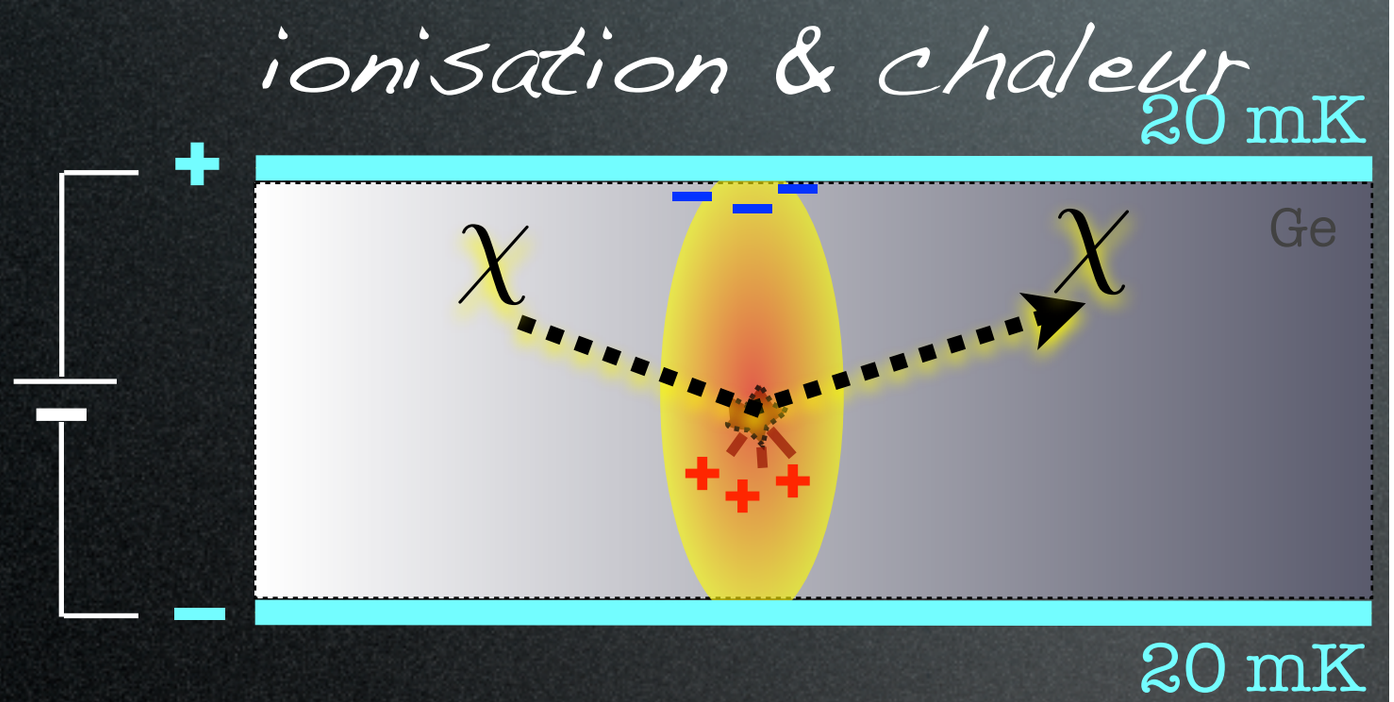

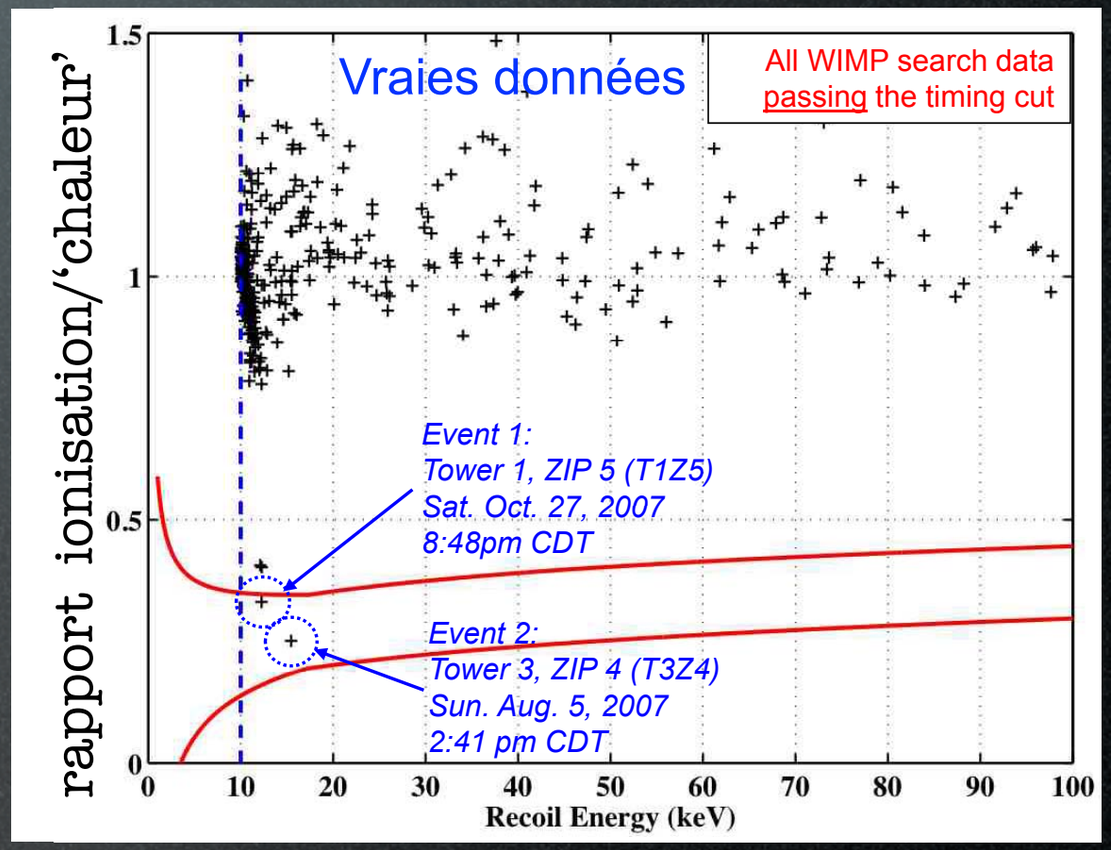

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Dans le corps humain: 10^{10} evt/kg/an

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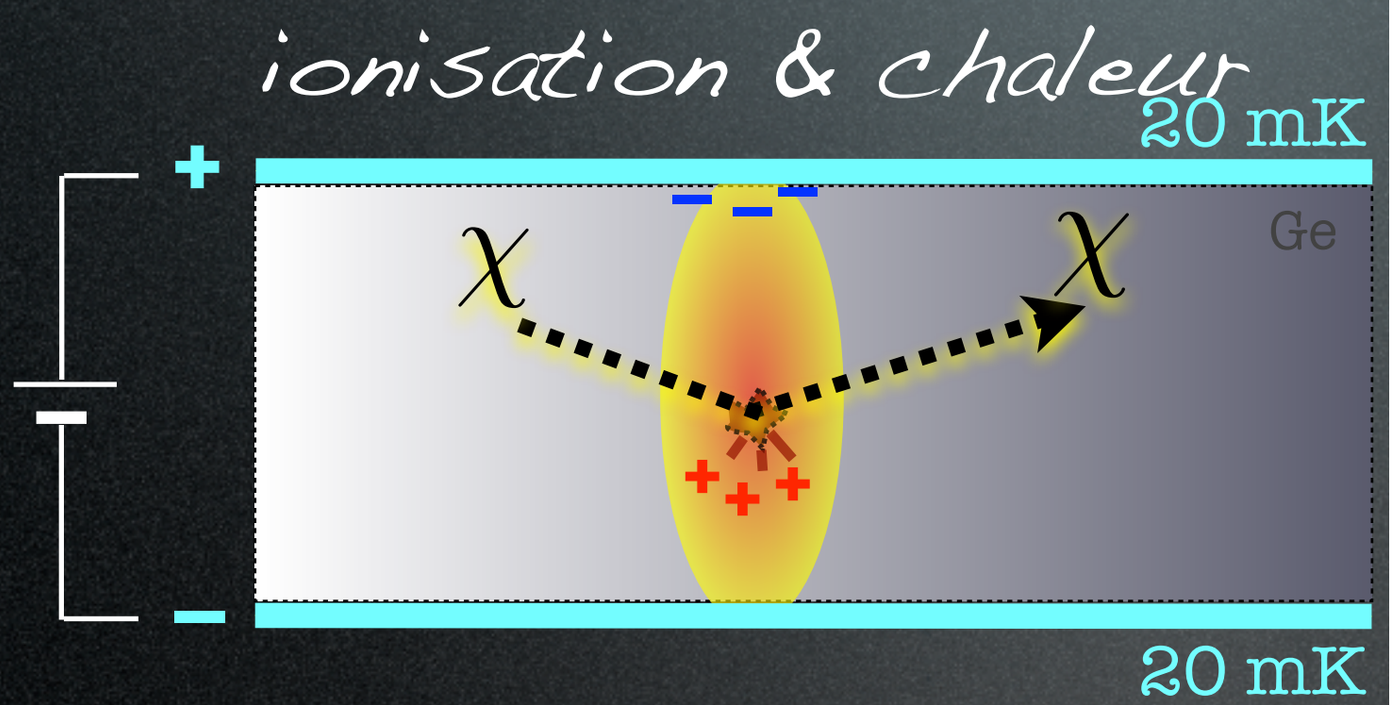

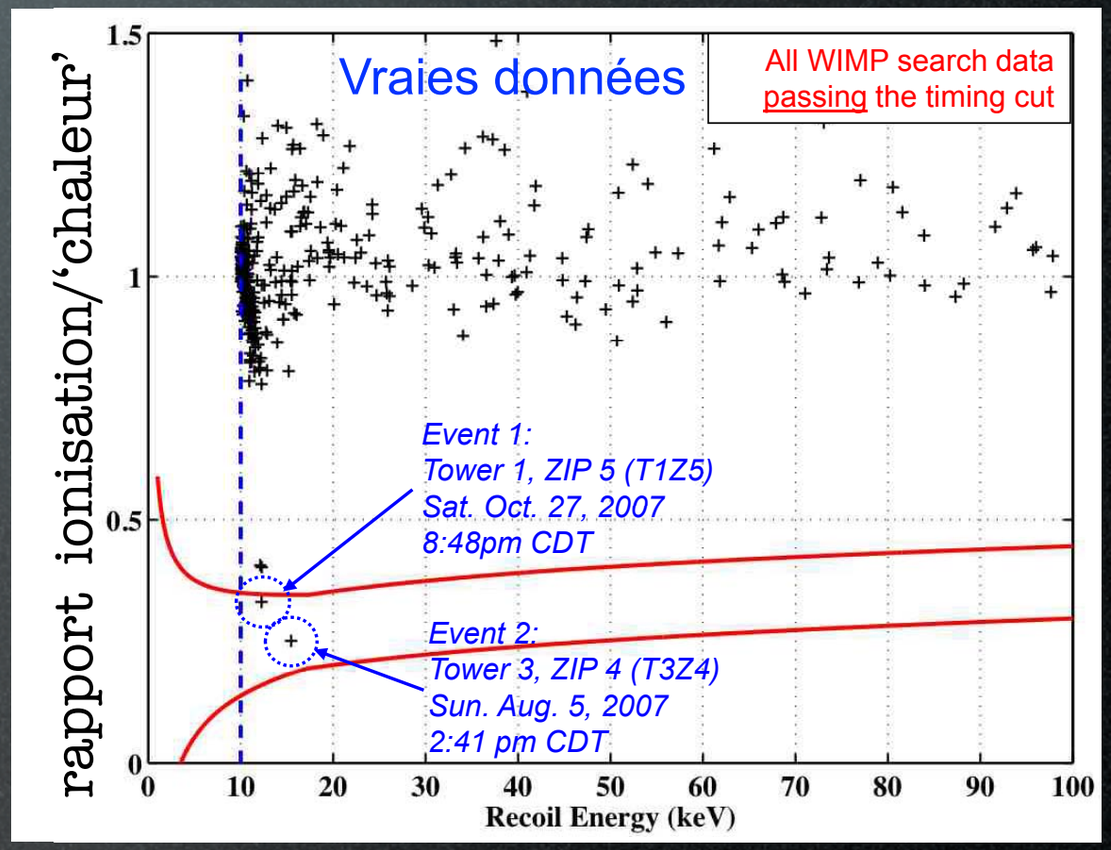

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Détection directe

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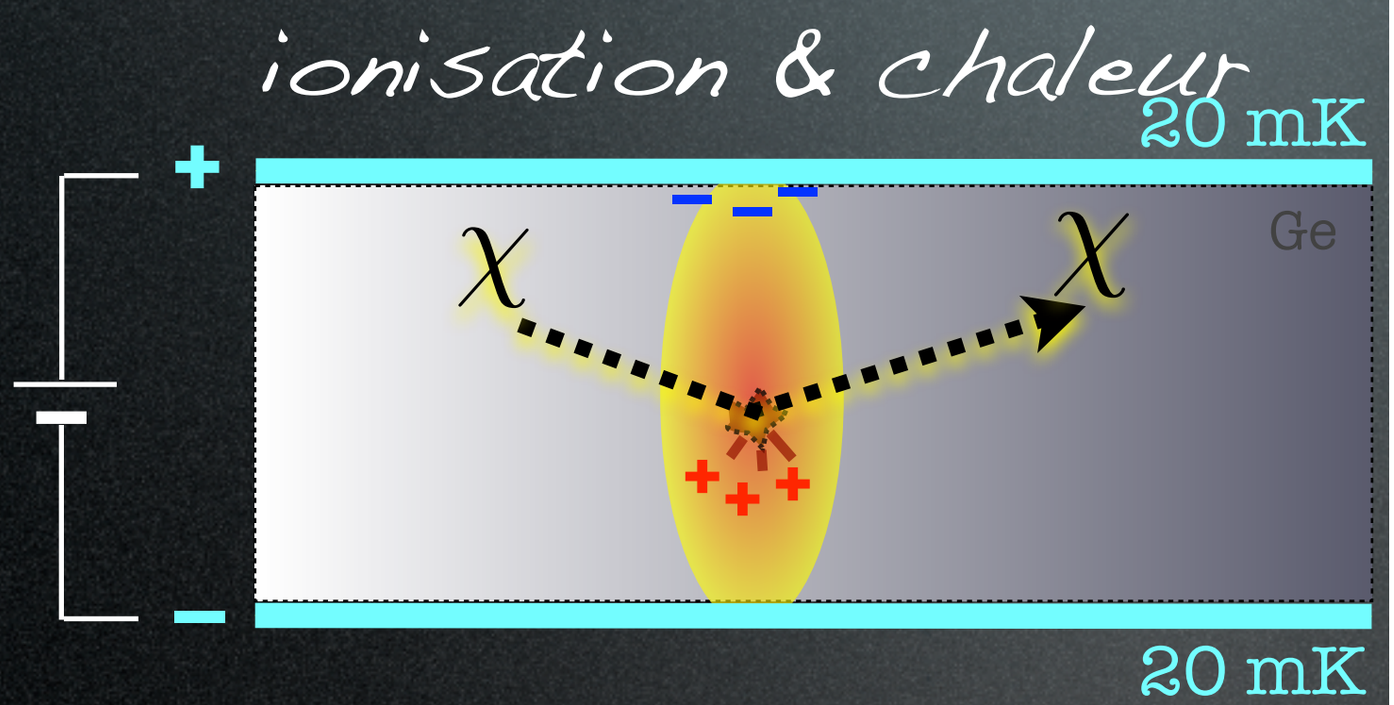

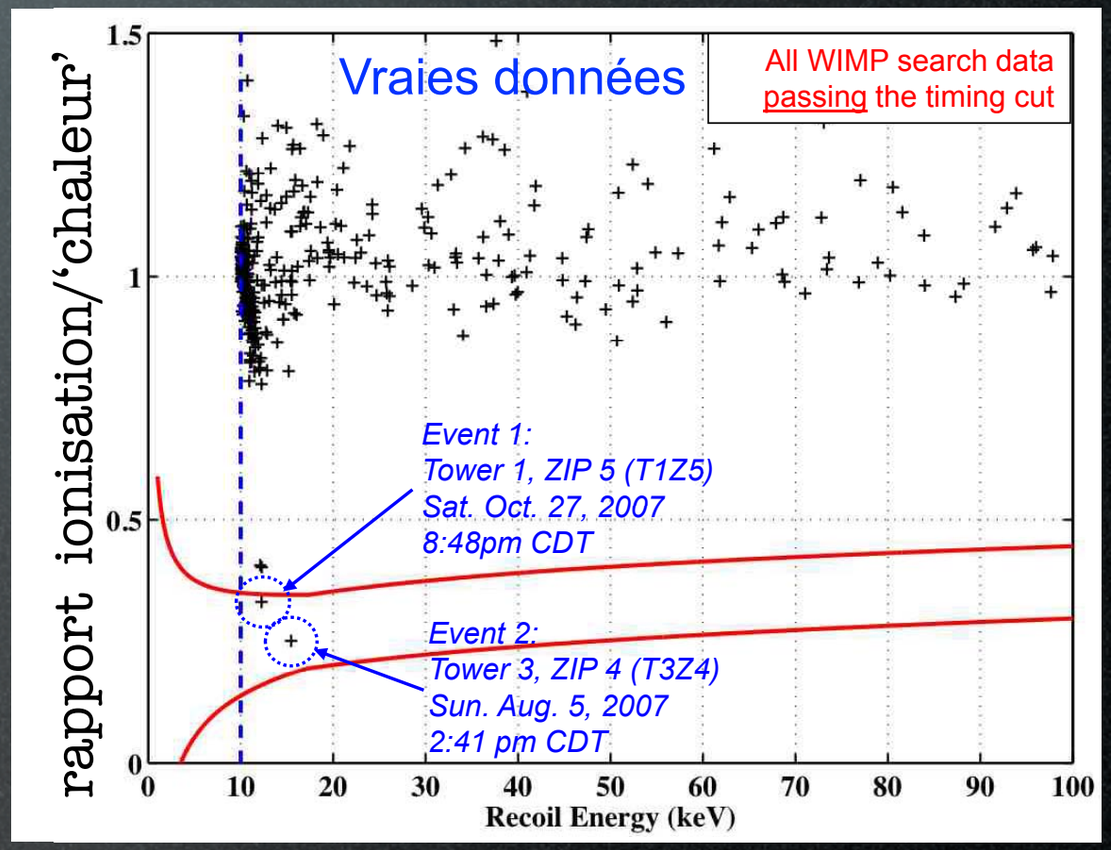

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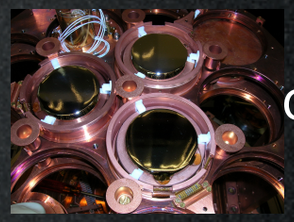
Edelweiss



contre

10 milliards de tonnes

Détection directe

Stratégie n.2: surfer sur la vague noire

collecter tous les évènements,
et détecter une modulation annuelle

Détection directe

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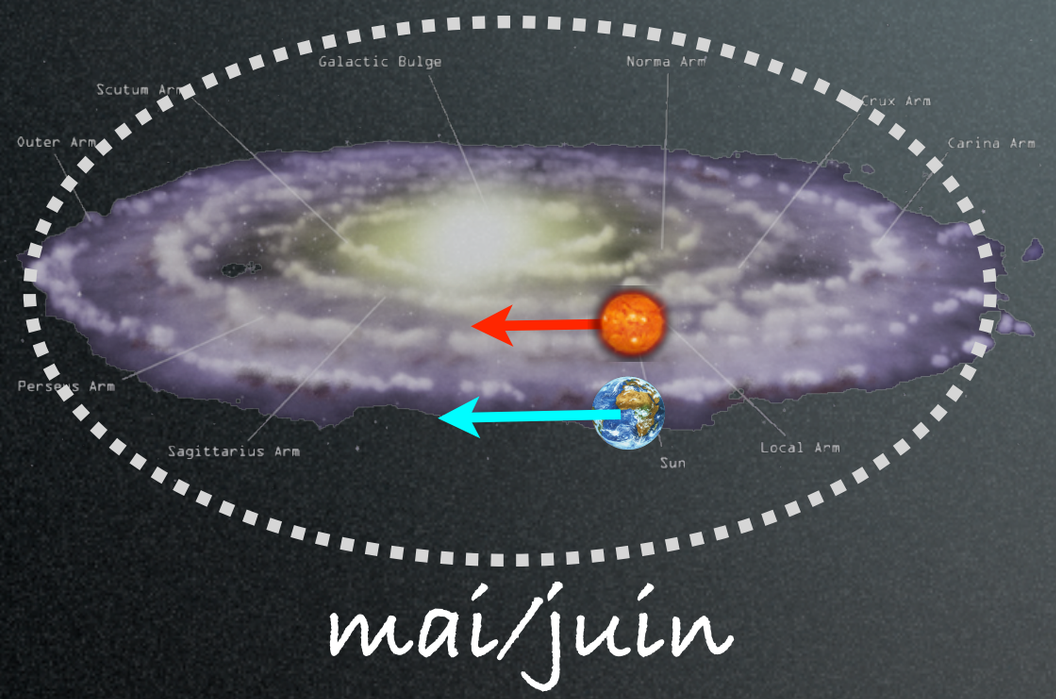

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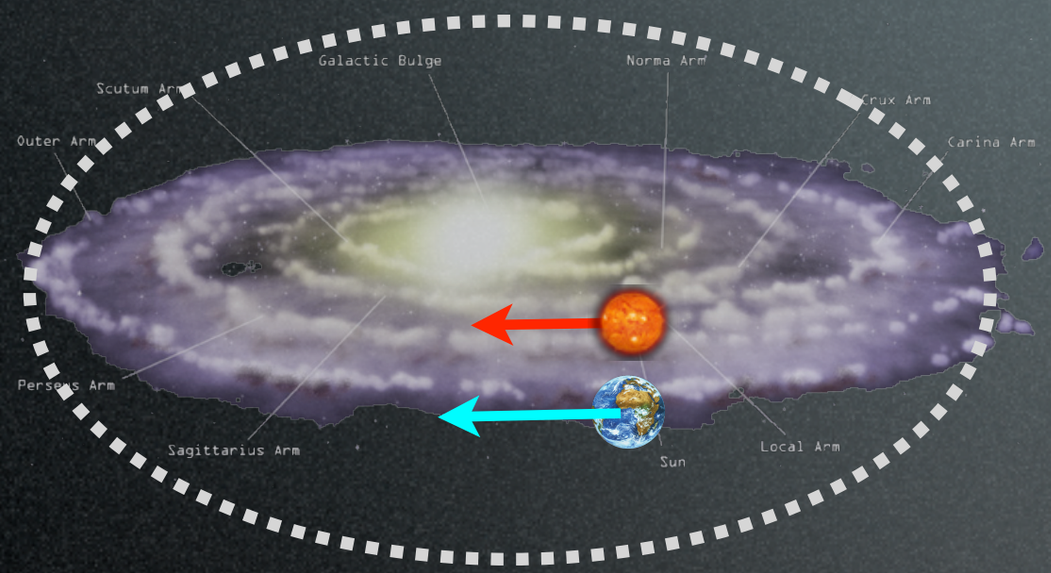
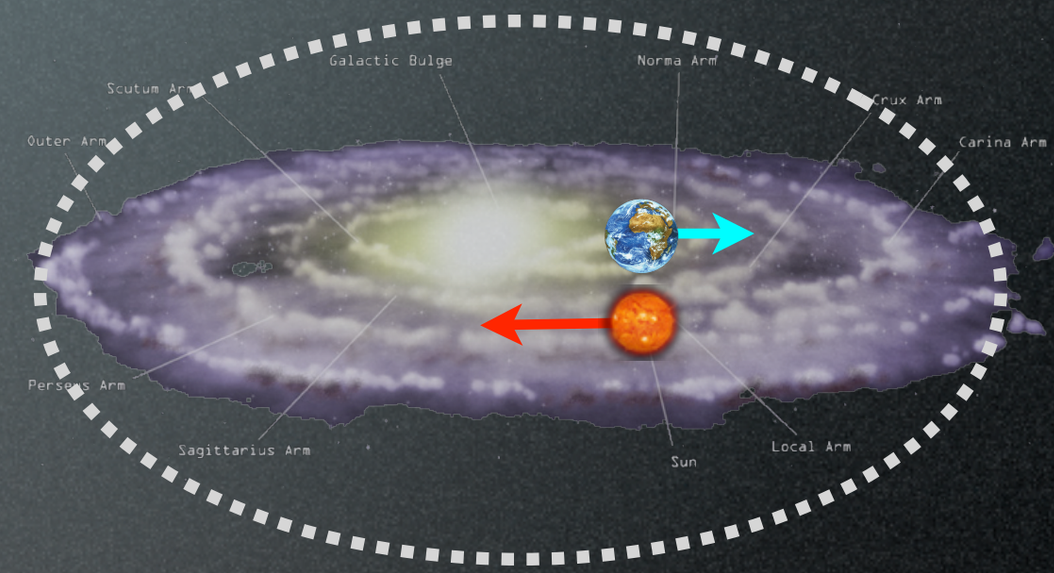


mai/juin



nov/déc

Détection directe

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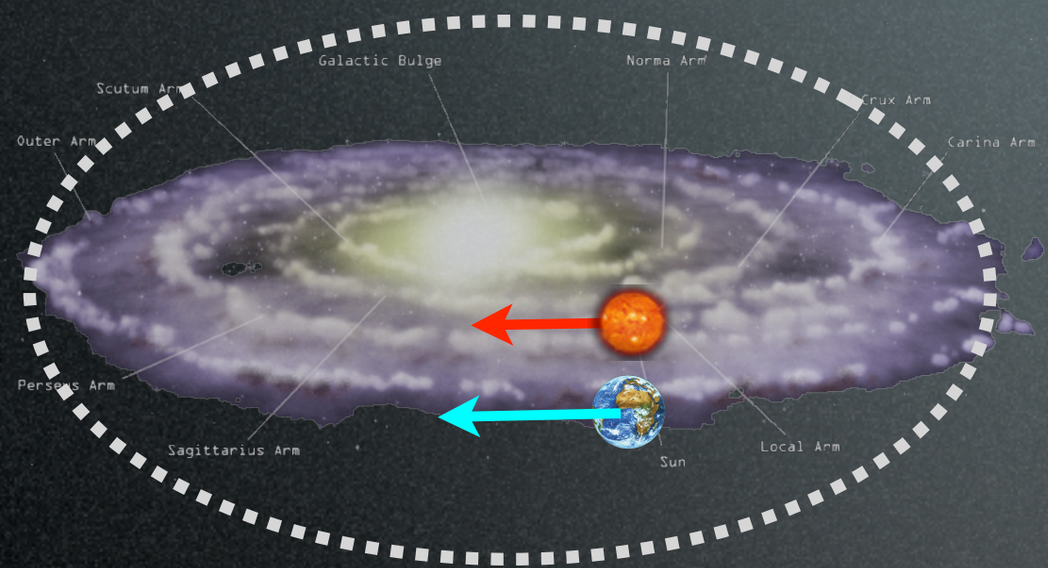
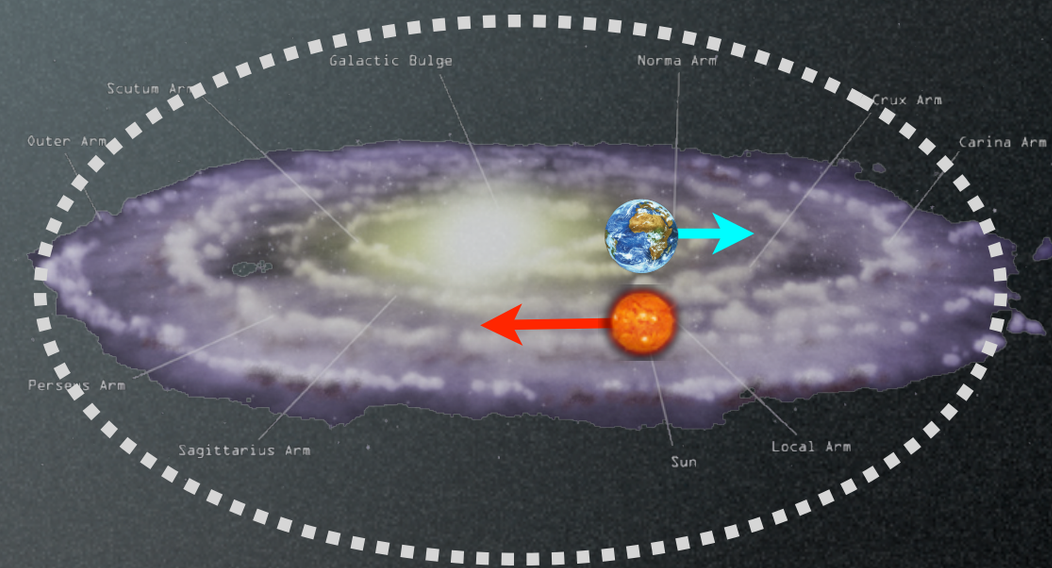
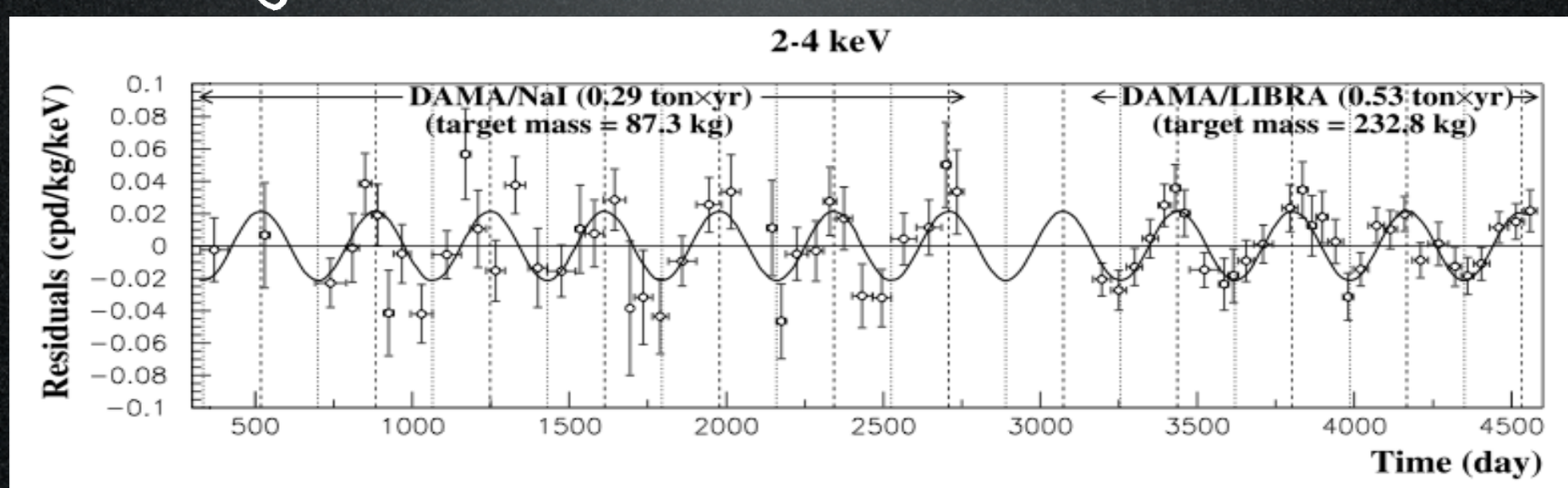
et détecter une modulation annuelle



mai/juin



nov/déc



DAMA Coll., 0804.2741, 2008

Détection directe: état de l'art

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Matière Noire!

Excès d'évènements et/ou **modulation** annuelle.

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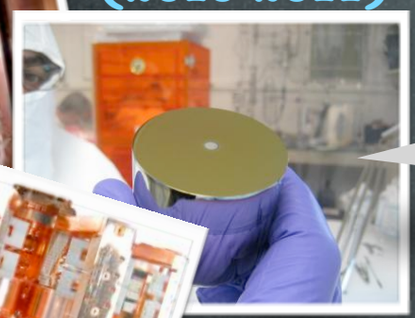

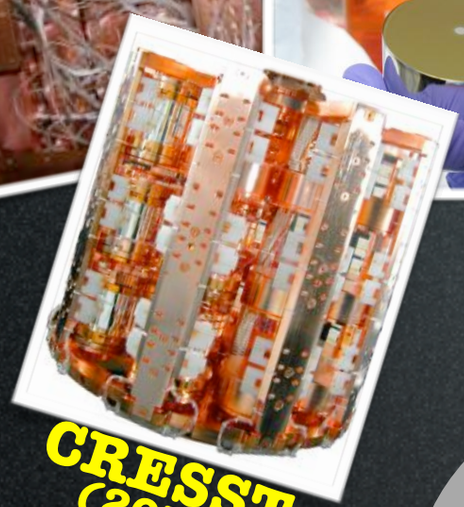

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Silence cosmique,
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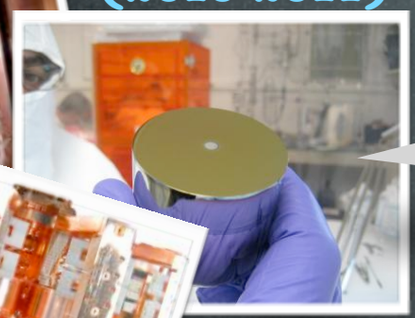

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Un théoricien lambda

Détection indirecte

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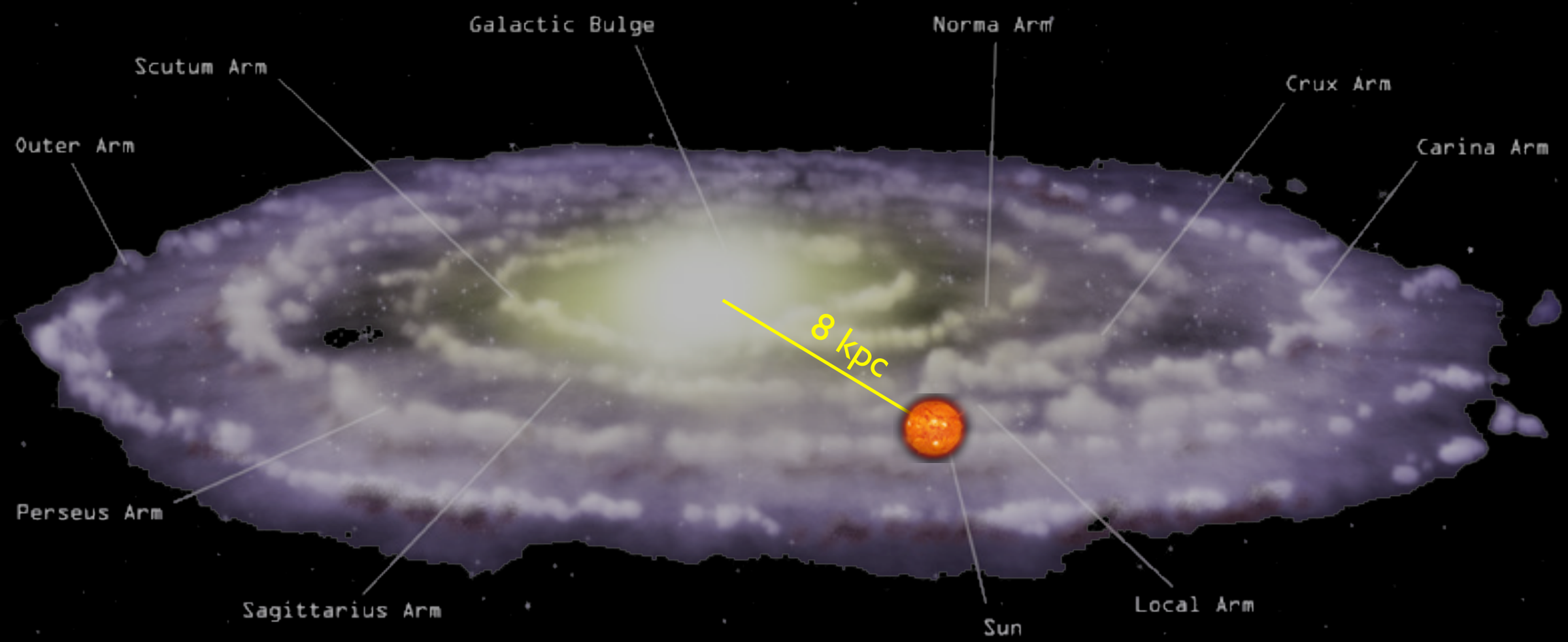
$\bar{p}$ et e^+ de l'annihilation de MN dans l'halo



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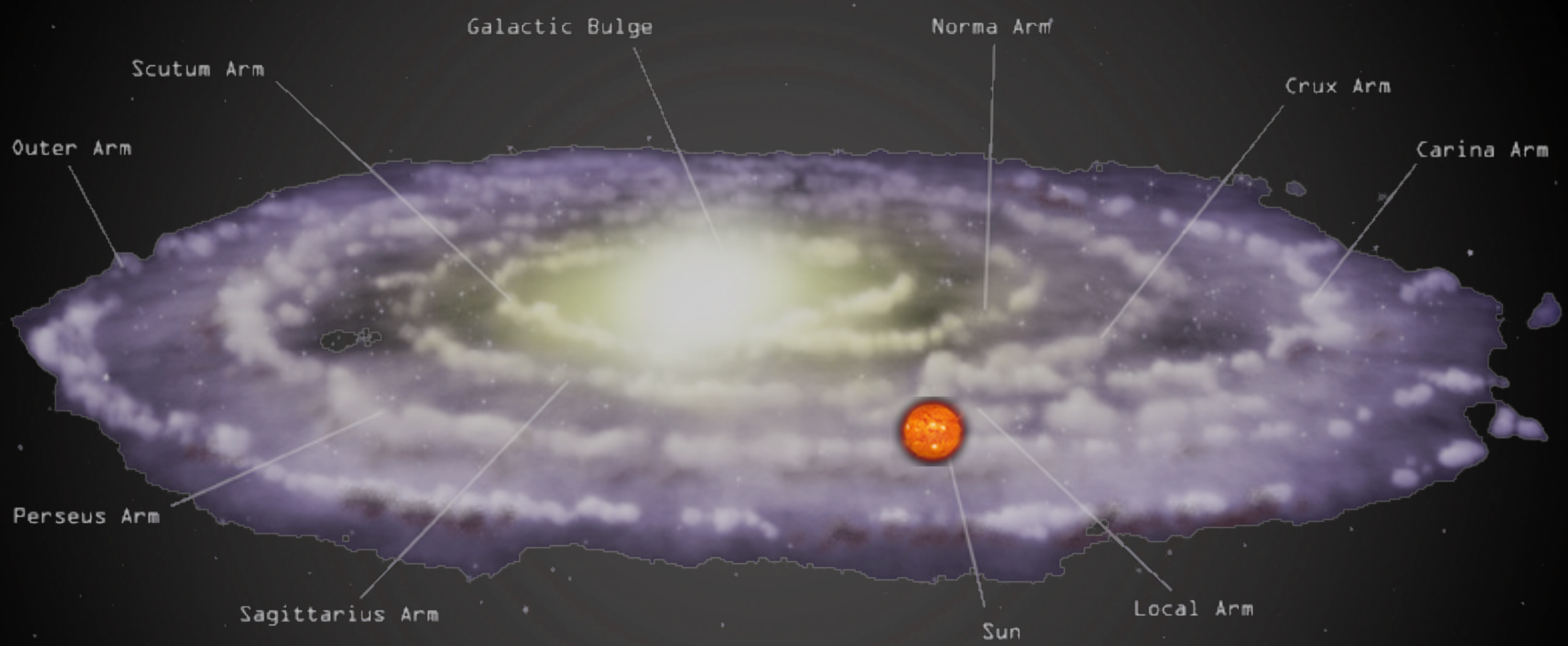

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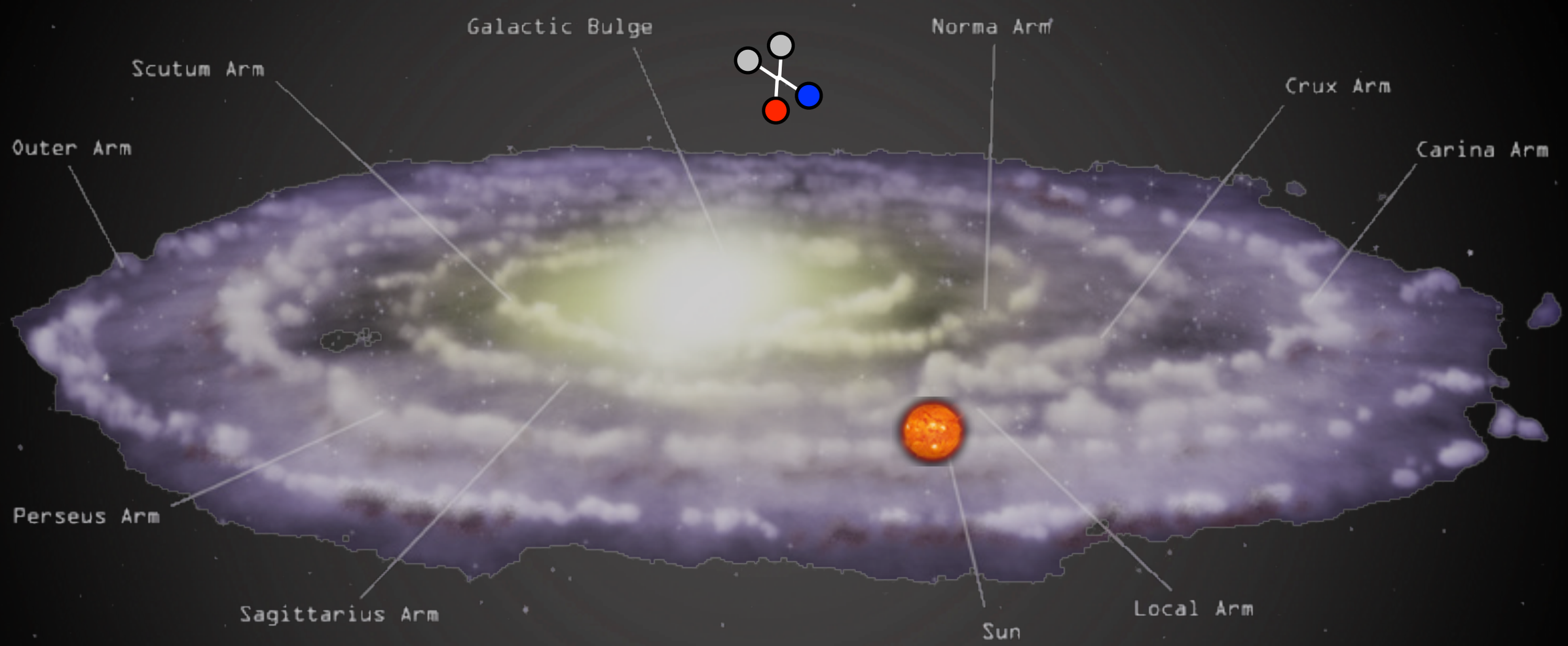

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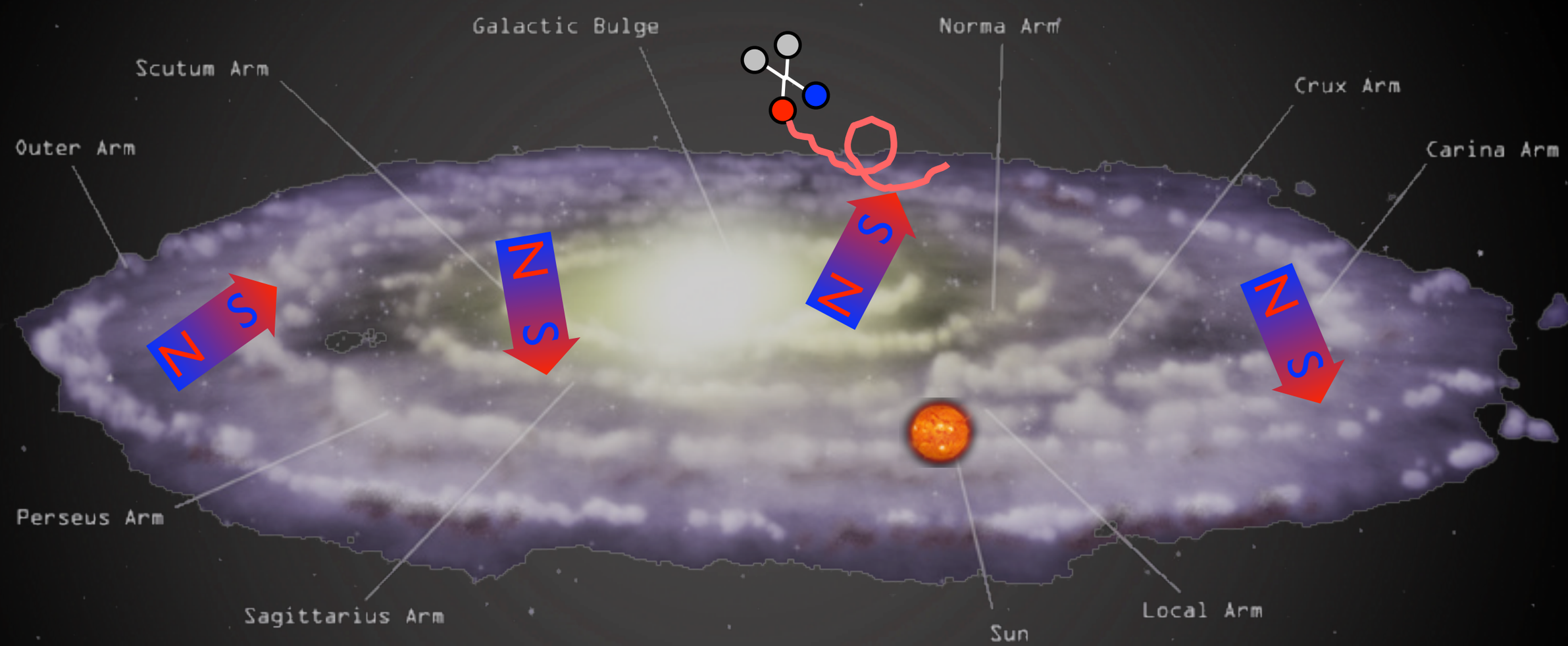

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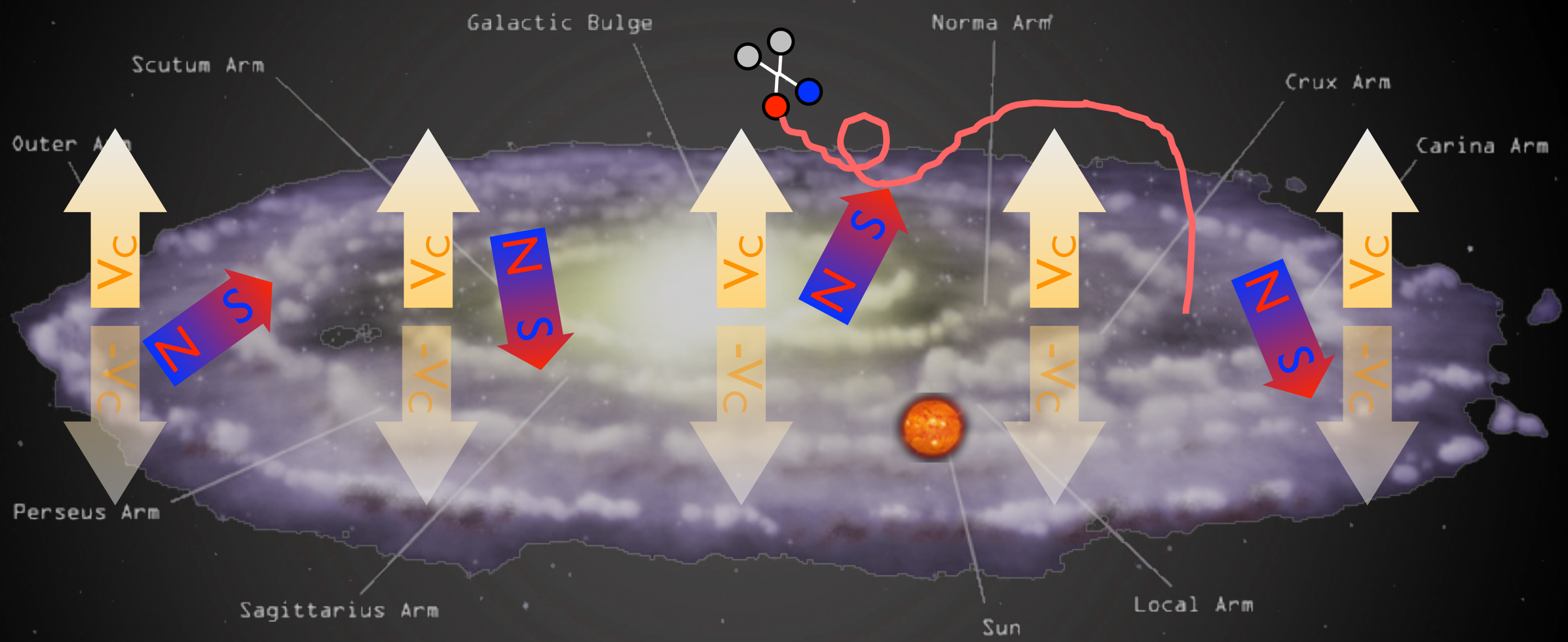

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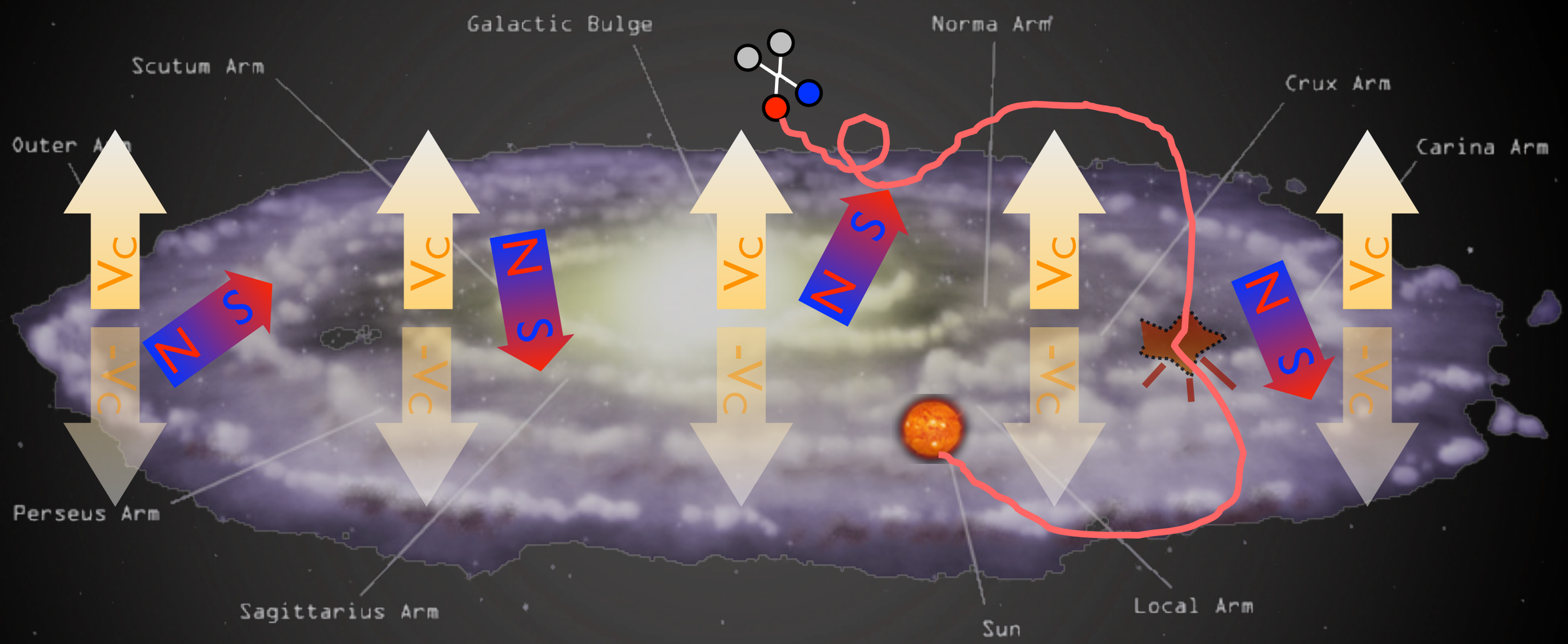

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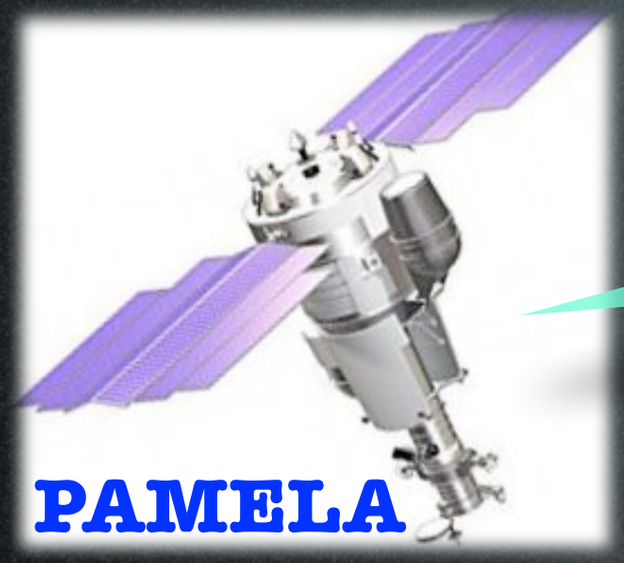

Oui! Matière noire!

Excès en **positrons**

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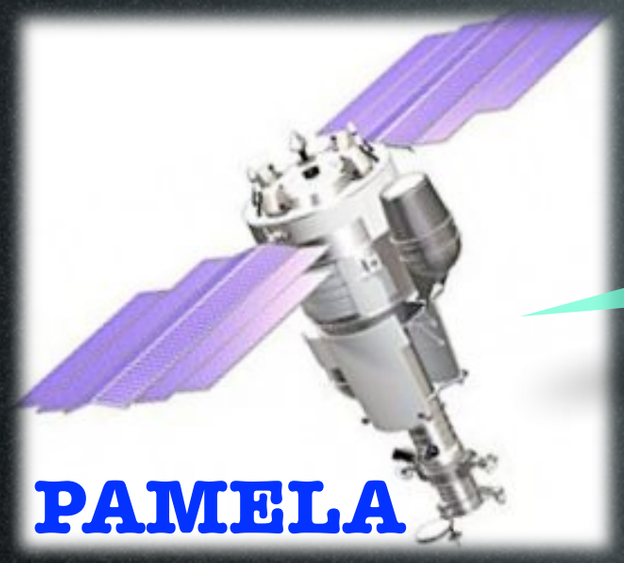

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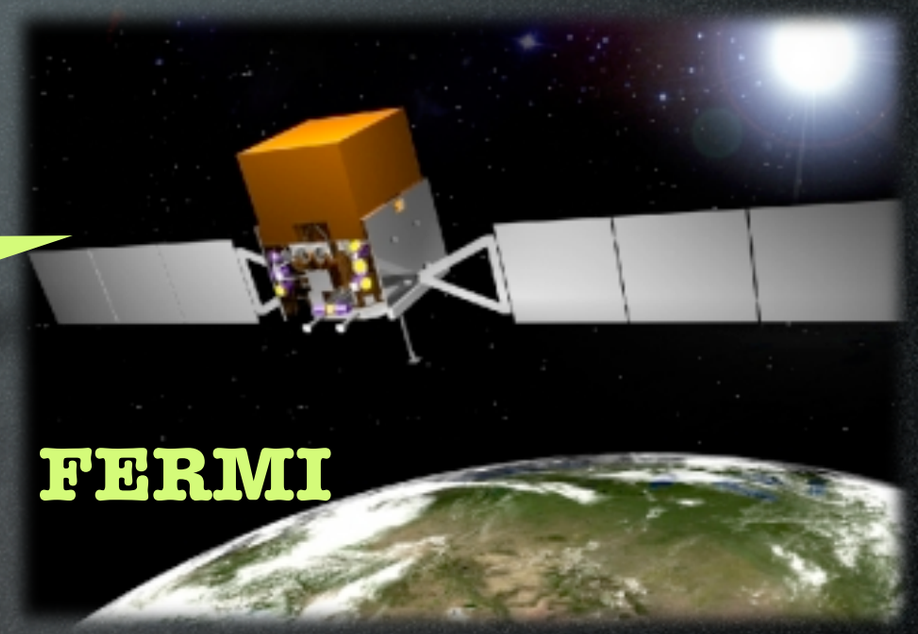

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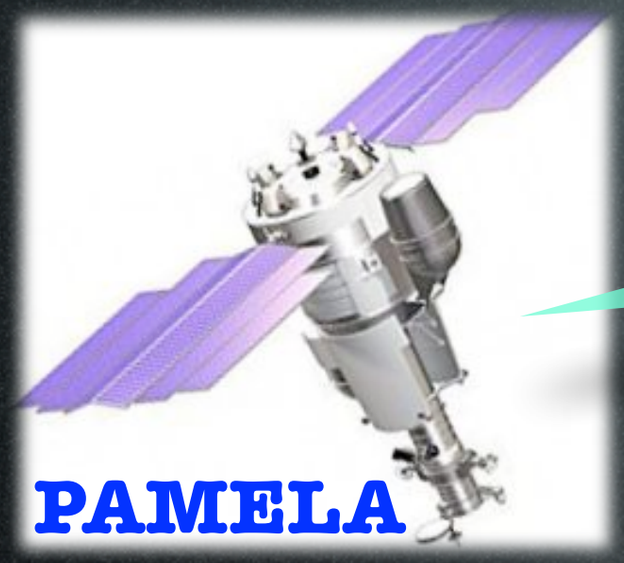

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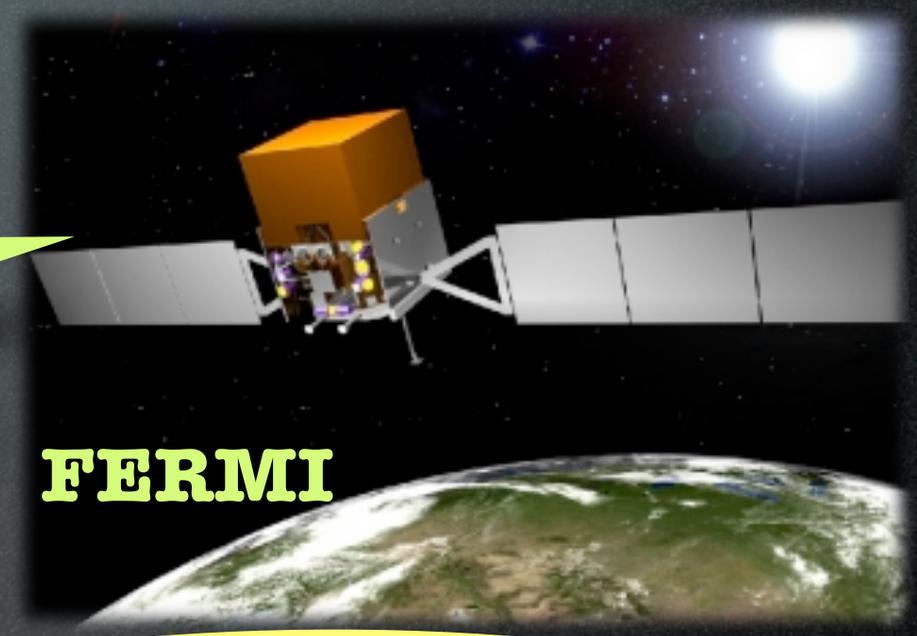

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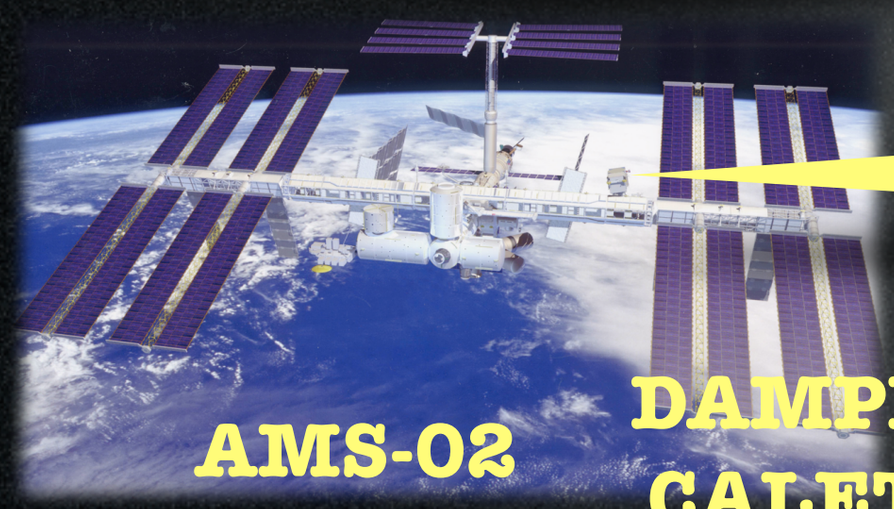

Voyons voir...

2011-2018...

DAMPE
CALET

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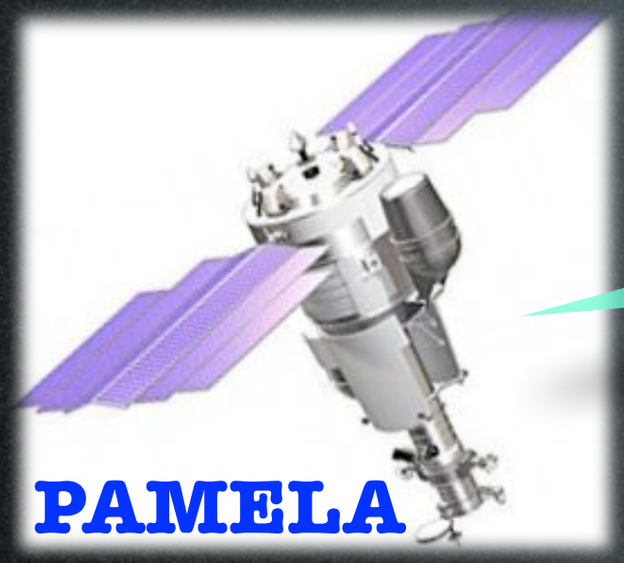

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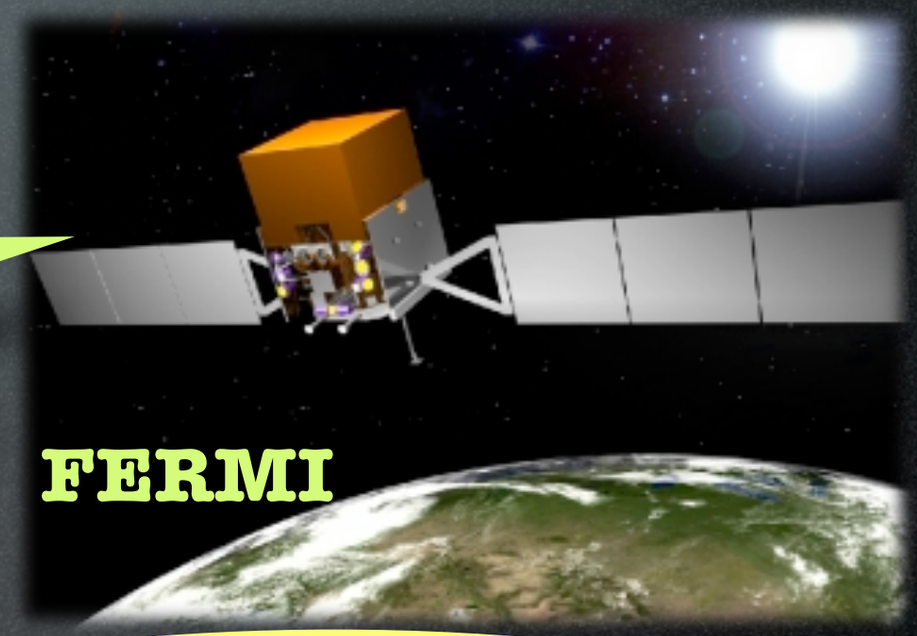

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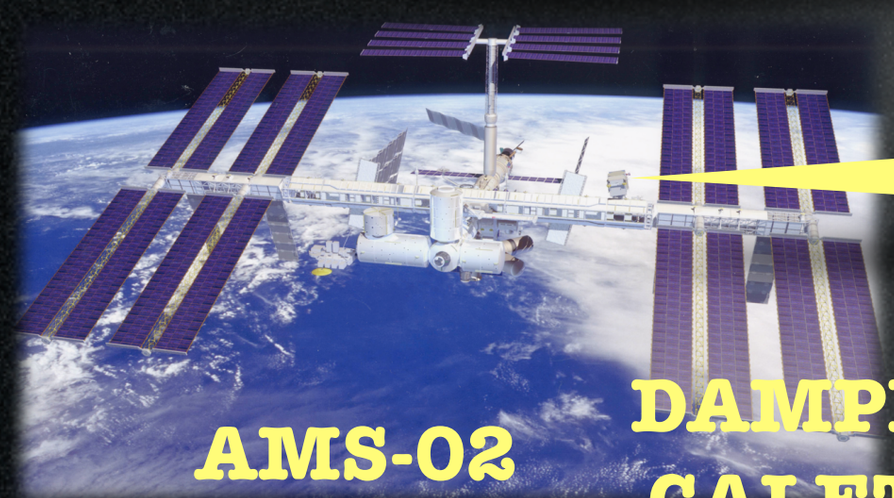

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Un théoricien lambda

Production aux collisionneurs

Production aux collisionneurs

Special guest star:
Fabio Cirelli

Production aux collisionneurs

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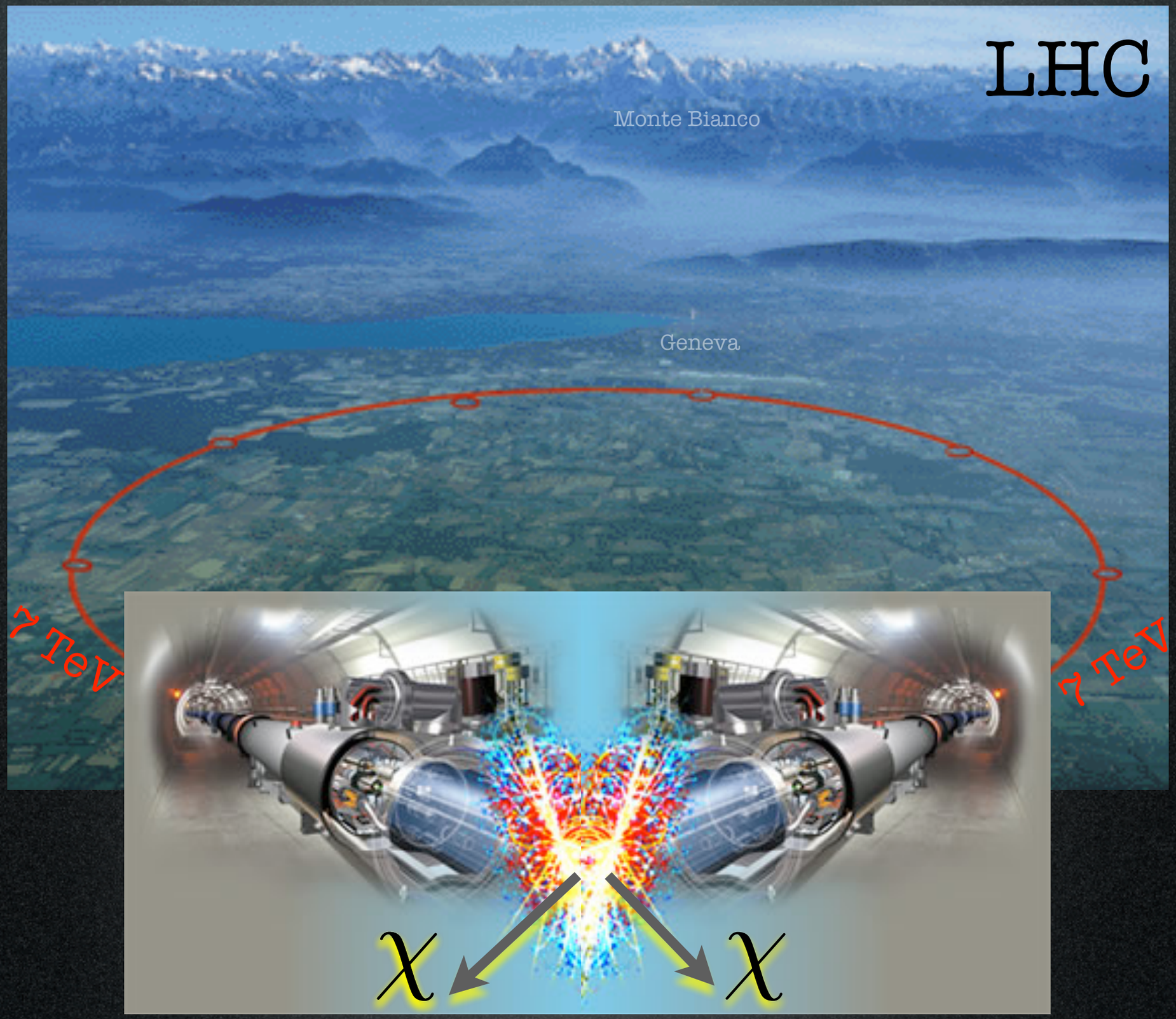

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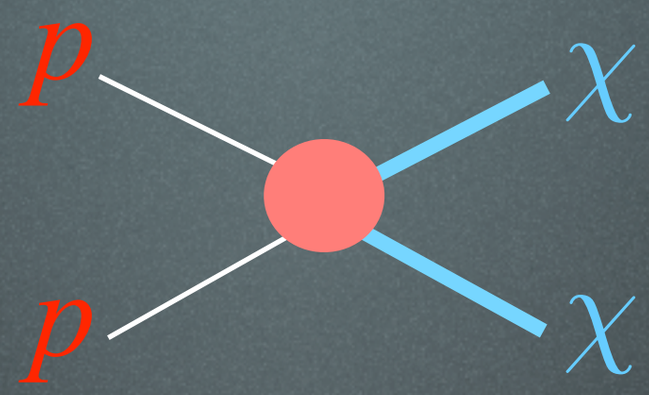

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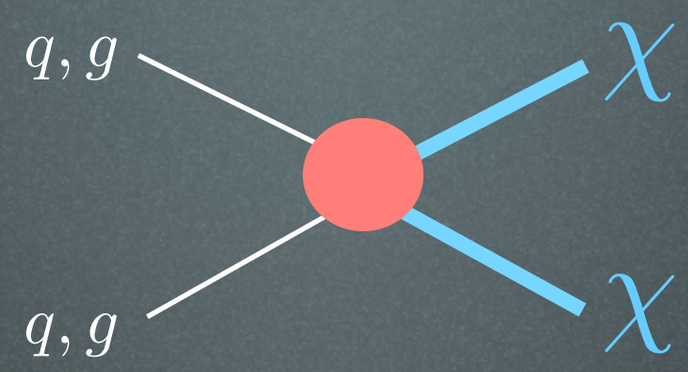

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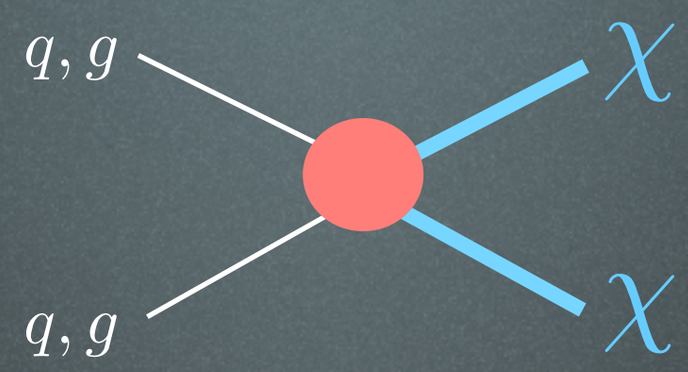

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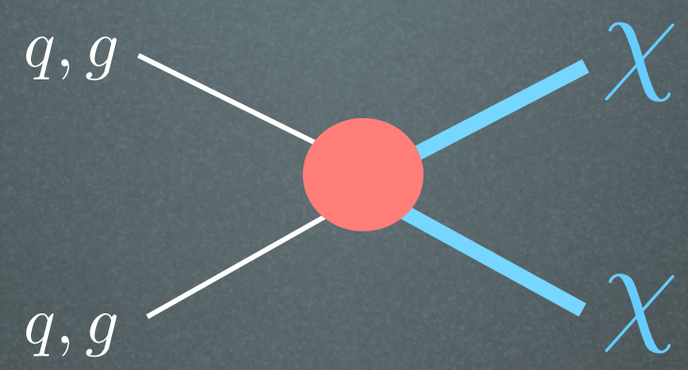

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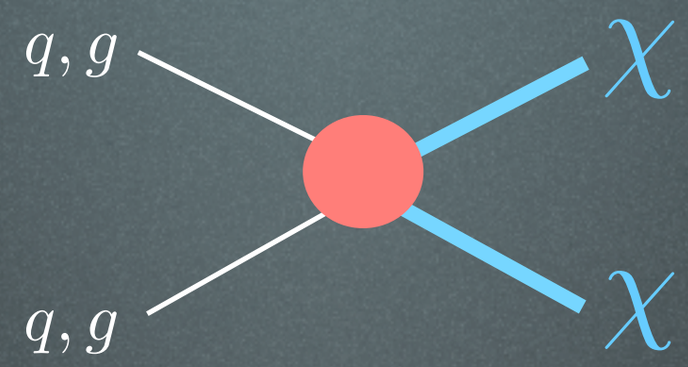

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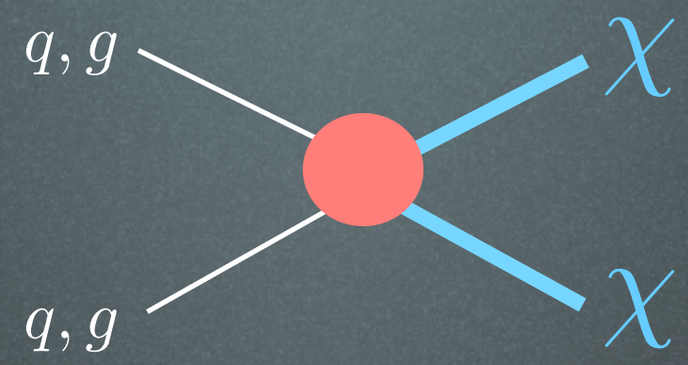

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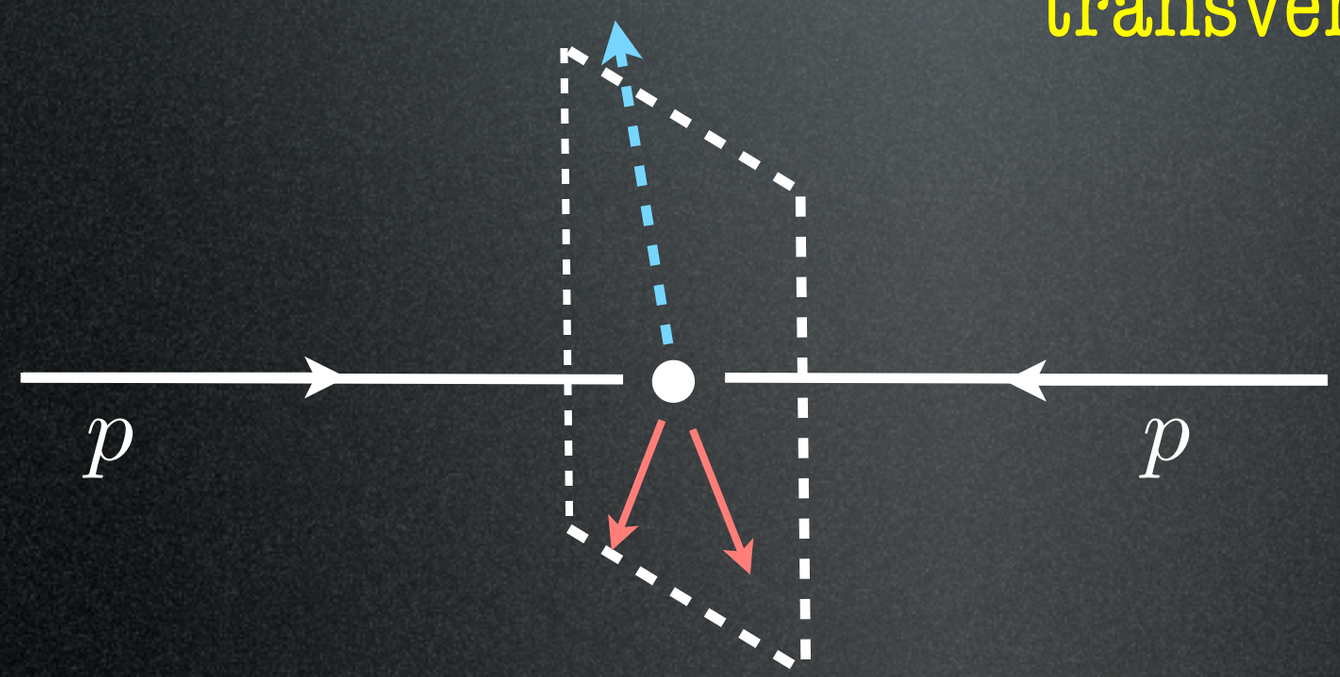

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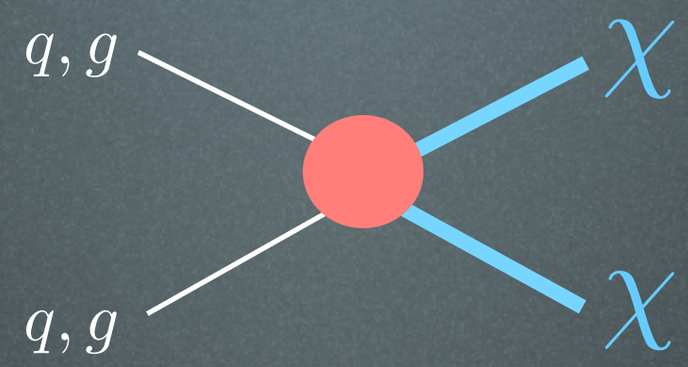

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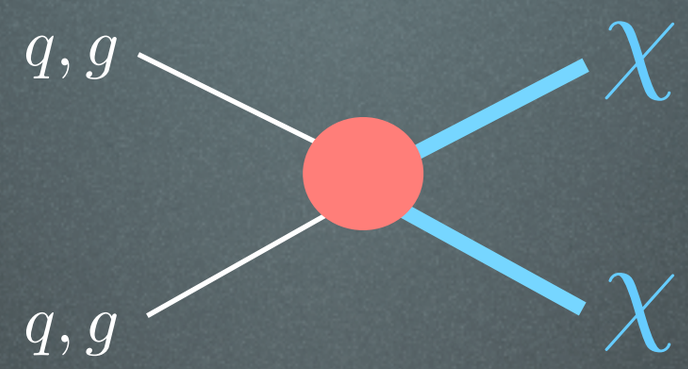

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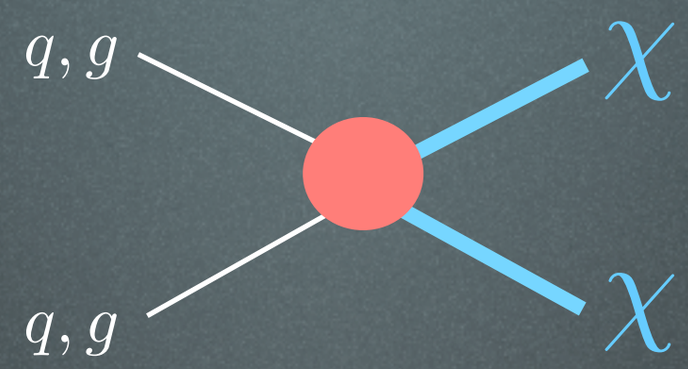

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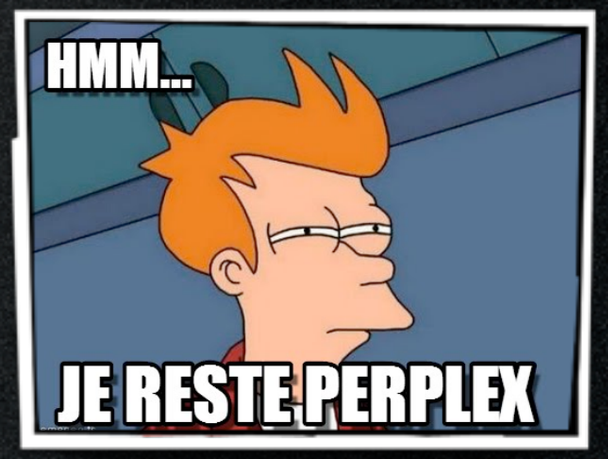

De quoi est fait notre Univers ?

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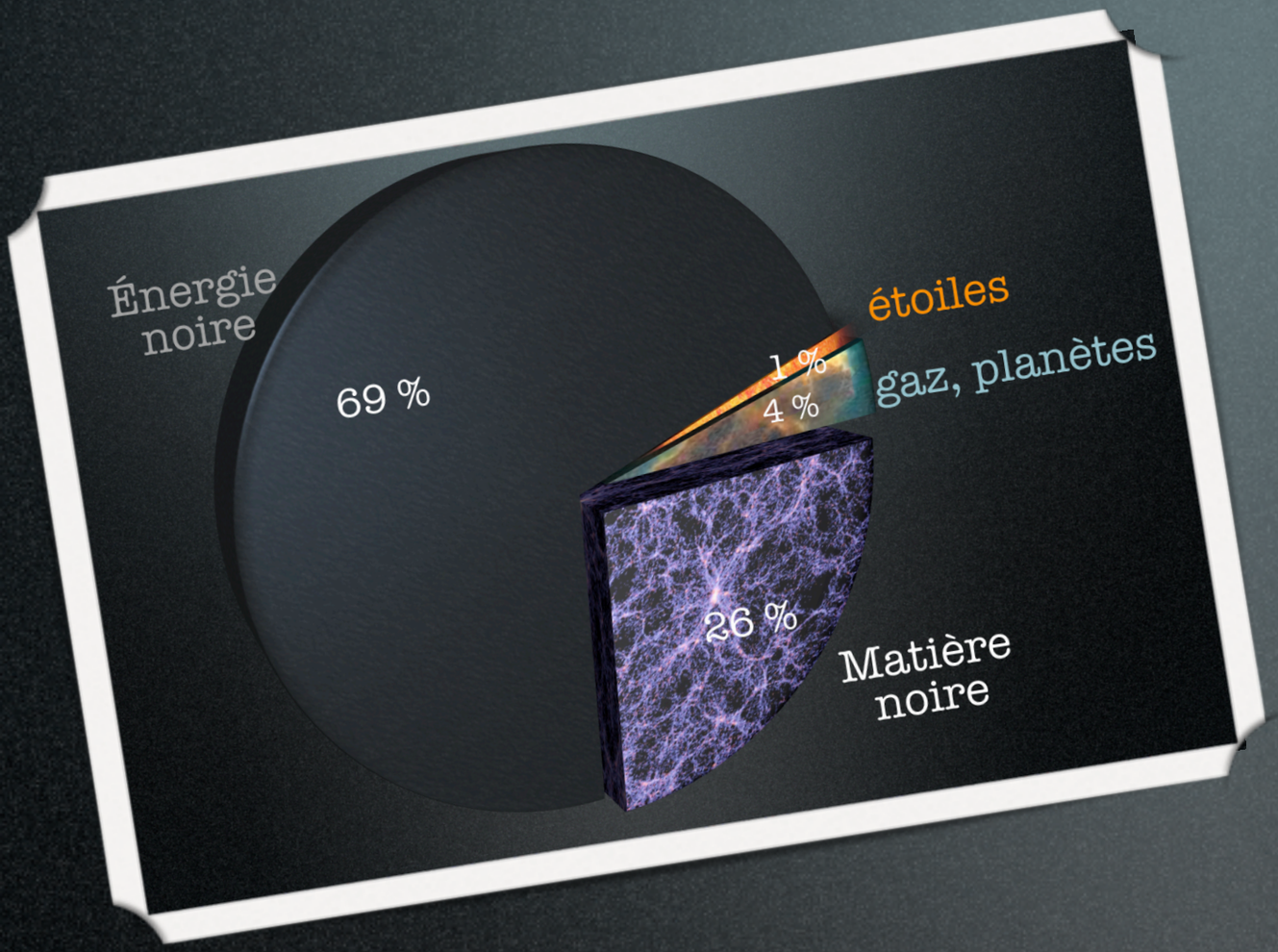

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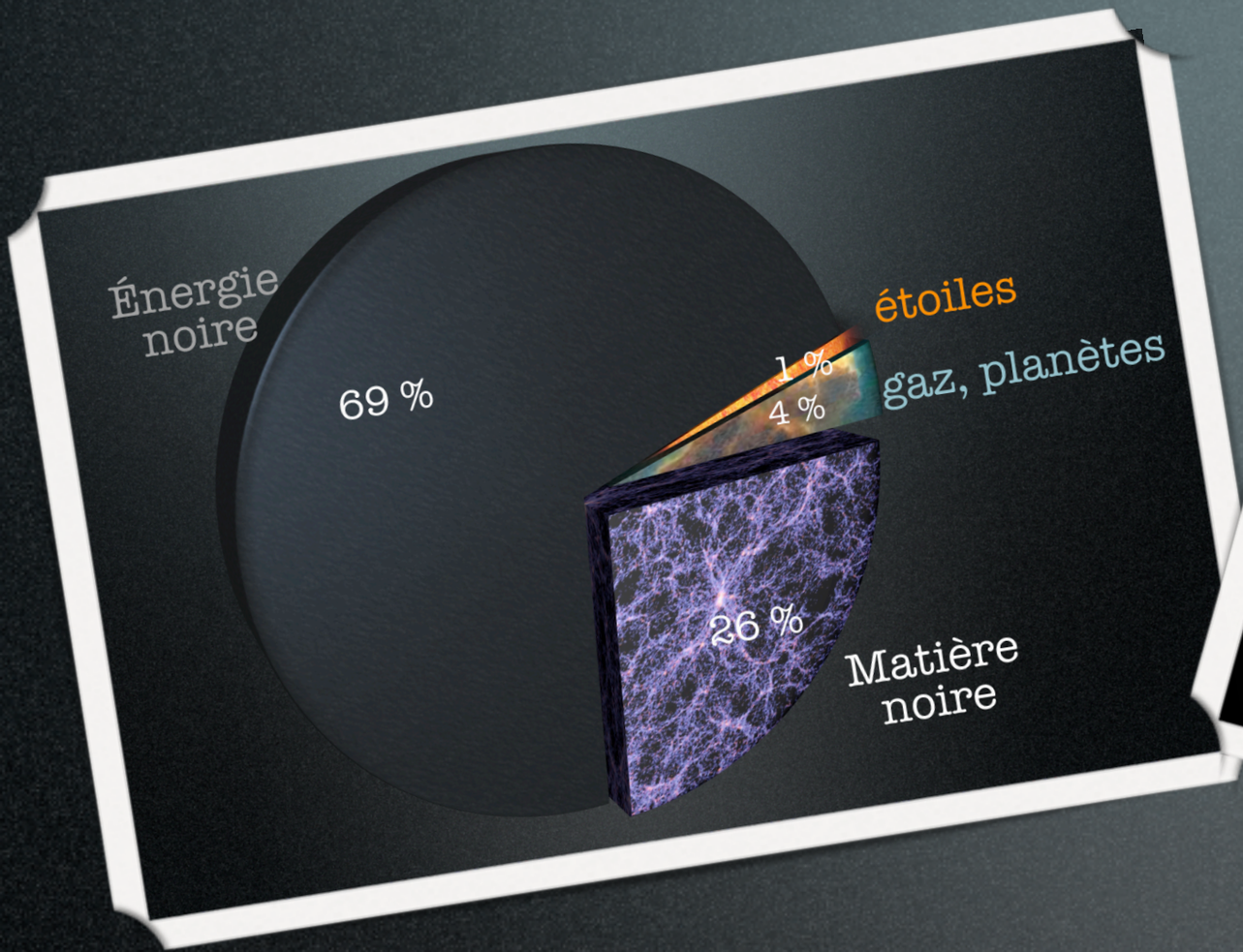

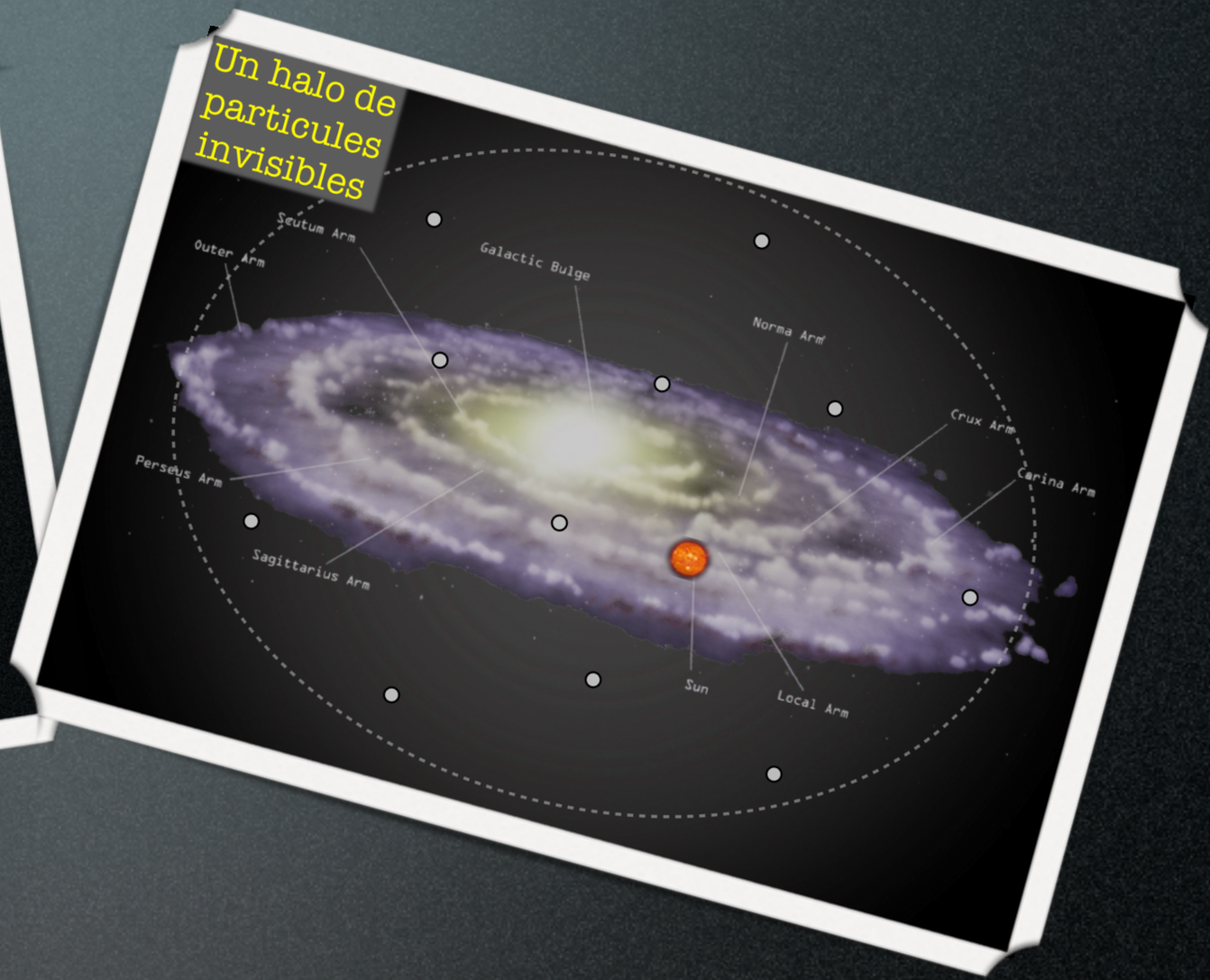

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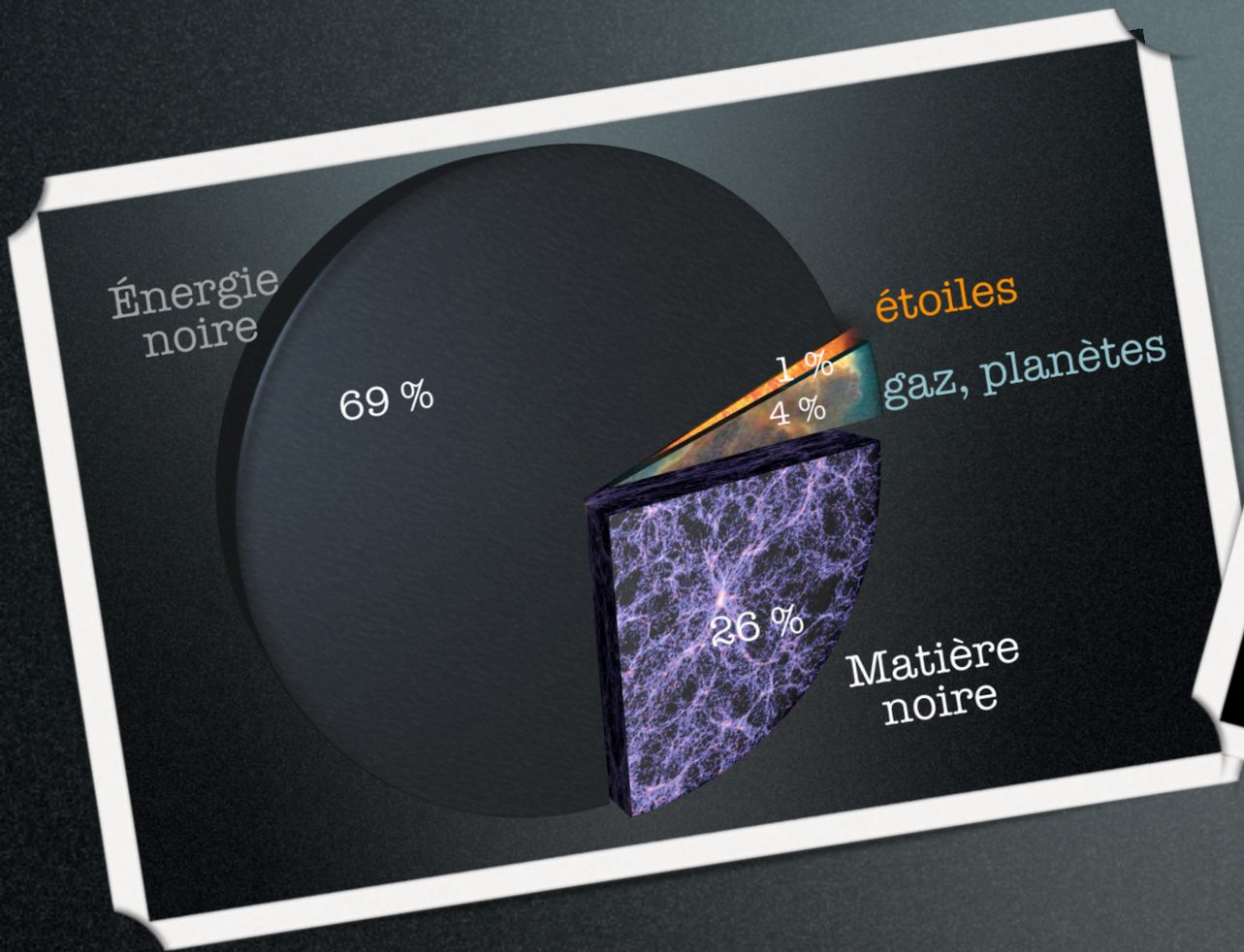
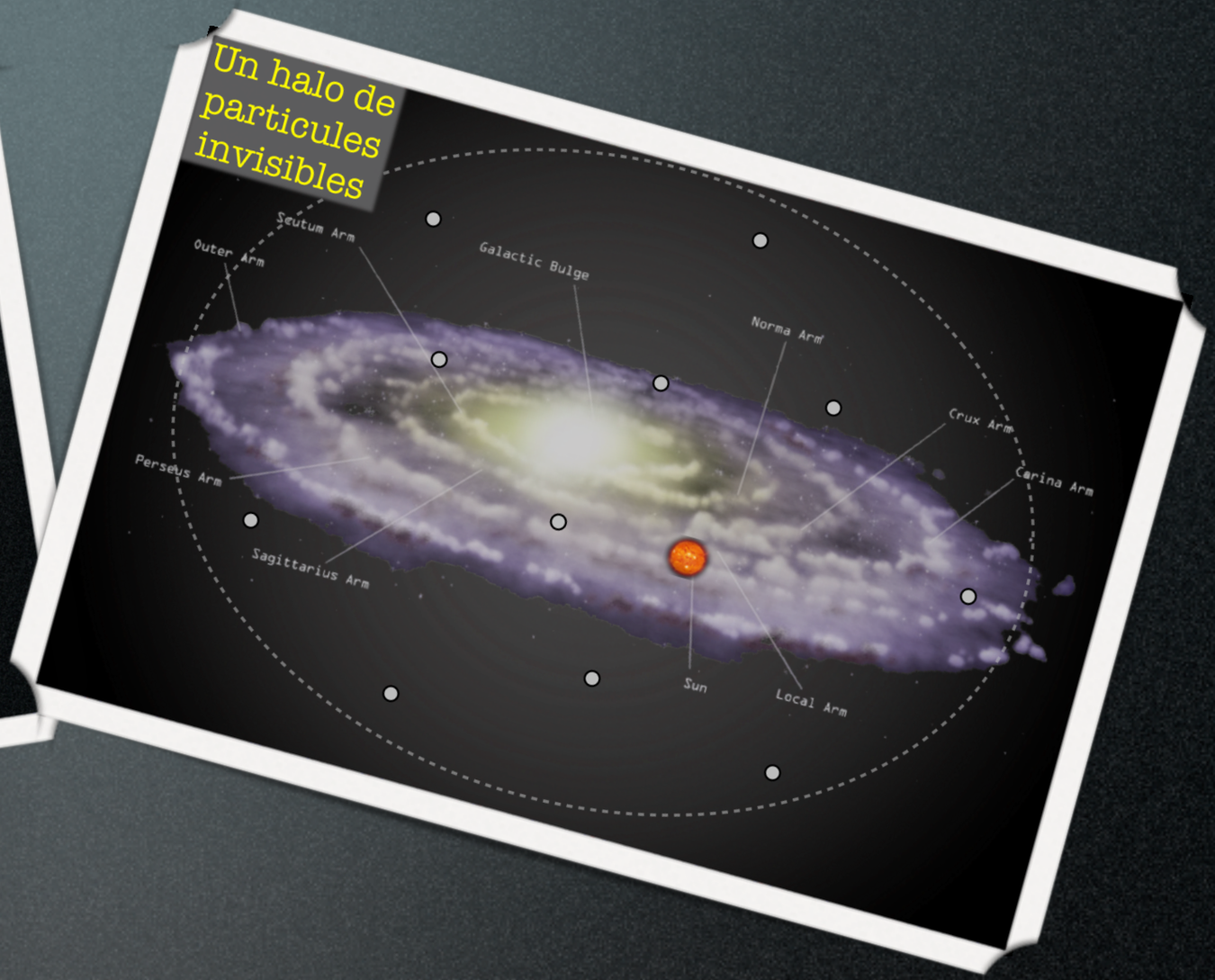
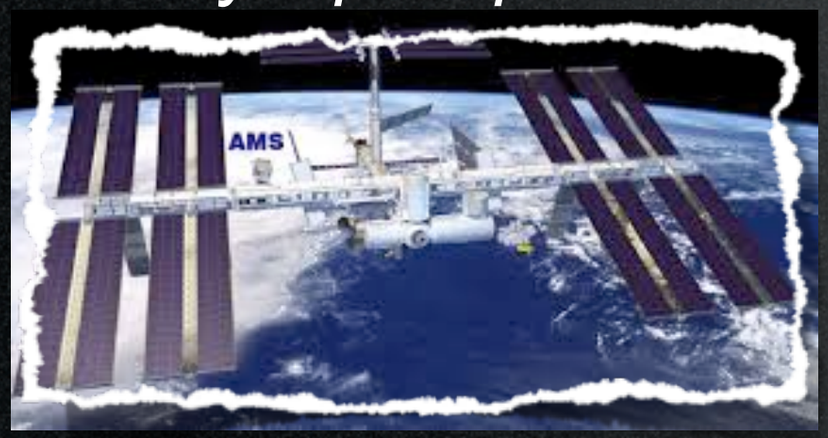


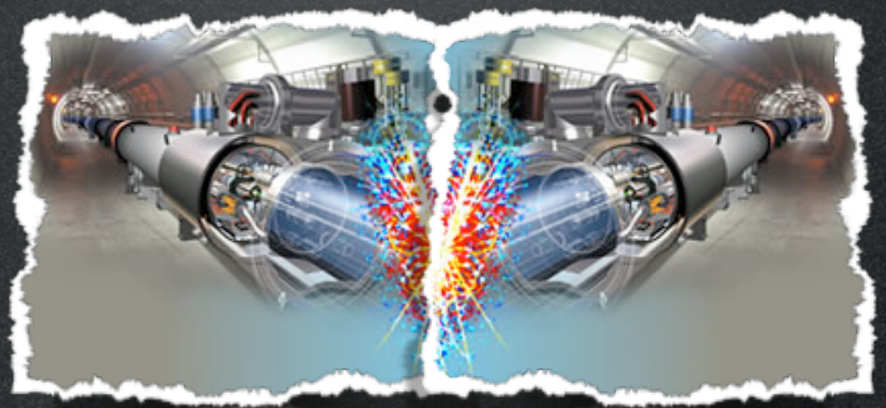


Physique spatiale



‘détection indirecte’

Physique aux collisionneurs



‘production’

Physique souterraine

‘détection directe’

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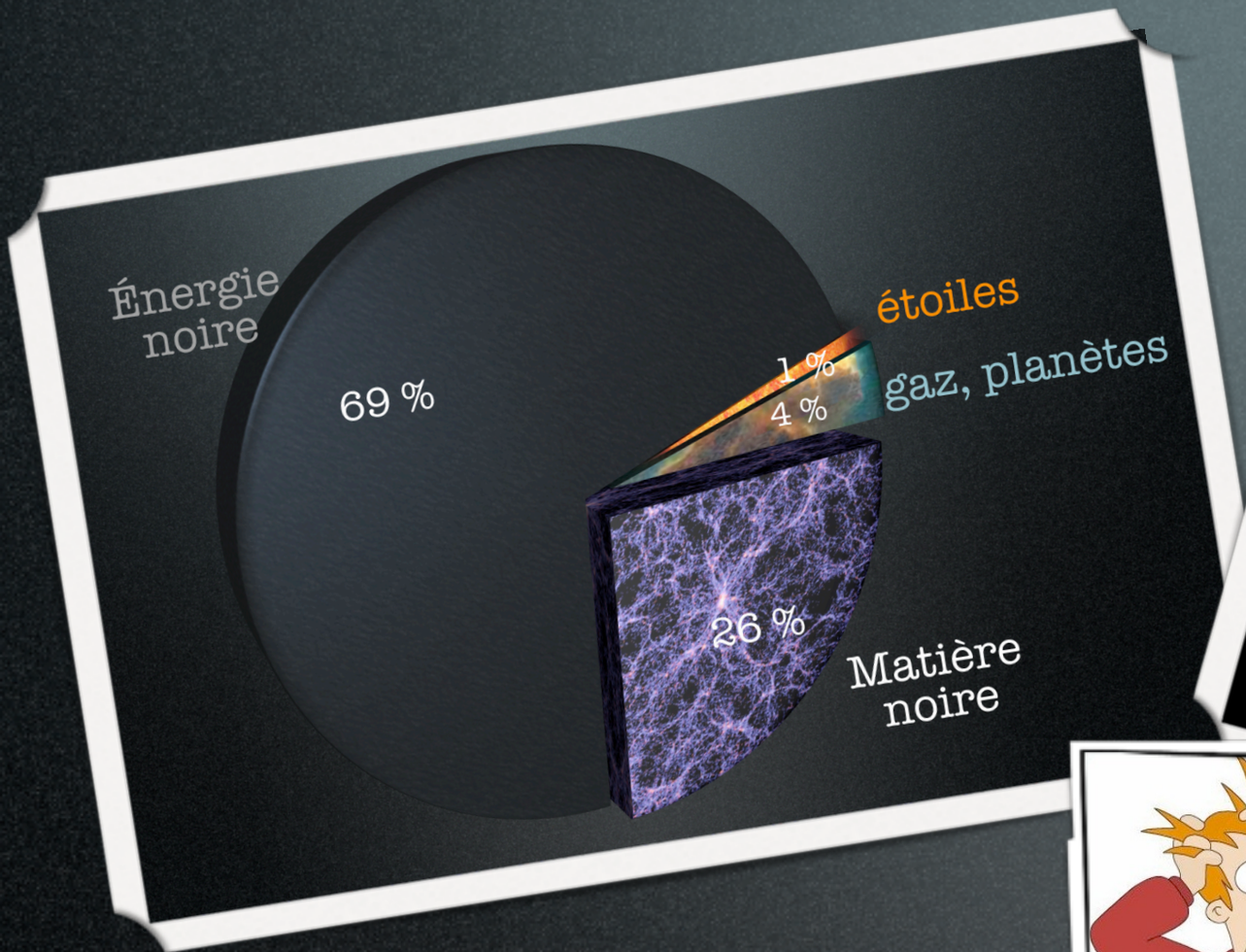

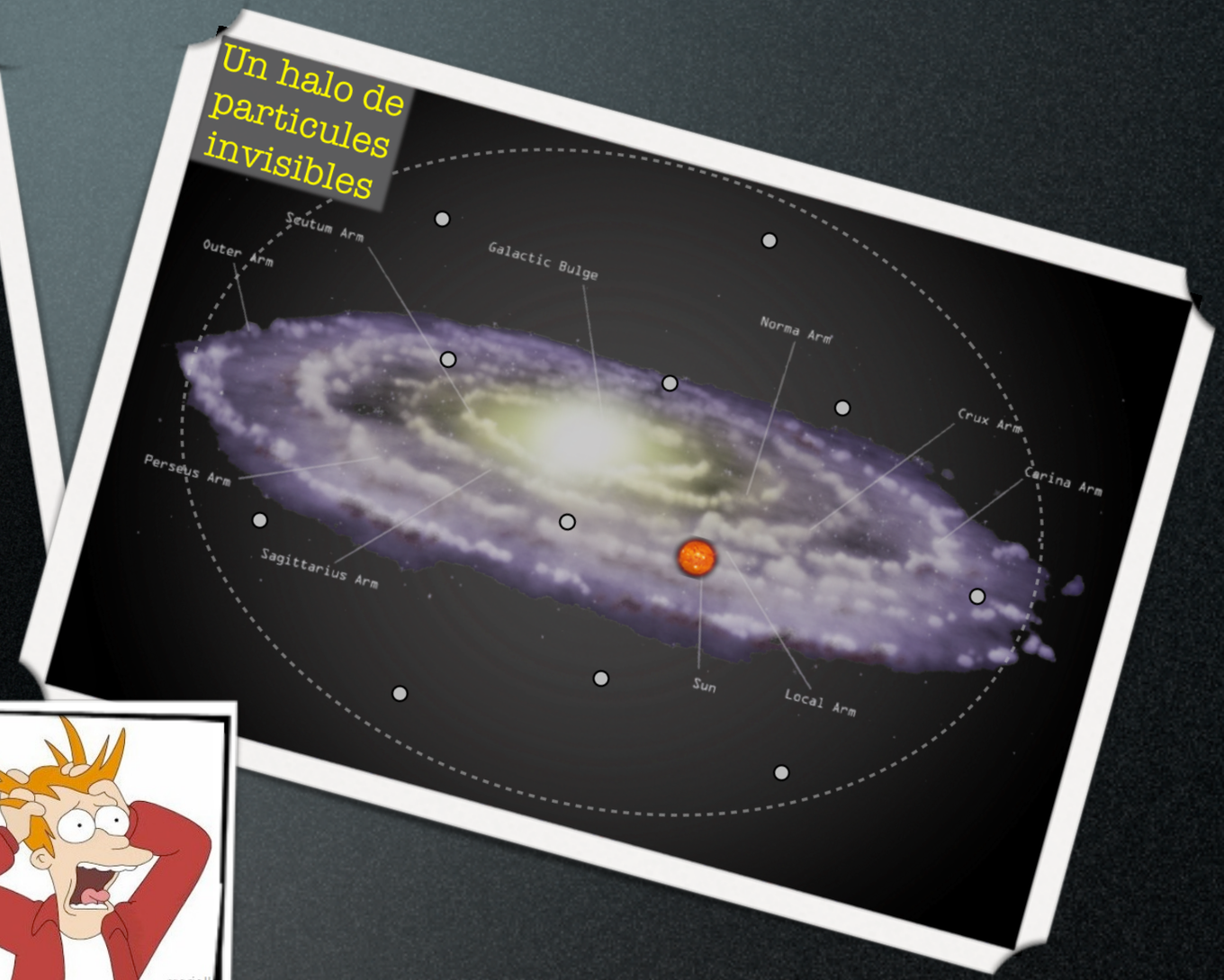

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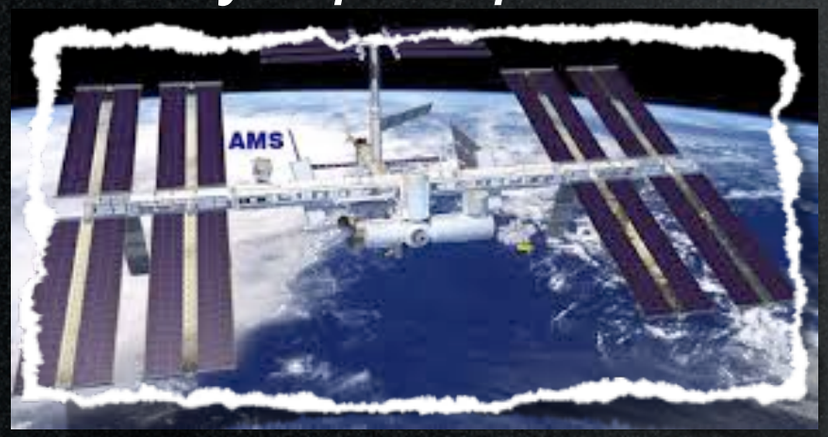

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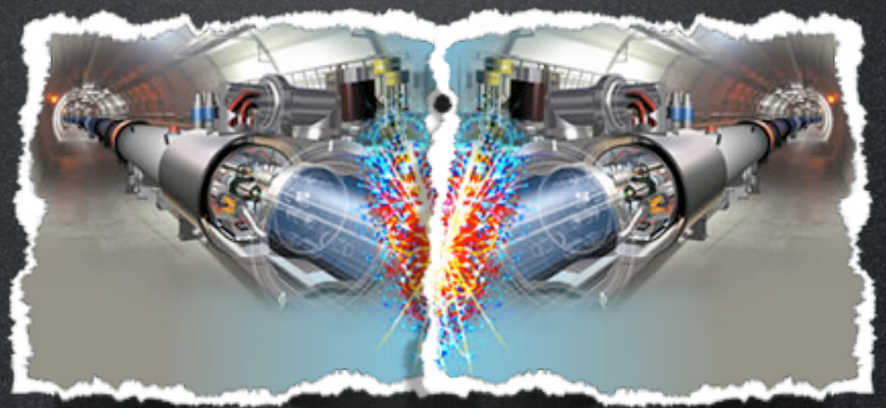

‘production’

Physique souterraine

‘détection directe’

Back-up slides

DM can **NOT** be:

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an astro *je ne sais pas quoi*:

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an astro *je ne sais pas quoi*:

- neutrons
- gas
- Black Holes
- brown dwarves

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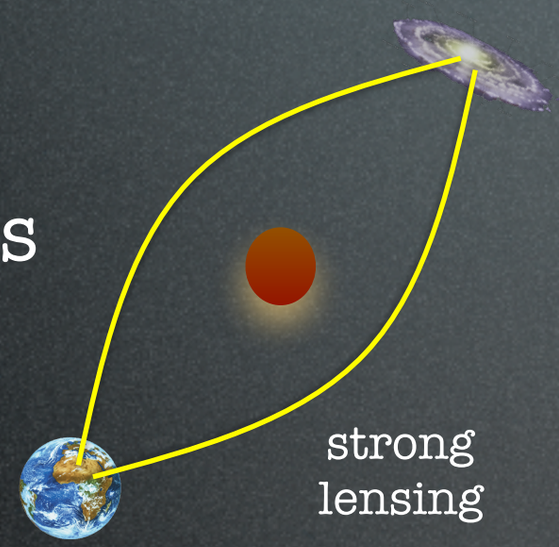

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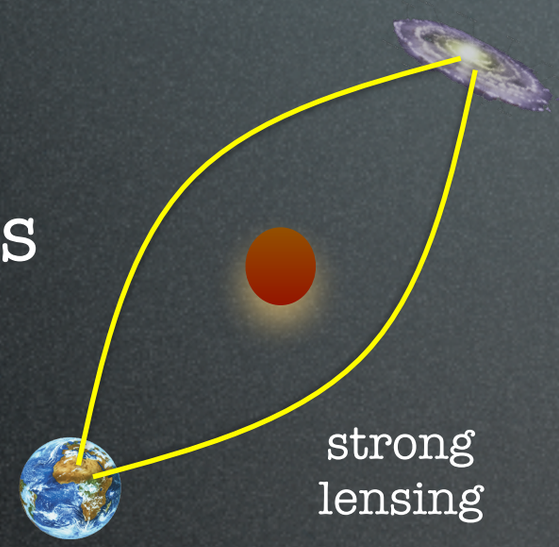
- ~~brown dwarves~~

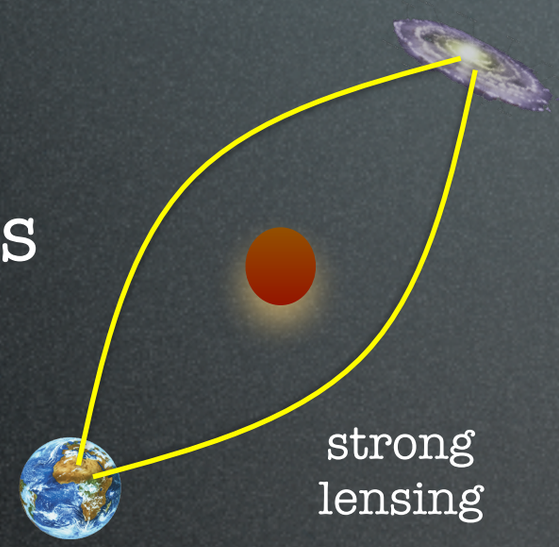


a baryon of the SM:

DM can **NOT** be:

an astro *je ne sais pas quoi*:

- ~~neutrons~~
- ~~gas~~
- ~~Black Holes~~
- ~~brown dwarves~~



a ~~baryon of the SM~~:

- BBN computes the abundance of He in terms of primordial baryons:
  too much baryons => Universe full of Helium
- CMB says baryons are 4% max

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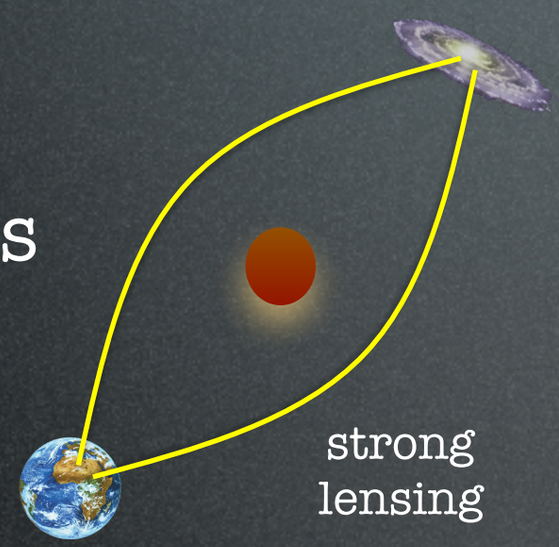

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neutrinos:

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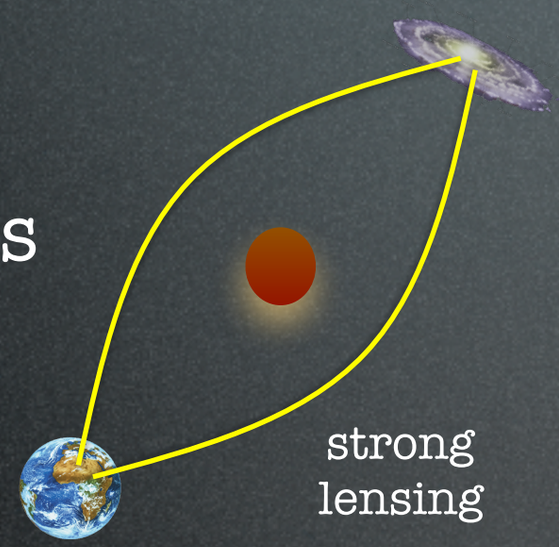

a ~~baryon of the SM~~:

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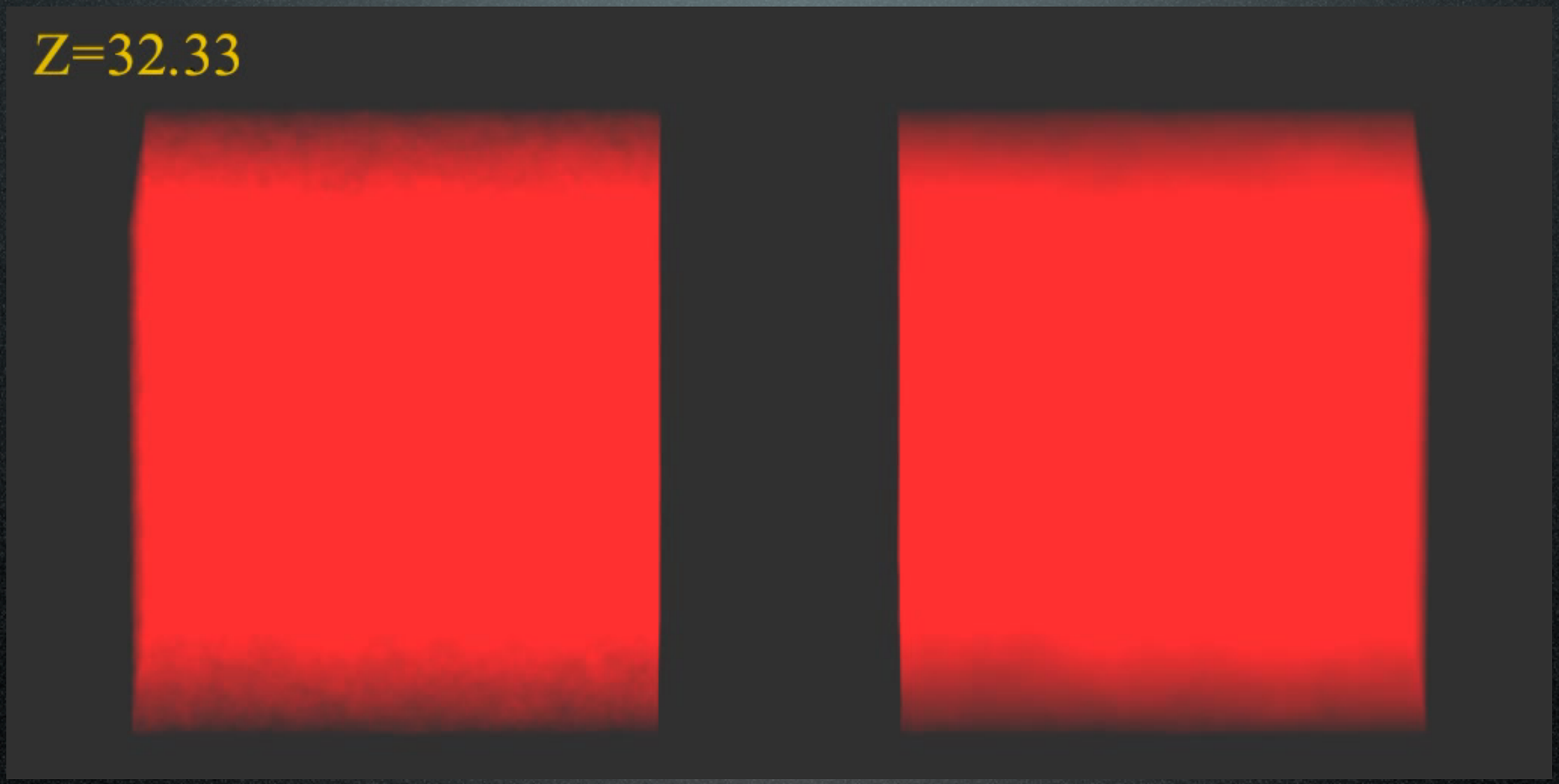
~~neutrinos~~:
too light!

$$m_\nu \lesssim 1\,\mathrm{eV}$$

do not have enough mass to act as gravitational attractors in galaxy collapse

(Neutrino) DM



no HDM

$\sum m_\nu = 0$

some HDM

$\sum m_\nu = 6.9$ eV

ΛCDM - Gadget2 - 768 Mpc^3

T.Haugboelle, S.Hannestad, Aarhus University