DARK MATTER

Sara Diglio

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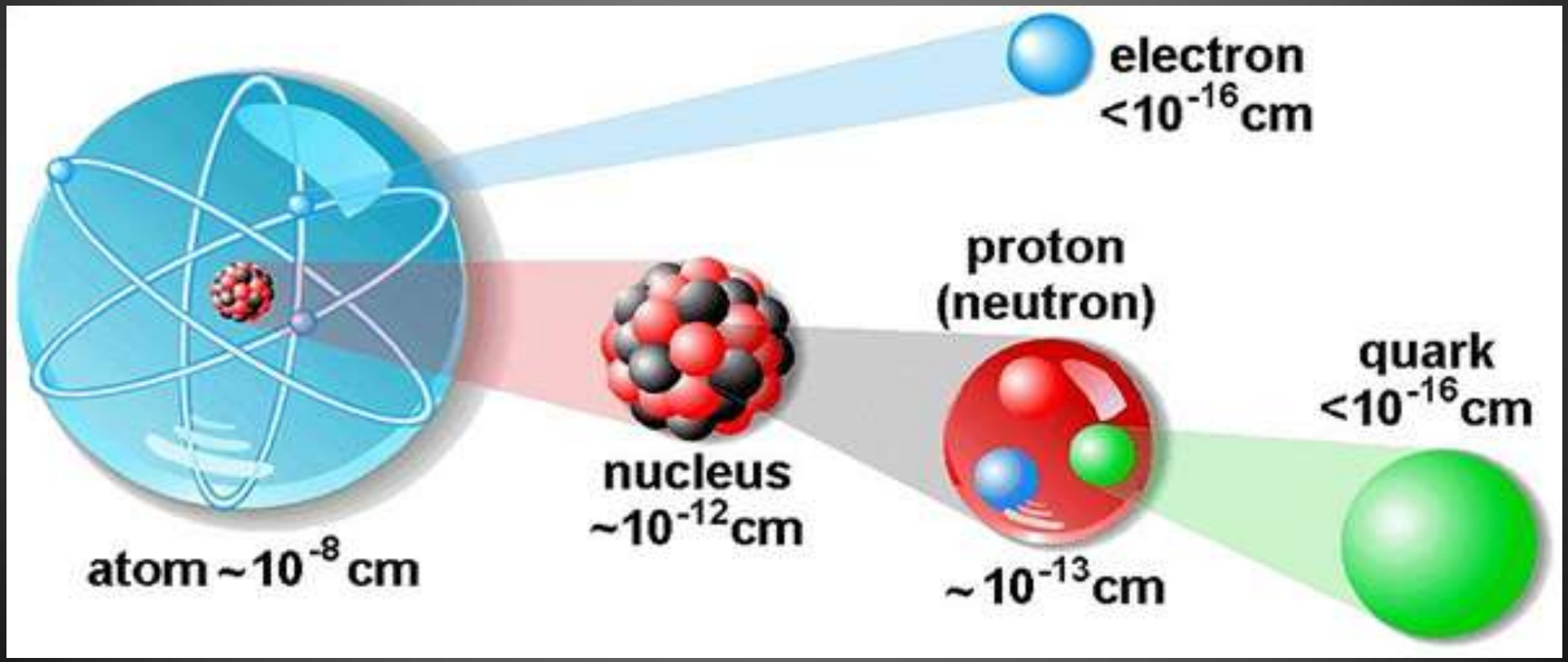
QUESTIONS

- What is the “Visible” Matter?
- Are we sure Dark Matter does exist?
- What could Dark Matter be made of ?
- How to search for Dark Matter ?

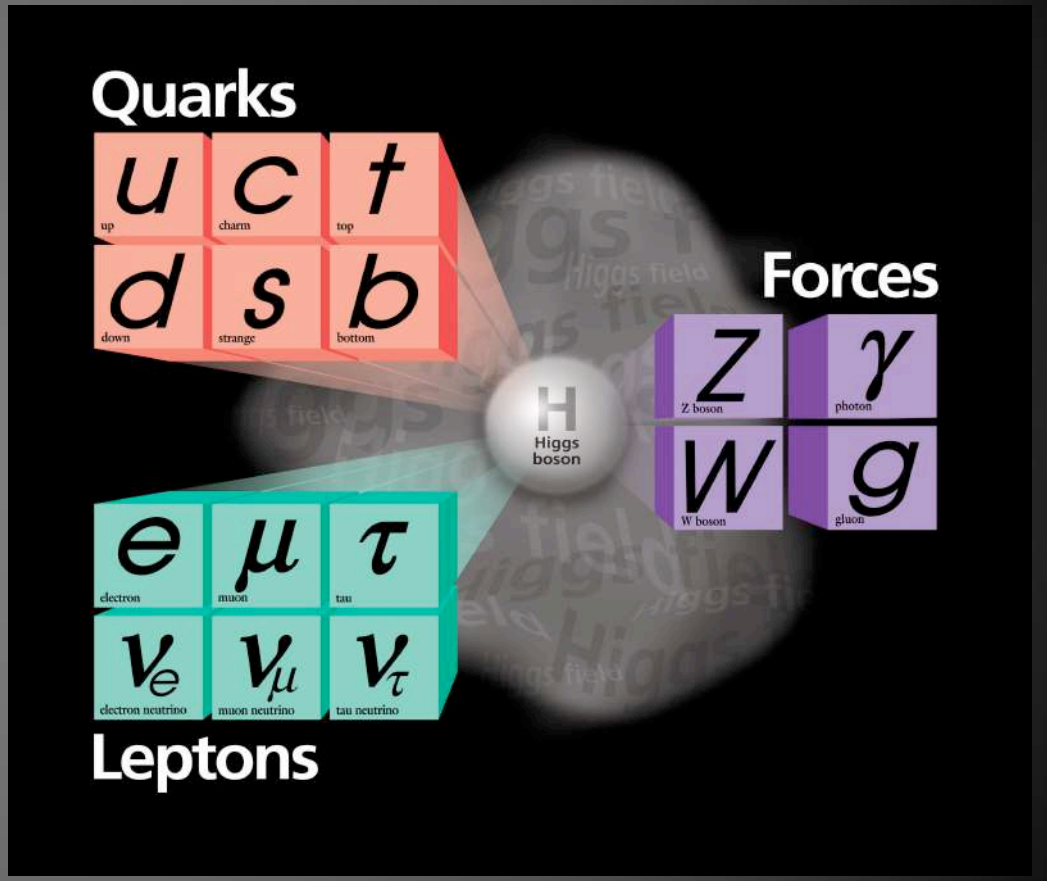
"Visible" Matter

The stuff that makes up everything we can see: all the dust, asteroids, comets, planet, stars, galaxies and you and me

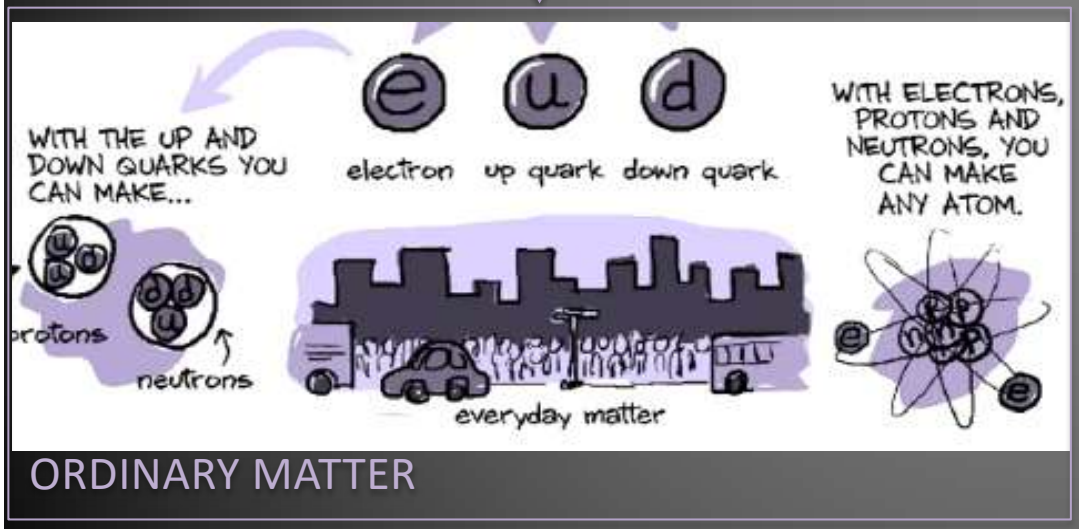


Are quarks and electrons fundamental?

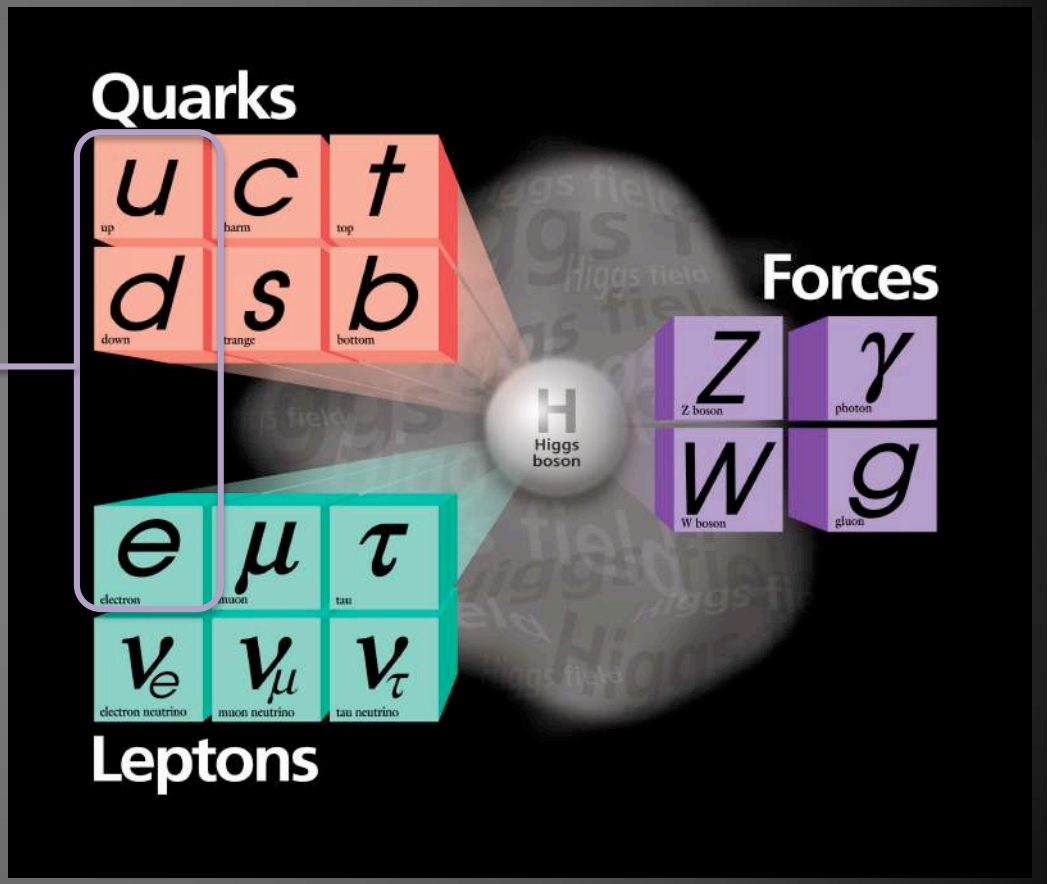
The Standard Model



THE STANDARD MODEL



ORDINARY MATTER



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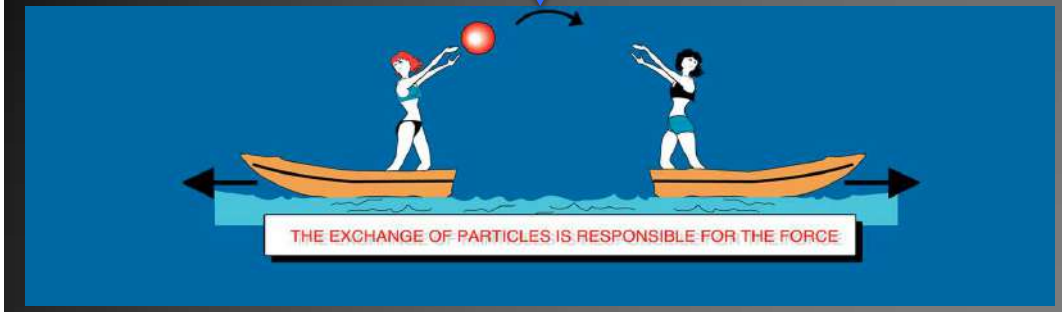

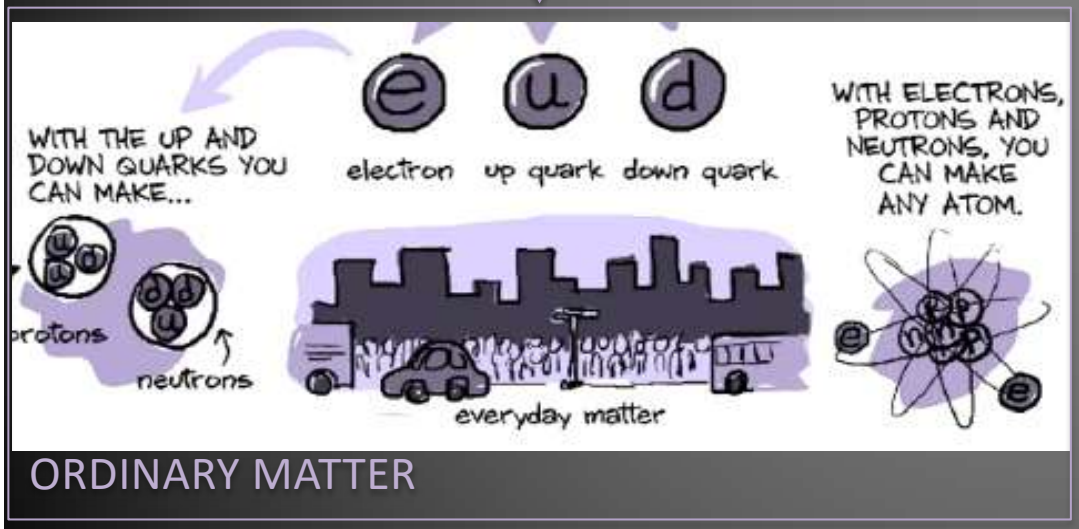

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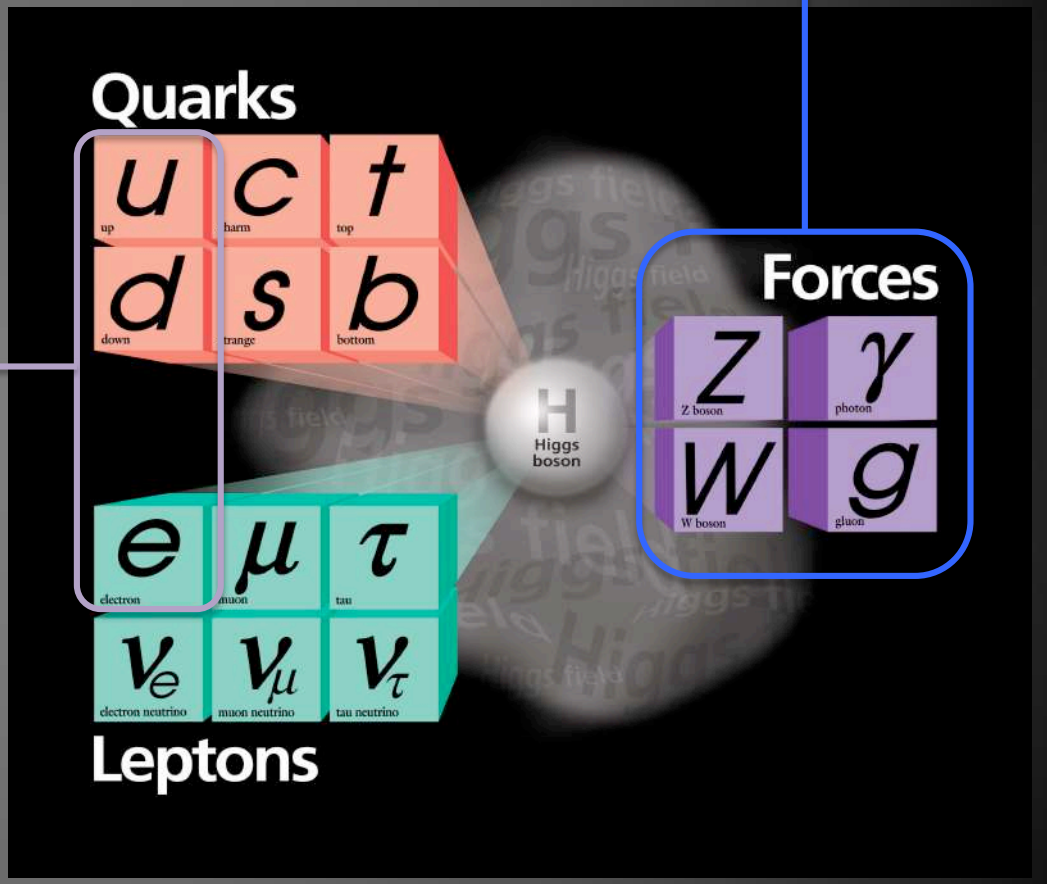


The Hidden Universe

Visible matter

Dark Matter

It does not interact with light → it is **invisible**

How can we be sure about its existence?

Définition

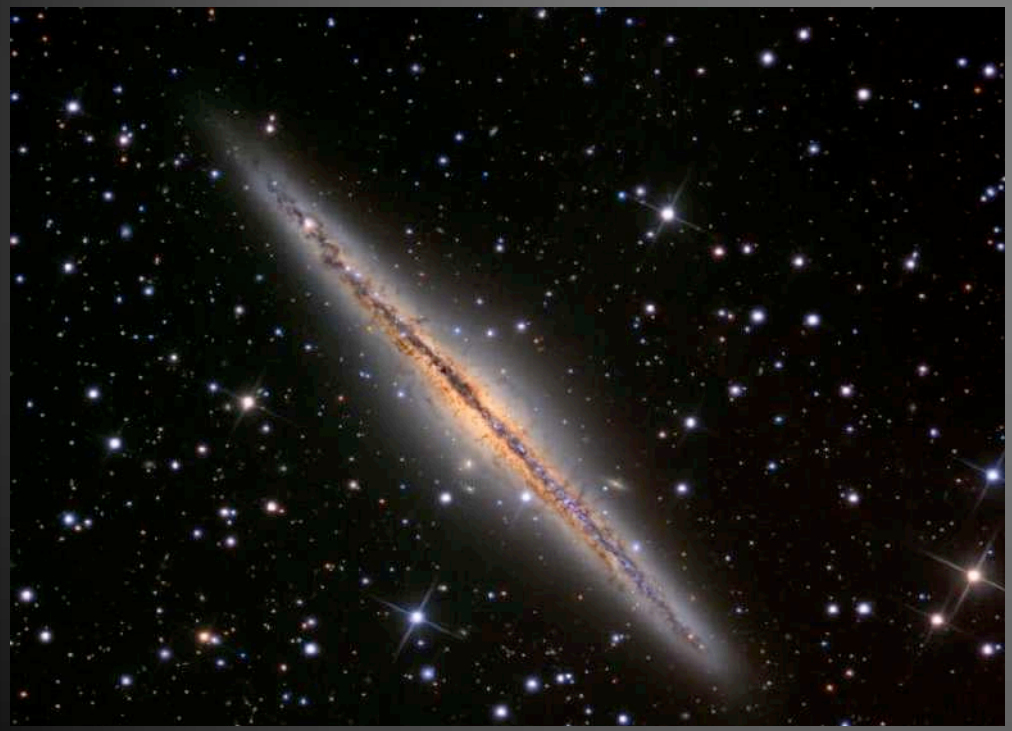
On entend par « matière noire » (ou encore « matière sombre » ou « masse manquante ») de la matière qui serait non visible, c'est-à-dire sans émission lumineuse associée (visible, UV, IR, radio, etc...)

... mais dont on présume l'existence de part ses effets gravitationnels dans :

1. les galaxies
2. les amas de galaxie
3. la cosmologie

1. Les galaxies

Les étoiles des galaxies spirales ne sont pas statiques mais ont un mouvement circulaire autour du centre de la galaxie.
La force centrifuge due à cette rotation compense la force de gravitation, c'est elle qui empêche les étoiles de s'effondrer vers le cœur des galaxies.



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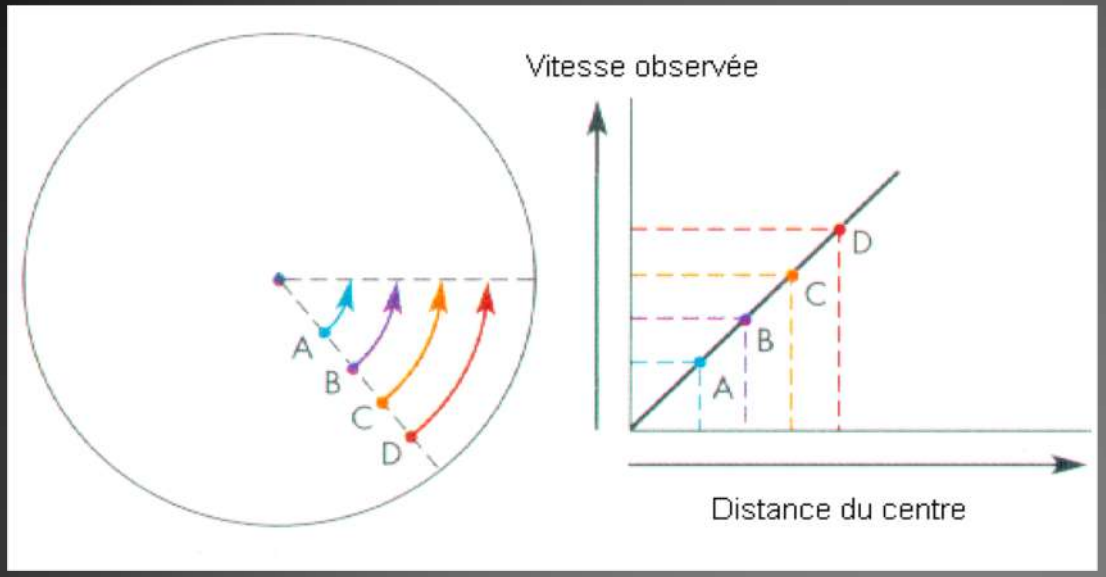
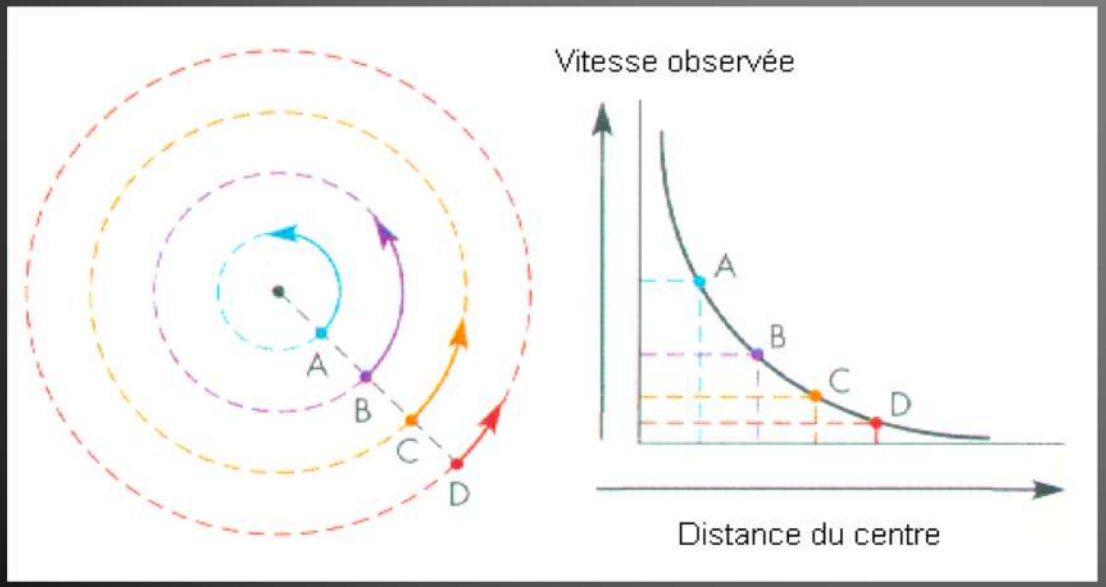


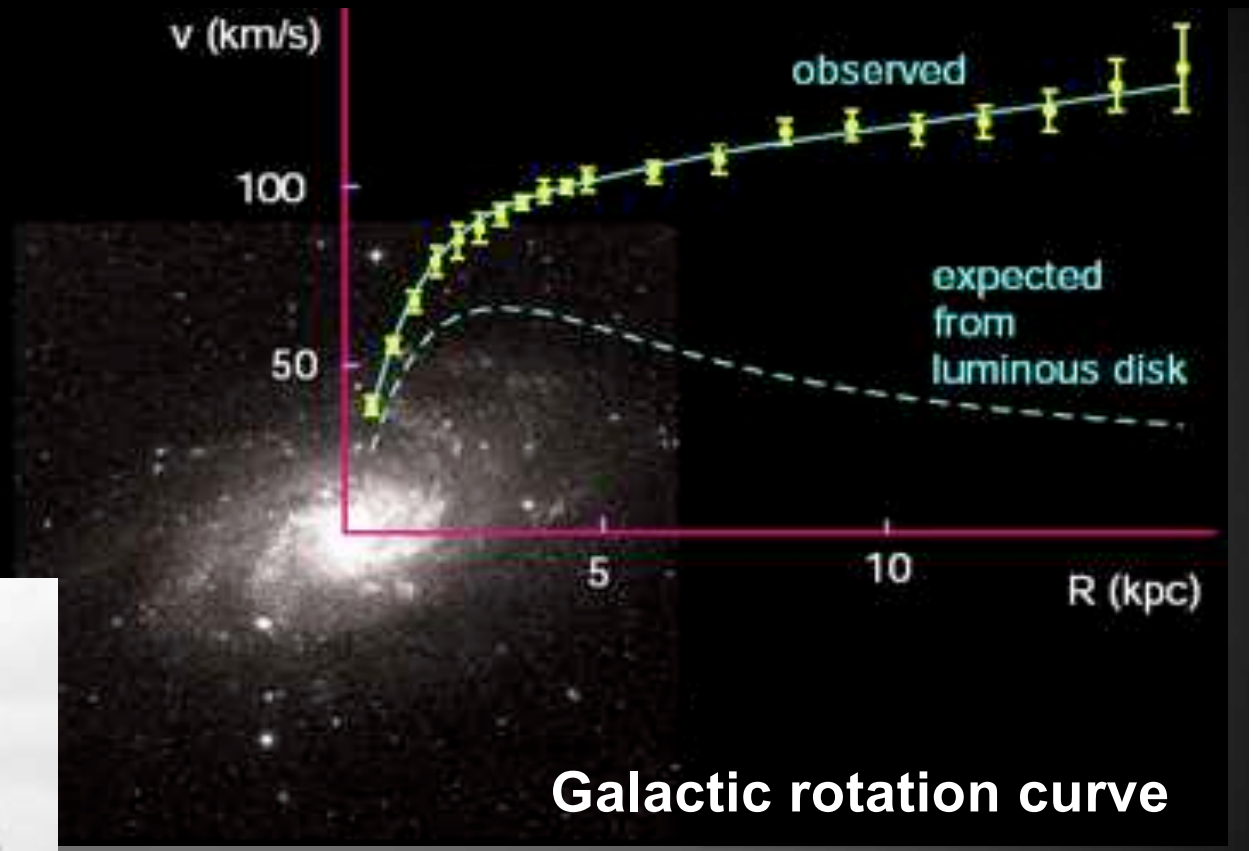
Mouvement solide



Mouvement planétaire

EARLY EVIDENCE FOR DARK MATTER

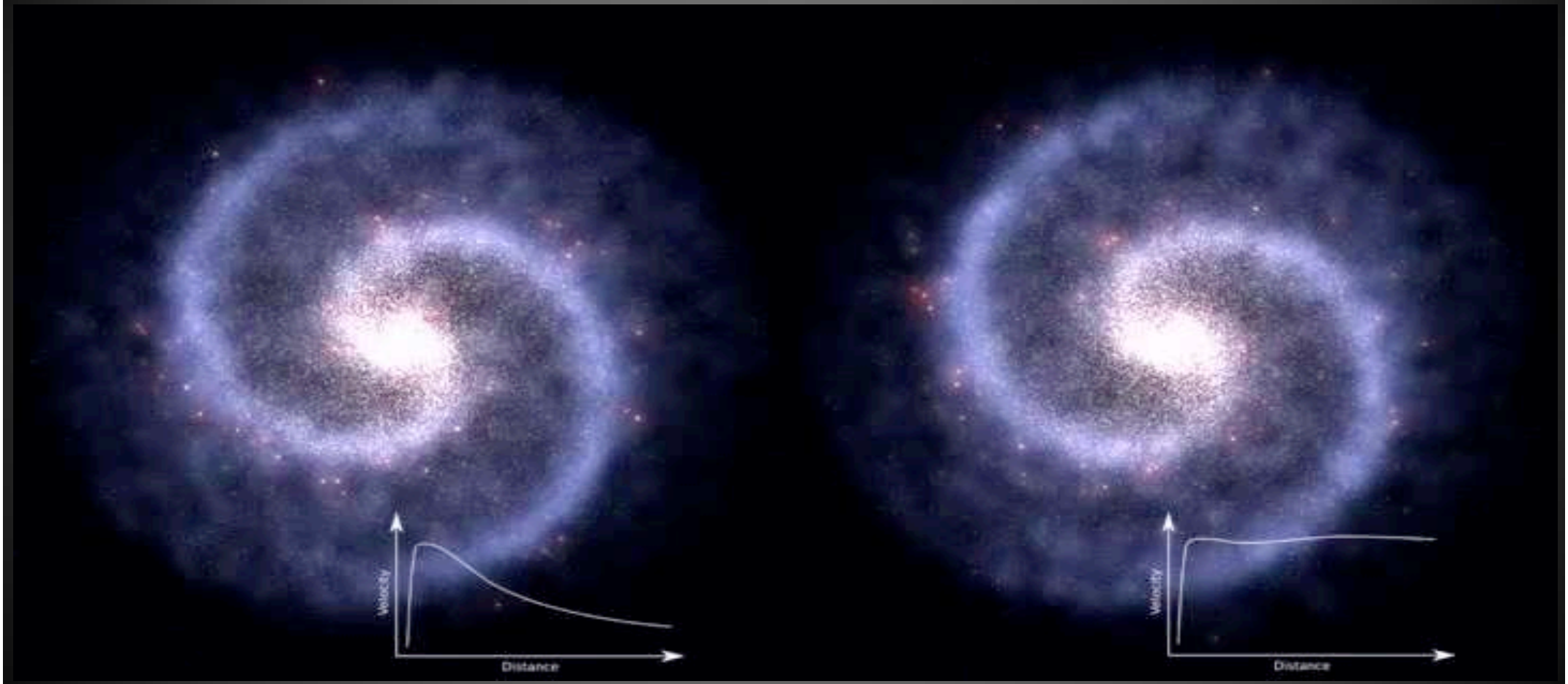
La vitesse des étoiles est quasiment constante
lorsque qu'on s'éloigne du centre
Alors que l'on s'attend à ce qu'elle diminue



Galactic rotation curve

➔ Présence d'un halo de matière invisible 5-10 fois plus massif que la matière visible

EARLY EVIDENCE FOR DARK MATTER



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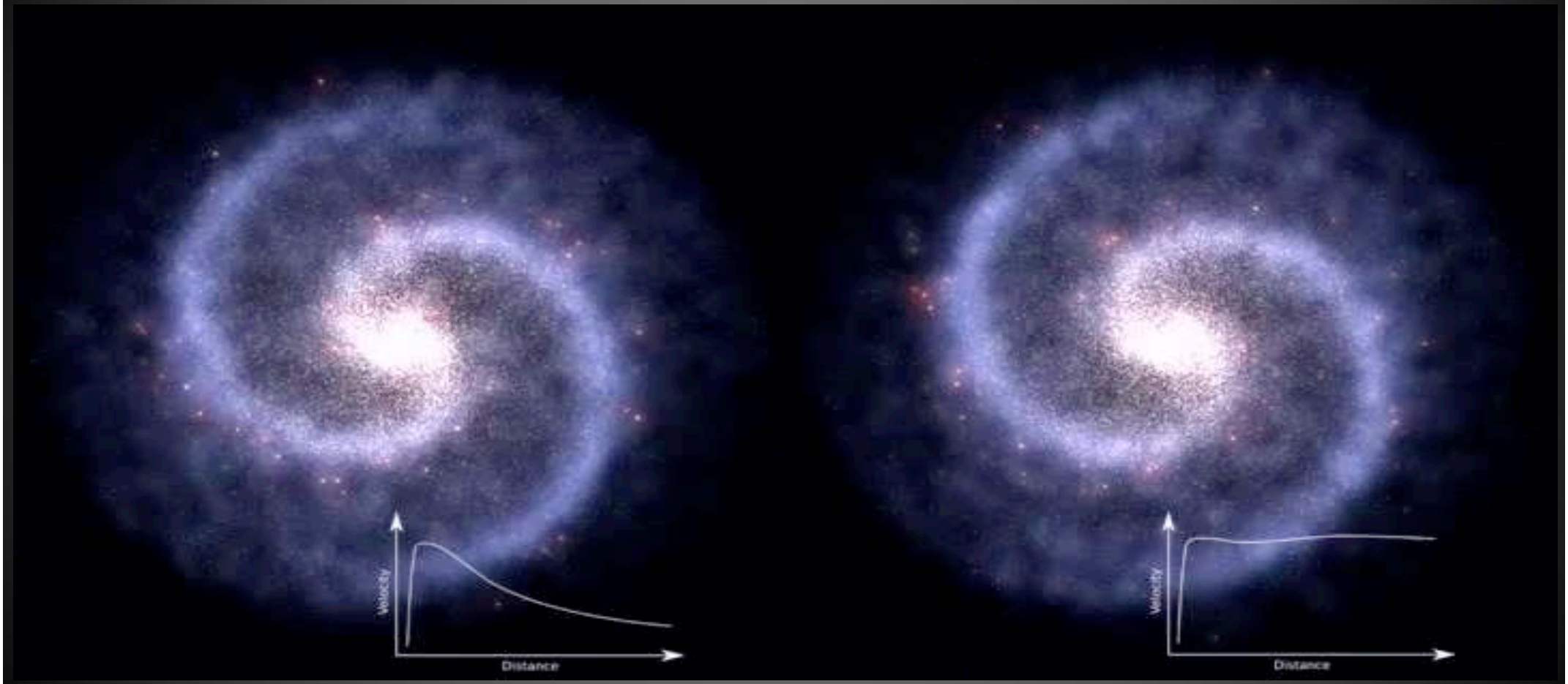


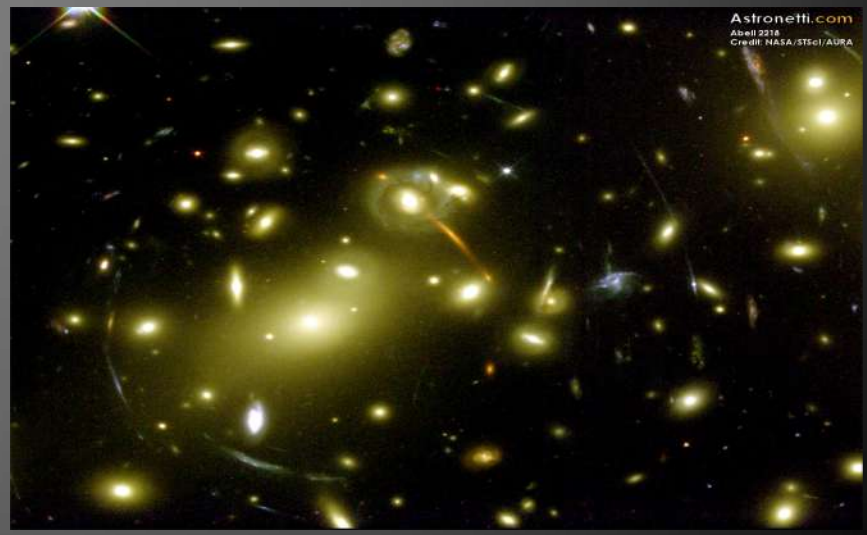
Lots more evidences since then …

2. Les amas de galaxies

Les galaxies se regroupent en amas (de quelques dizaines à quelques centaines d'unité) qui contiennent également une grande quantité de gaz chaud.
Les galaxies sont en mouvement autour du centre de l'amas et leur vitesse est mesurable.

Objets très intéressant pour contraindre la matière noire car on peut étudier leur distribution de masse par plusieurs méthodes indépendantes :

a. le mouvement des galaxies
b. les lentilles gravitationnelles
c. les collisions d'amas



2.a) Le mouvement des galaxies

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME 86 OCTOBER 1937 NUMBER 3

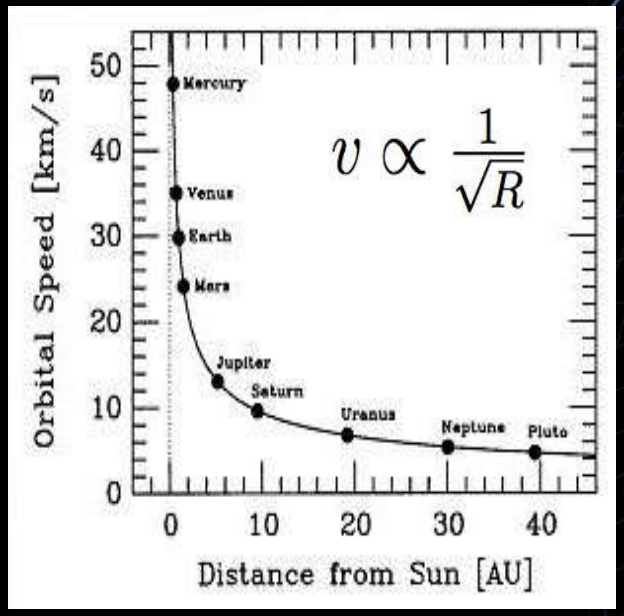
ON THE MASSES OF NEBULAE AND OF CLUSTERS OF NEBULAE

F. ZWICKY

La masse calculée de l'amas de Coma est des centaines de fois plus grande que la masse totale des galaxies estimée à partir de la lumière émise!

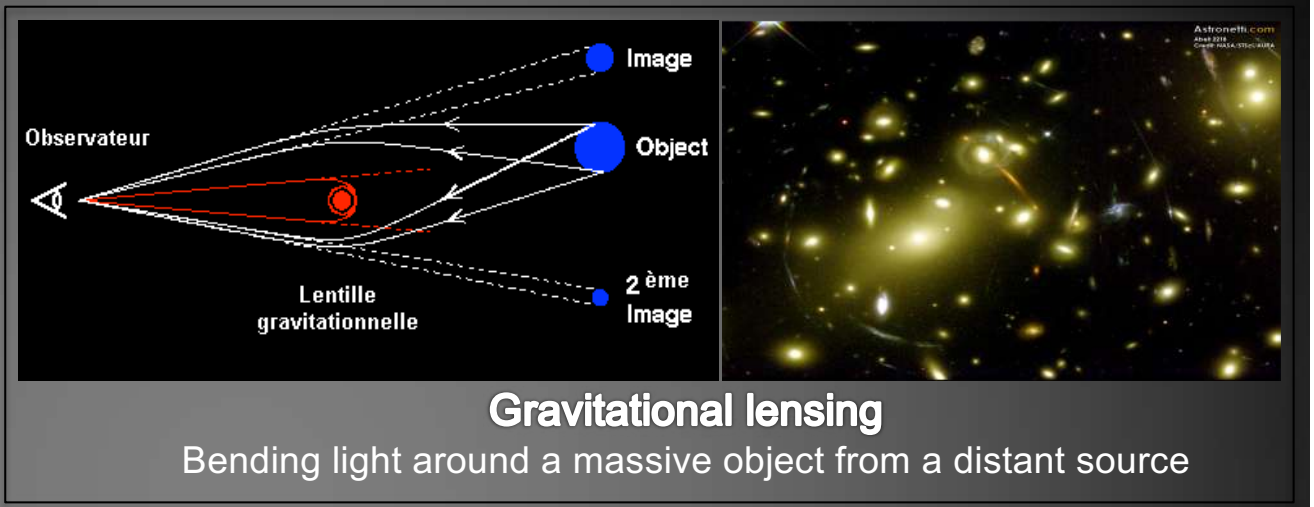
2.a) Le mouvement des galaxies

1. Looked at Galaxy cluster
2. Observed their motion
3. Applied Kepler's laws
4. Compared calculated and observed trajectories of known planets



5. Deduced that there must be more mass present than is seen

2.b) Les lentilles gravitationnelles



Gravitational lensing

Bending light around a massive object from a distant source

L'étude de ces lentilles gravitationnelles permet de sonder la masse des amas, avec une particularité intéressante : cet effet est sensible à l'ensemble des masses présentes, indépendamment de leur nature

La matière visible représente, encore environ 10 % de la masse responsable des effets de lentille.

2.c) Les collisions d'amas

Collision of galaxy clusters
Baryonic matter from X-ray (red),does not coincide with mass distribution from gravitational lensing (blue)

Superposition de trois images d'une collision entre deux amas de galaxies

- Les galaxies (en blanc)
- Le gaz (en rouge)
- La matière noire (en bleu)

➔ La masse dans l'amas est dominée par de la matière noire qui, contrairement au gaz chaud, n'est pas ralentie lors de la collision car elle interagit très peu

3. La Cosmologie

Du fait des interactions gravitationnelles, la naissance et l'évolution de l'Univers vont fortement dépendre de la quantité de matière présente dans l'Univers, quantité qui peut évoluer dans le temps.

Il n'est donc pas étonnant de pouvoir contraindre la quantité de matière grâce aux observations cosmologiques.

Plusieurs phénomènes cosmologiques apportent des informations :

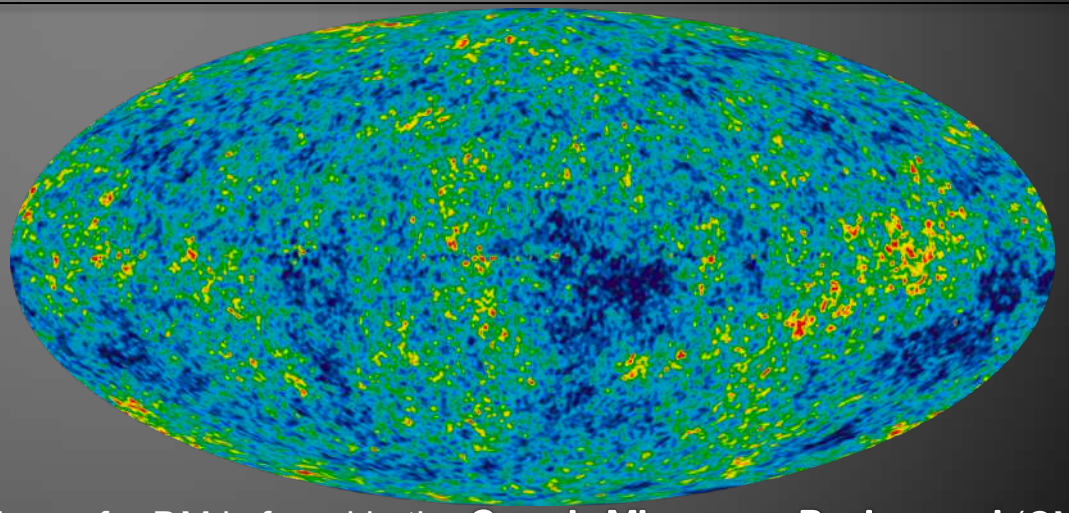
a. le fond de photons cosmologique (CMB)
b. la formation des structures
c. l'expansion accélérée de l'Univers
d. les oscillations baryoniques
e. la nucléosynthèse primordiale

3.a) Le fond diffus cosmologique

Le fond cosmologique (CMB) correspond aux photons qui se sont échappés lors du découplage entre la lumière et la matière
(300000 ans après le Big Bang)

L'univers est plat.
Il contient

- matière visible ~4,9%
- matière noire ~26,6%
- énergie noire ~68,5%



Evidence for DM is found in the **Cosmic Microwave Background** (CMB), the faint afterglow of the big bang. Temperature fluctuations in the CMB currently cannot be explained without DM

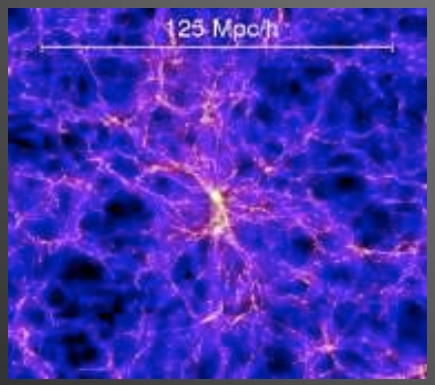
3.b) La formation des grandes structures

Les simulations N corps permettent de simuler la formations des grandes structures dans l'Univers qui découlent de la présence de matière noire (la matière visible a été attirée par gravitation par la matière noire)

Le CMB est trop homogène pour entrainer la formation des galaxies observées aujourd'hui

➔ Matière noire froide non baryonique

Cold dark matter to be consistent with formation of **Large Scale Structures**



Scénario HDM / CDM

➔ les résultats diffèrent selon les modèles de matière noire

INDIRECT EVIDENCES

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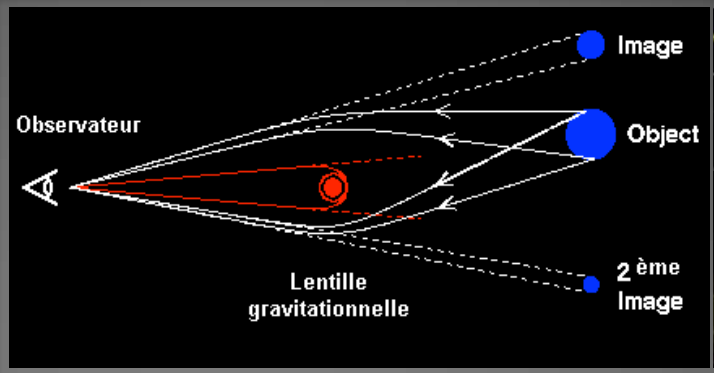

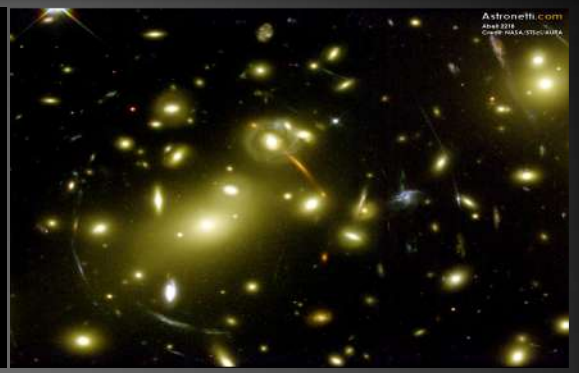

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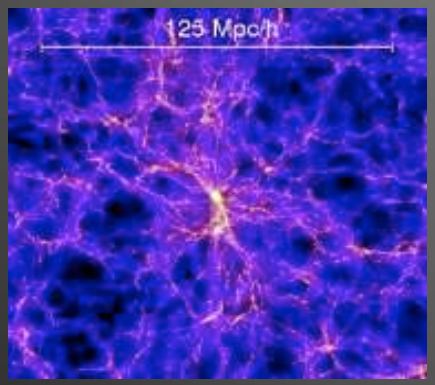

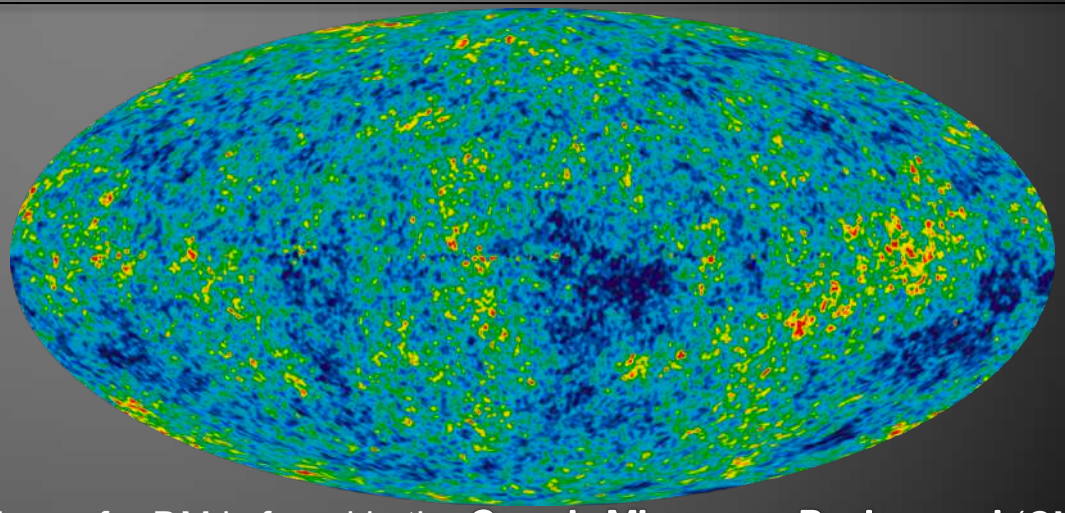

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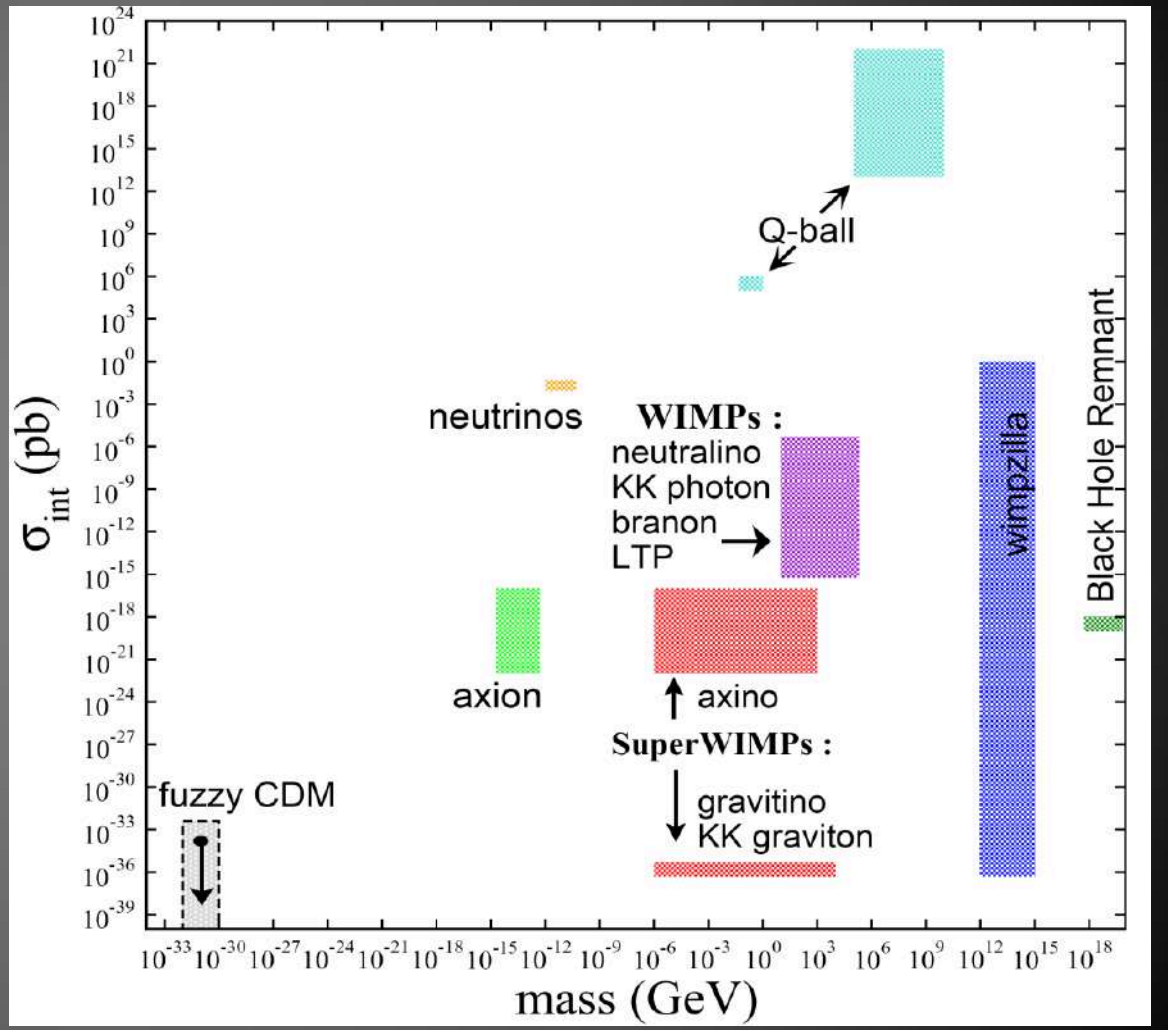
Evidence for DM convincing at all scales.. BUT only from gravitational effects

Dark Matter Candidates

- Plenty of models
  - WIMPs
    (Weakly Interactive Massive Particles)
  - axions
  - gravitinos
  - ...
- Masses and interaction strengths span many order of magnitude

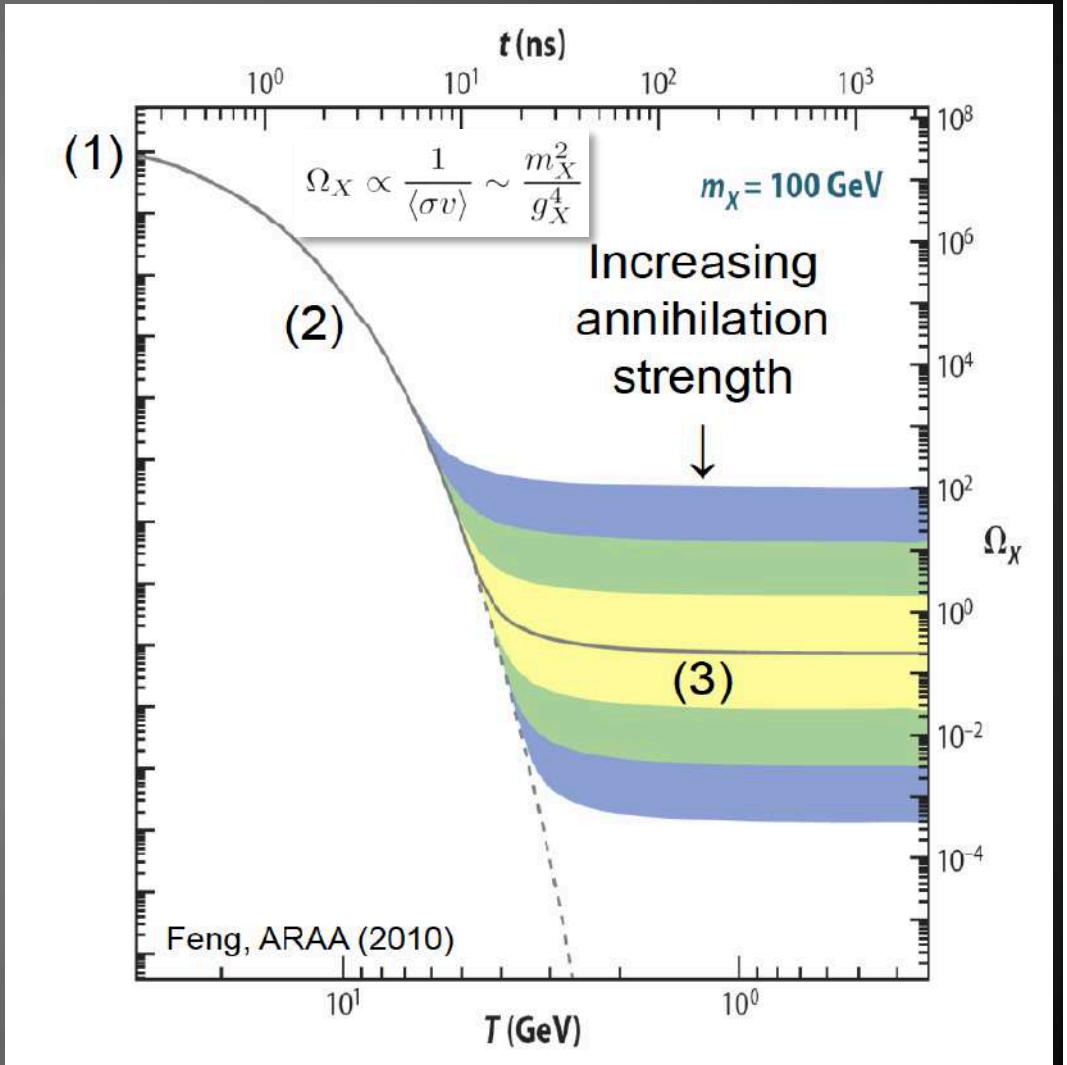


HEPAP/AAAC DMSAG Subpanel (2007)

THE WIMP MIRACLE

- (1) Assume a new heavy particle χ is initially in thermal equilibrium with SM particles

$$\chi\chi \longleftrightarrow \text{SM SM}$$



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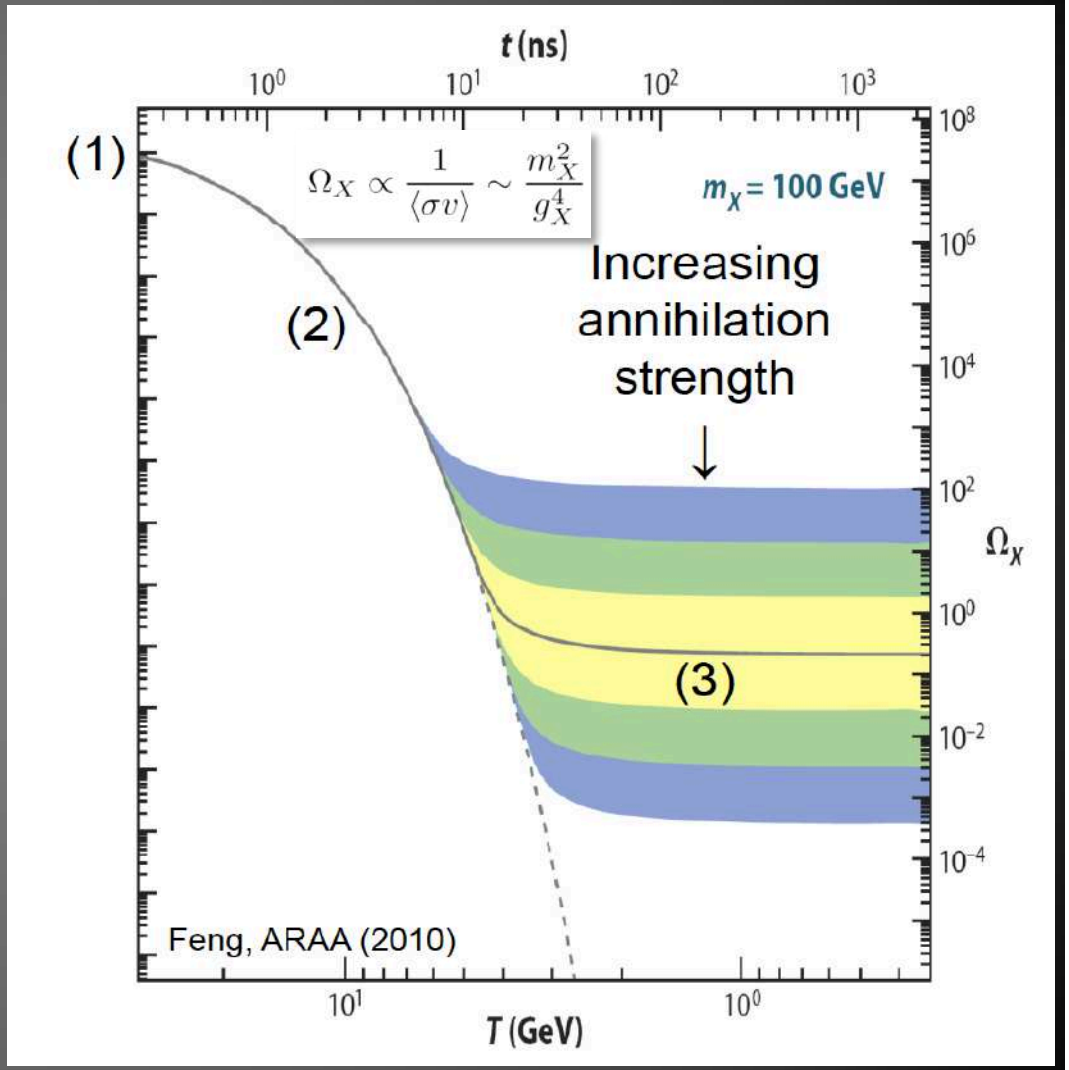

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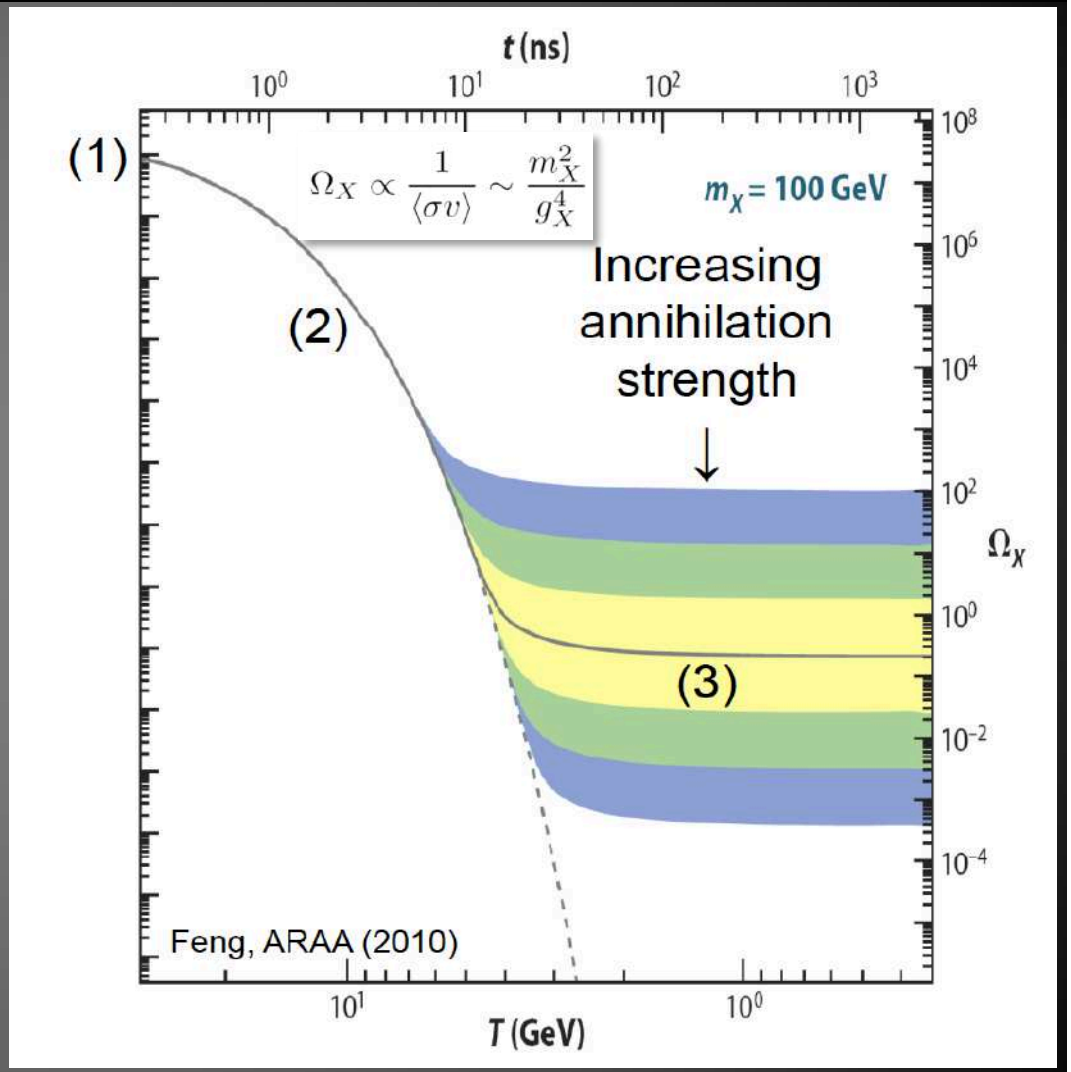

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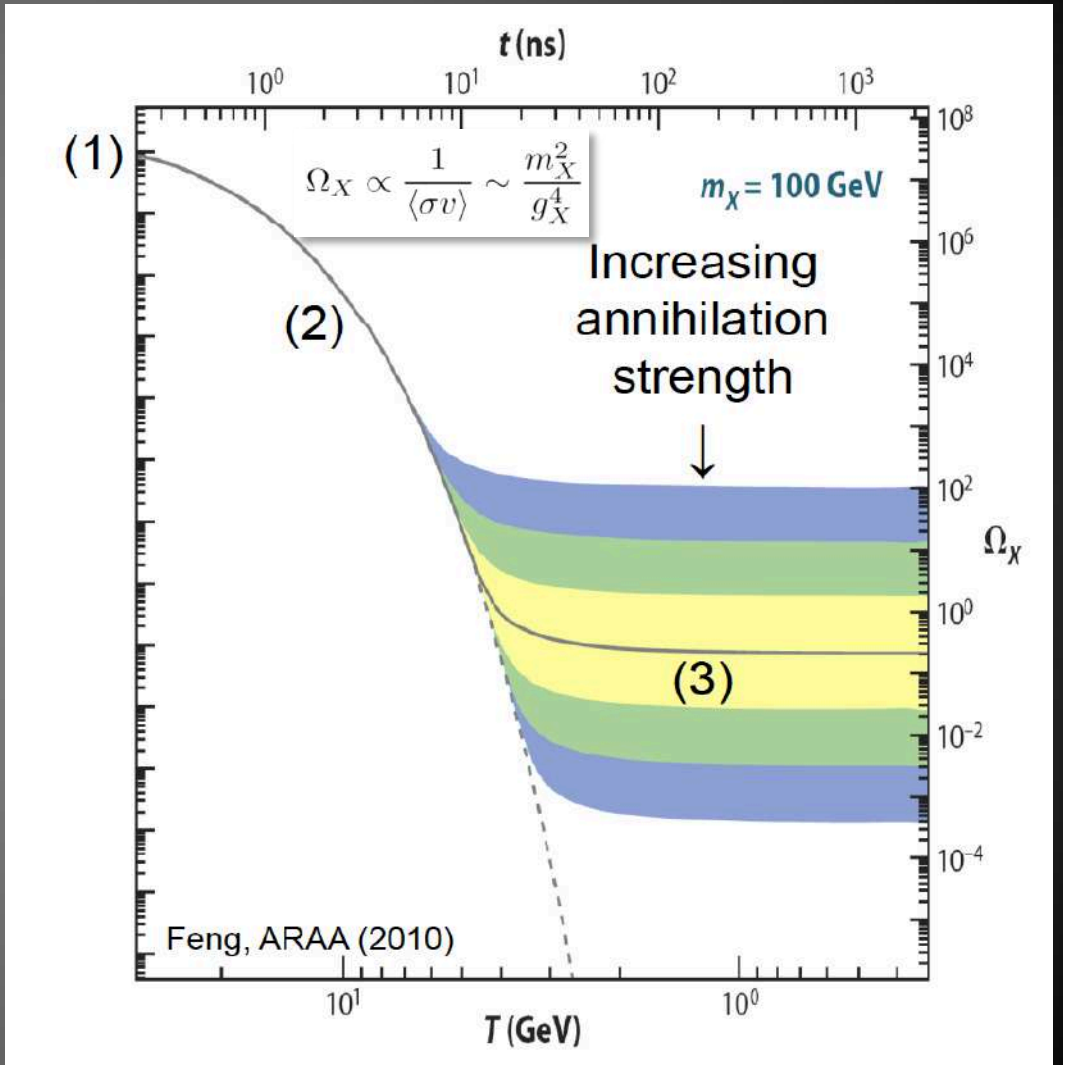
→ the density of χ freezes out the relic density



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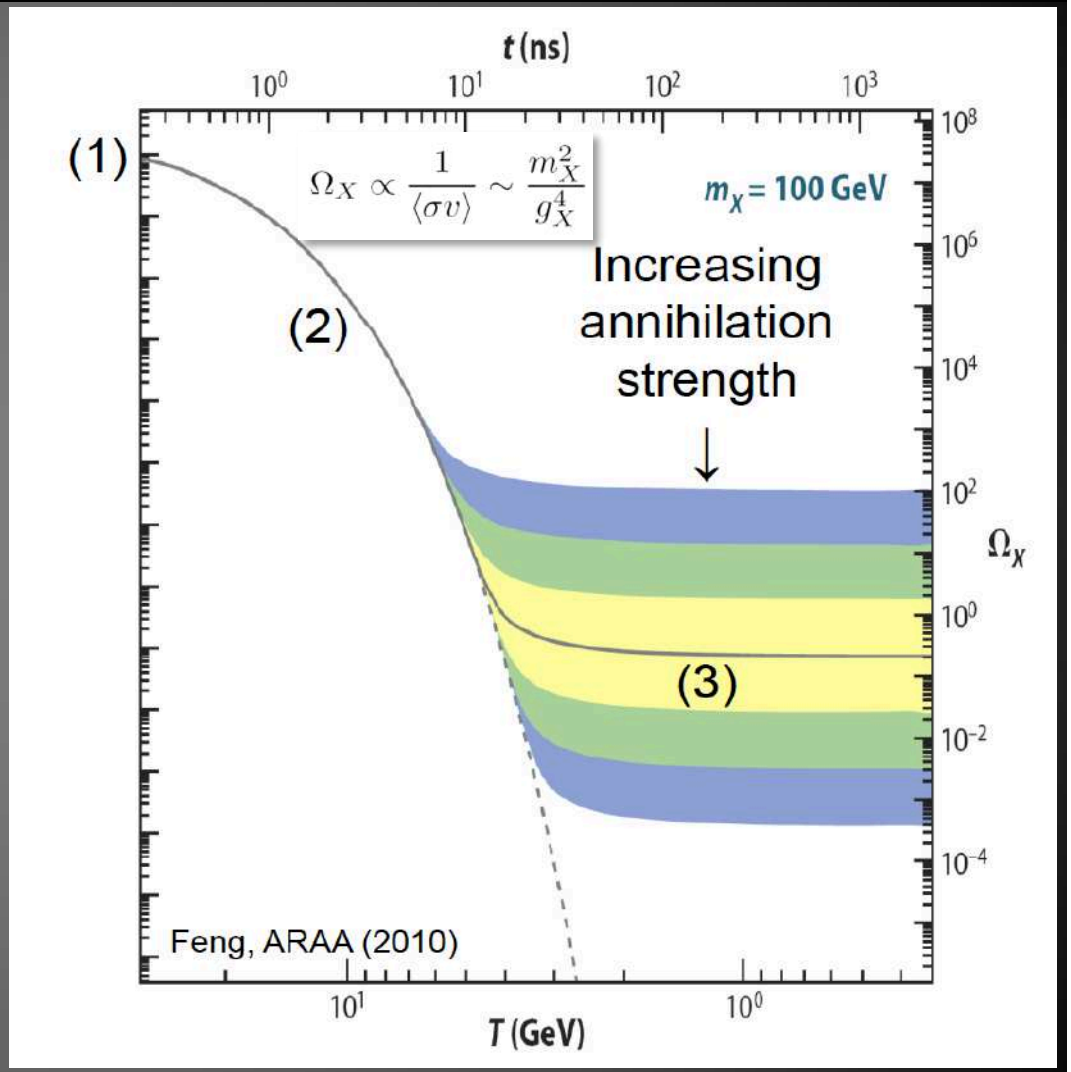
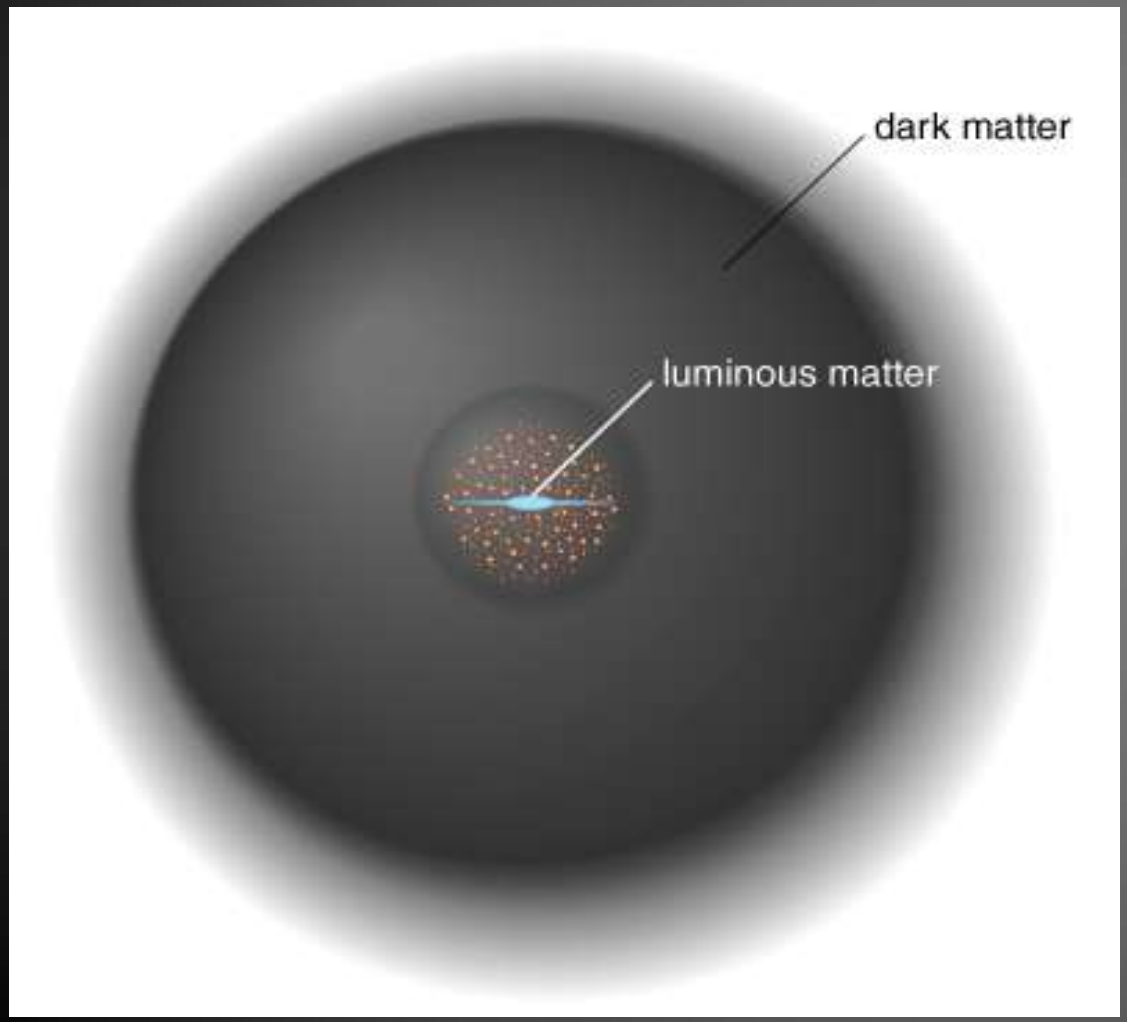


Weak scale interactions give the correct relic density!

Weakly Interactive Massive Particles

WIMPs



- Origin ?

Produced after the BIG BANG (~14 bilion of years ago)

- Mass ?

Natural mass range 10 GeV – TeV

- Interactivity ?

1 billion pass trough our bodies every day

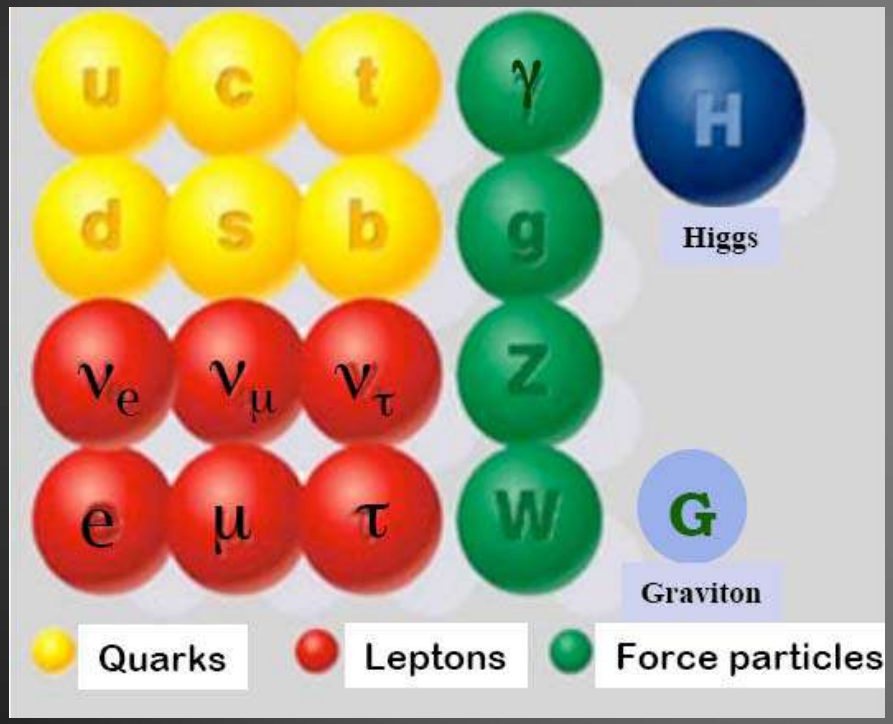
- Distribution ?

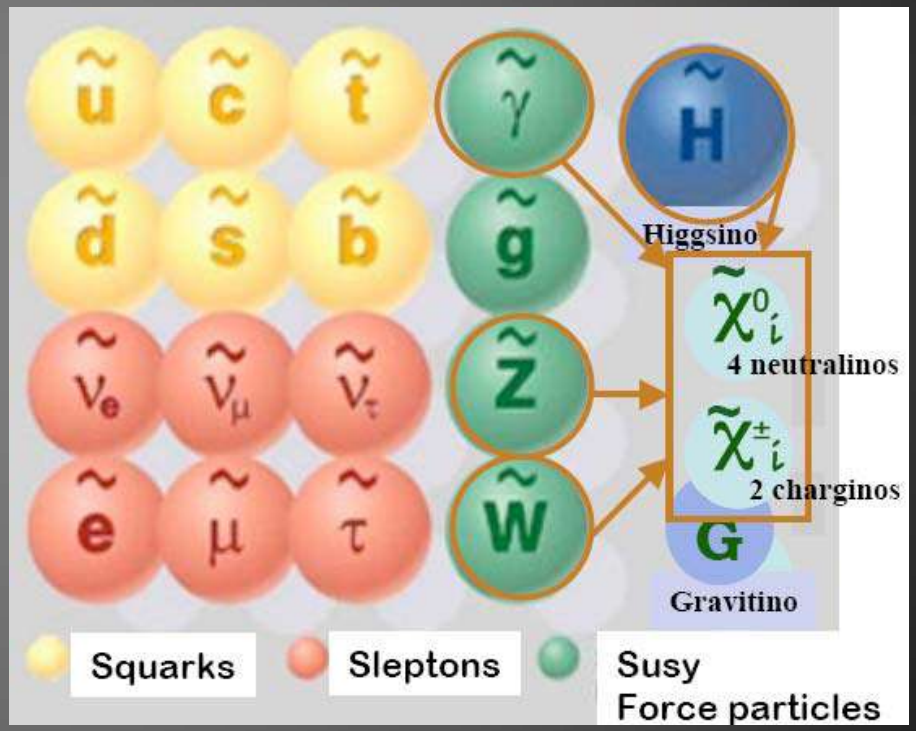
Extended halos around galaxies

WIMPs & SUSY

Supersymmetry extends the SM by predicting a new symmetry

Spin 1/2 matter particles (fermions) ←→ Spin 1 force carriers (bosons)





The lightest neutralino χ is a WIMP candidate

CONCLUSIONS

- There is more matter out there than we can see in stars, planets, etc ...
- This matter does not interact with light, it is neutral, cold and long lived
- Until now it is evident only by its gravitational influence
- It is *fundamentally* different from standard matter (and it interacts weakly with the standard matter)
- We have several candidates for what this stuff might be → one of the most compelling are WIMPs
- We never direct observed it

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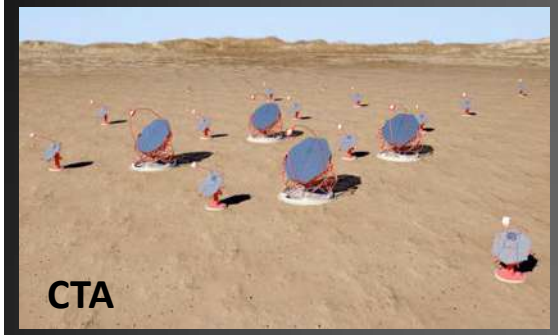
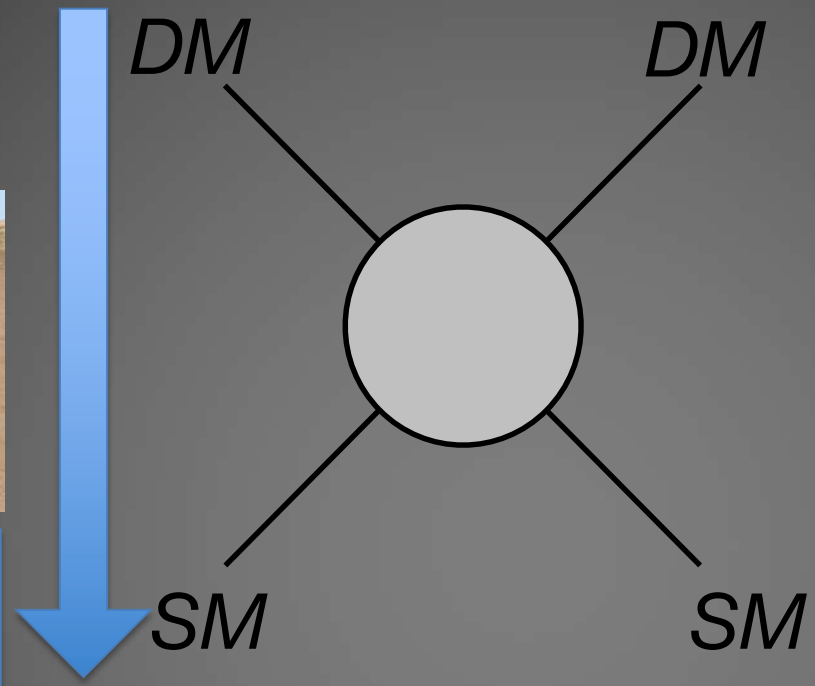
Let's search for it!

Dark Matter Detection

Indirect Detection



DM annihilation into SM particles



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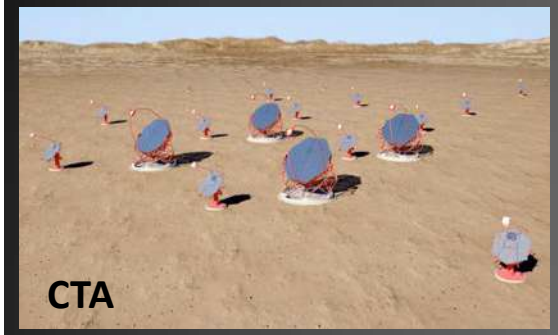

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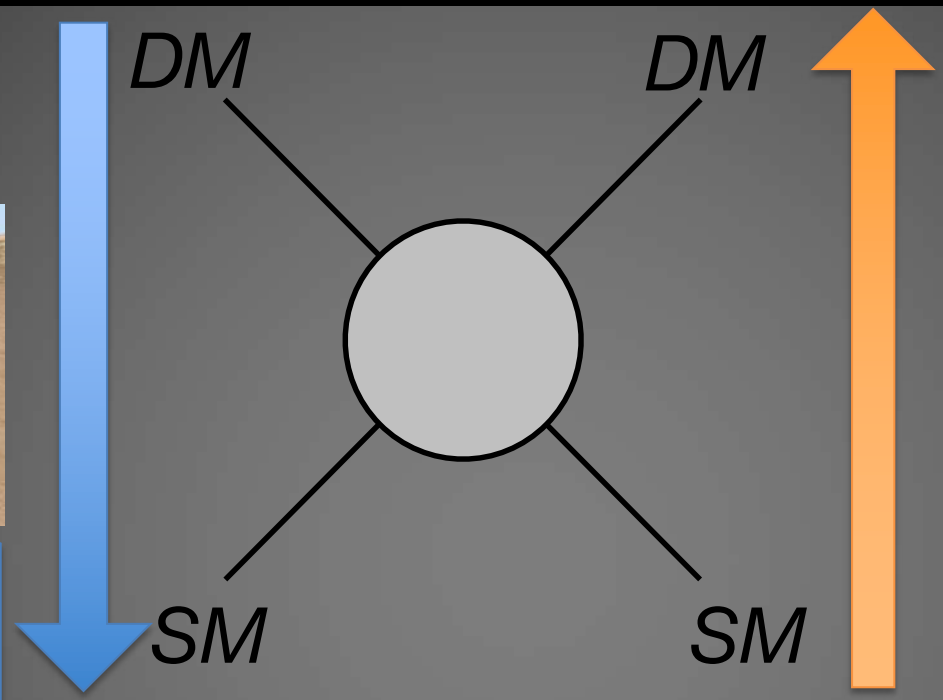
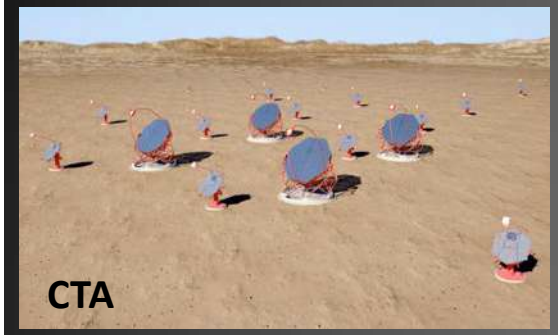


Direct or by decay DM production

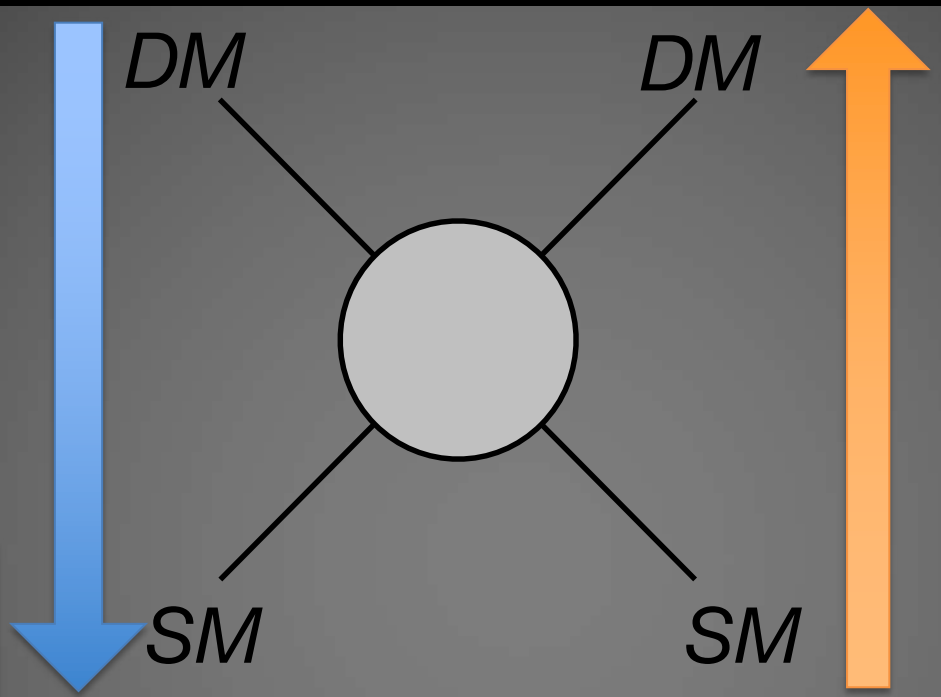
Particle Colliders

Dark Matter Detection

Indirect Detection



DM annihilation into SM particles



Direct or by decay DM production

Particle Colliders

Direct Detection

DM scattering on target nuclei (SM)