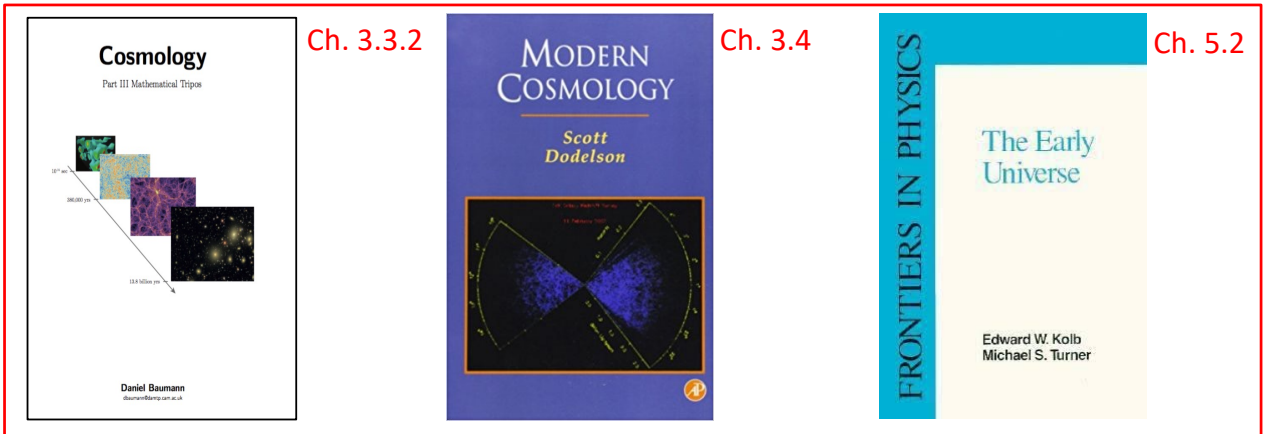# Universo Primitivo
2022-2023 (1º Semestre)

Mestrado em Física - Astronomia

Chapter 5

5   Dark Matter

- Observational evidences;
- Types of Dark Matter;
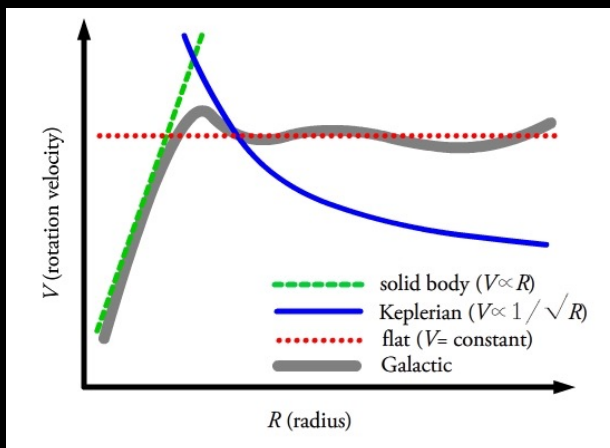- Dark matter relics: WIMPs freeze out;
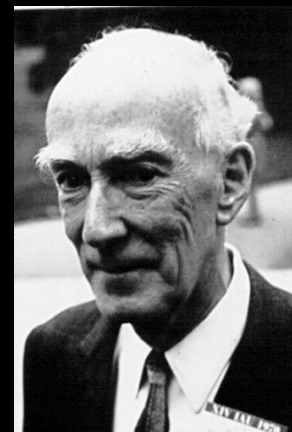- The WIMP miracle;

References:

Ch. 3.3.2   Ch. 3.4   Ch. 5.2

+

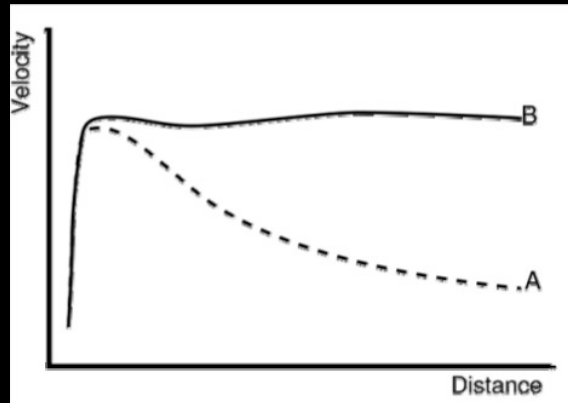# Black board lectures

Dark Mater: Observational evidences

From:

Jan Oort

1927: Jan Oort studies the rotation of stars in our galaxy and infers that their rotation is not consistent with Keplerian motion.

$$v_{circ} = \sqrt{\frac{GM(R)}{r}}$$

Dark Mater: Observational evidences

B: Observations

A: theoretical expectations

1980: Vera Rubin and others also find that stars rotate too fast in the outskirts of spiral galaxies to remain bound assuming that gravity is produced only by visible matter.
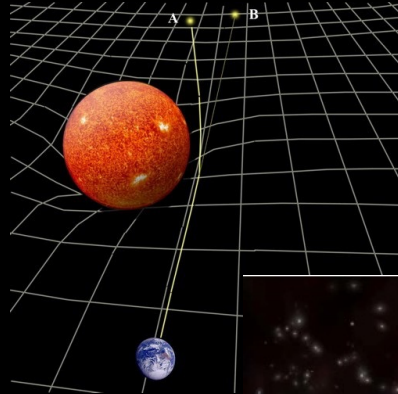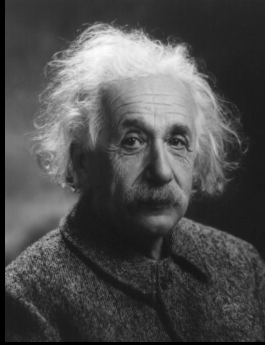
Dark Mater: Observational evidences

Fritz Zwicky

1936: Fritz Zwicky applied the Virial theorem to the velocities of galaxies in the Coma cluster and finds very high Υ =M/L for them to remain bound ($\Upsilon_{coma}/\Upsilon_{sun} \sim 500 \gg 2 - 10$ for galaxies).

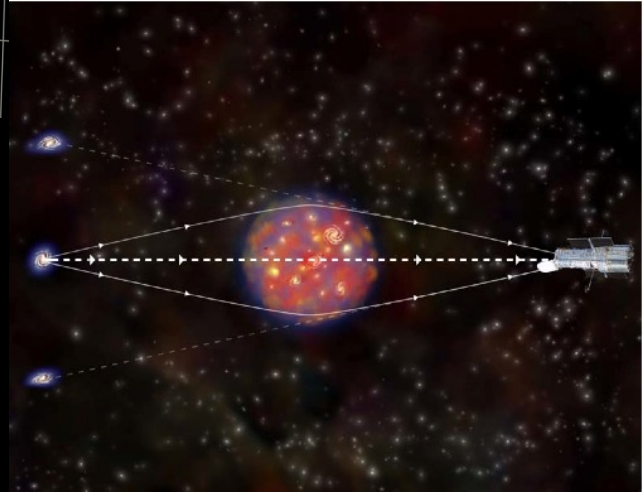- Viral theorem (for gravitationally relaxed systems): $2\bar{E}_k + \bar{E}_p = 0$

- Mass from the virial theorem: $M_V = <v^2><R>/G$

- Visible (luminous) Mass: $M_L = N_g\, R_{ML}\, L_g$

  (R_{ML} – typical mass to light ratio of galaxies;
  N_g, L_g number and luminosity of individual galaxies)

Dark Mater: Observational evidences

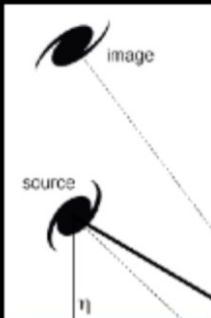lensing effects: weak and strong lensing

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

From:

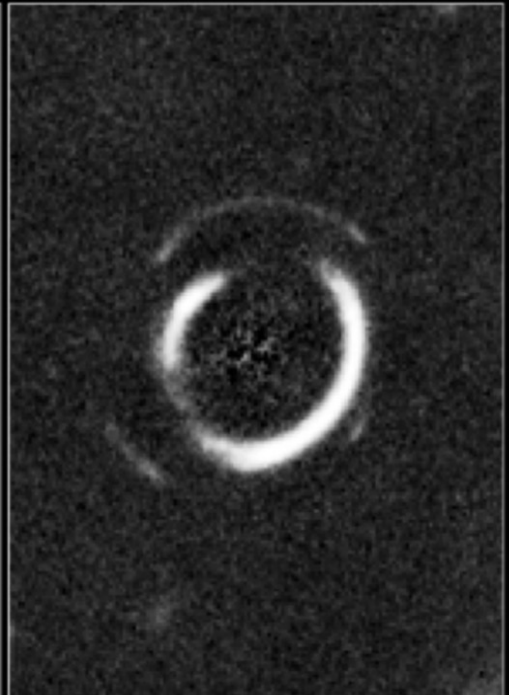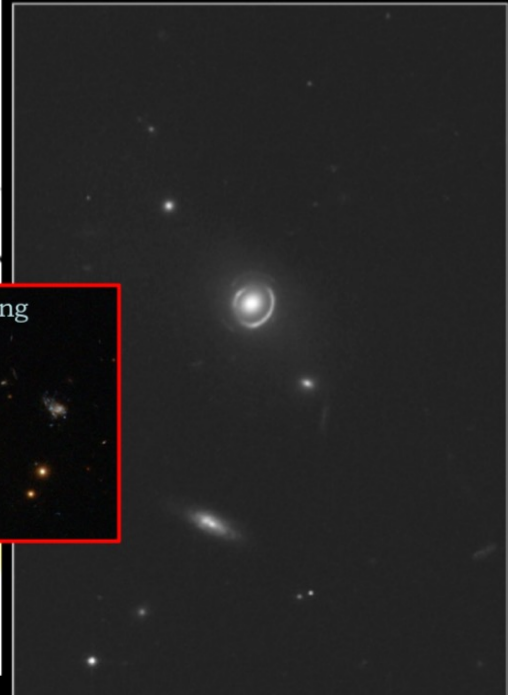# Dark Mater: Observational evidences

lensing effects: strong lensing

Einstein Rings

image

source

η

Galaxy-galaxy lensing

Double Einstein Ring SDSSJ0946+1006

Hubble Space Telescope · ACS/WFC

NASA, ESA, R. Gavazzi and T. Treu (University of California, Santa Barbara), and the SLACS Team

STScI-PRC08-04

Dark Mater: Observational evidences

2003: X-ray (produced by extremely hot gas – in red) vs weak lensing observations (probing the total mass distribution in blue) of the Bullet Cluster put in evidence that galaxy clusters must contain "dark matter"

1E 0657–56   X-rays   Bullet Cluster

Chandra 0.5 Msec image   0.5 Mpc   z=0.3

X-rays + lensing + visible

1.5'
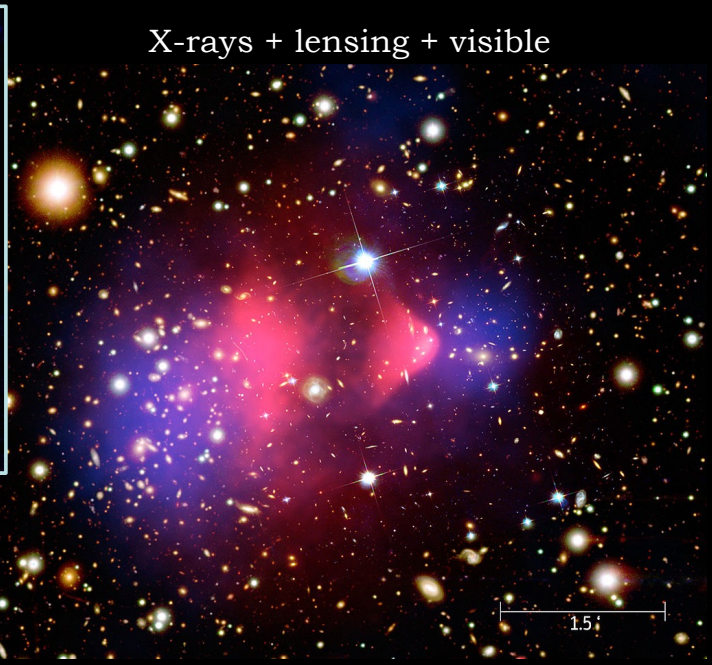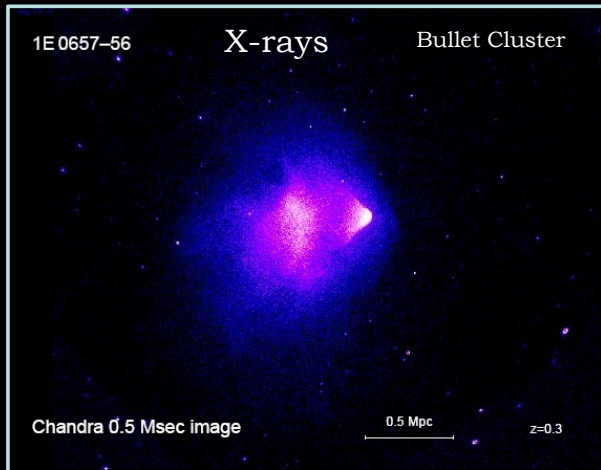
Refs:
astro-ph/0309303
astro-ph/0312273

Types of "Dark Matter"

Some definitions:

Dark matter **is not non-luminous** (invisible) ordinary matter!

Non-luminous baryonic "dark matter"
$\begin{cases} \text{White dwarfs} \\ \text{Neutron stars} \\ \text{Black holes} \\ \text{MACHOS (Massive Compact Halo Objects)} \\ \dots \end{cases}$

"Non-baryonic" dark matter
$\begin{cases} \textbf{Hot (HDM)}\text{: massless or very small mass relativistic particles,} \\ \qquad \text{(e.g. neutrinos)} \\ \textbf{Warm (WDM)}\text{: hypothetical with intermediate properties,} \\ \qquad \text{(e.g. keVins and GeVins - keV and Gev inert fermions)} \\ \textbf{Cold (CDM)}\text{: massive, non-relativistic particles,} \\ \qquad \text{(e.g. Axions, light supersymmetric} \\ \qquad \text{particles - gravitino, neutralino,} \\ \qquad \text{WIMPS - Weak Interactive Massive Particles)} \end{cases}$

Types of "Dark Matter"

Model candidates:
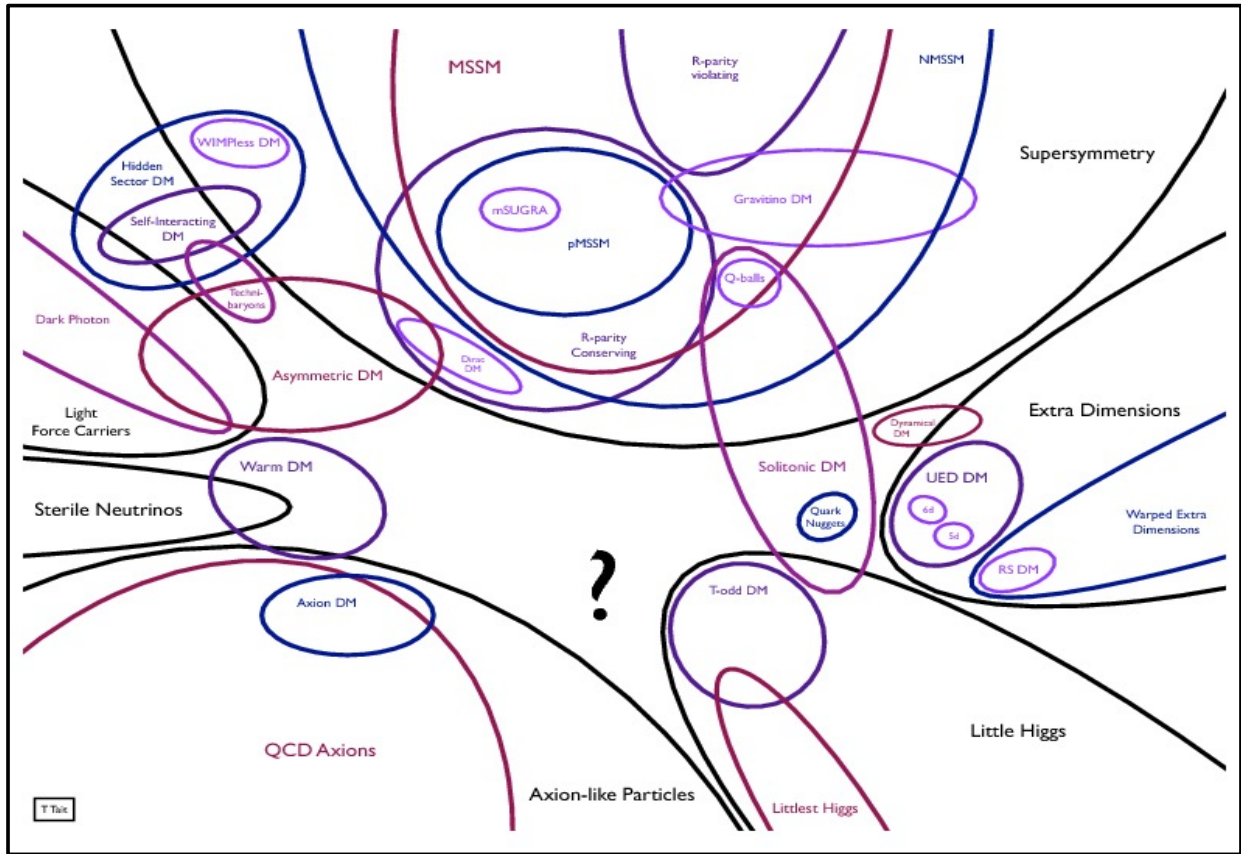
Dark Matter relics: WIMP Freeze out

Weakly Interactive Massive Particles:

Black board lecture
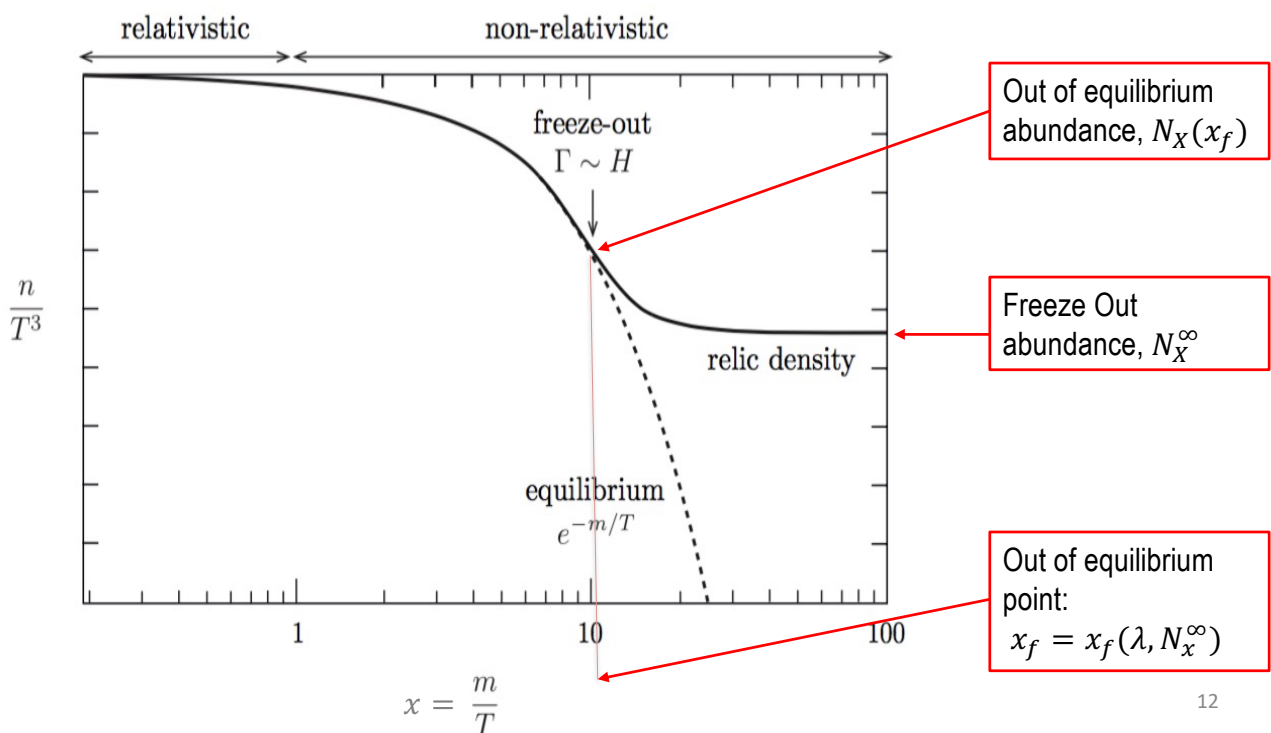
Dark Matter relics: WIMP Freeze out

Ricatti Equation:

Black board lecture

Dark Matter relics: WIMP Freeze out

WIMP miracle:

Black board lecture

Dark Matter relics code packages

http://lapth.cnrs.fr/micromegas/

Dark Matter relic code packages

http://superiso.in2p3.fr/relic/