Universo Primitivo
2020-2021 (1º Semestre)

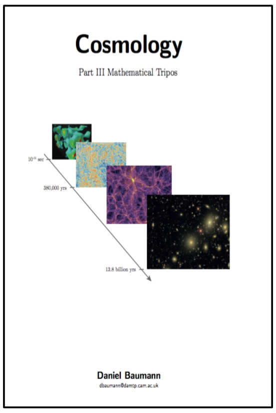
Mestrado em Física - Astronomia

Chapter 5

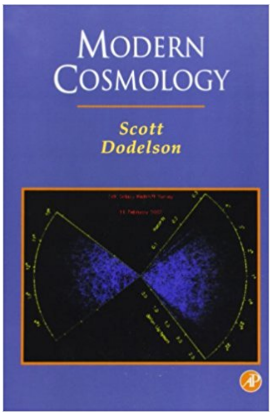
5 Dark Matter

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

References:



Ch. 3.3.2



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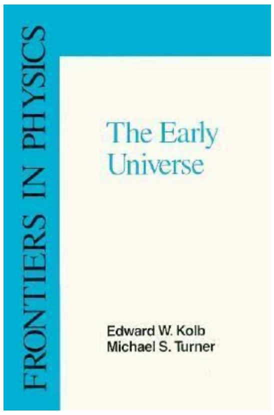

Ch. 5.2

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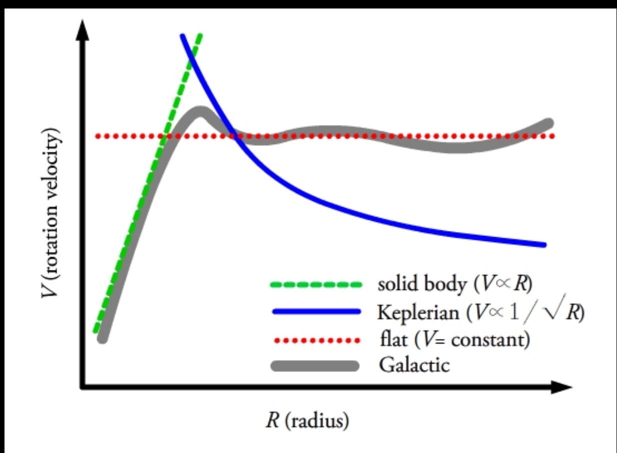
Black board lectures

Dark Mater: Observational evidences



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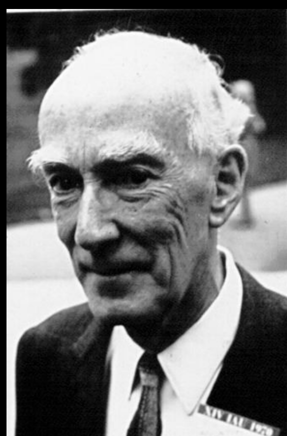
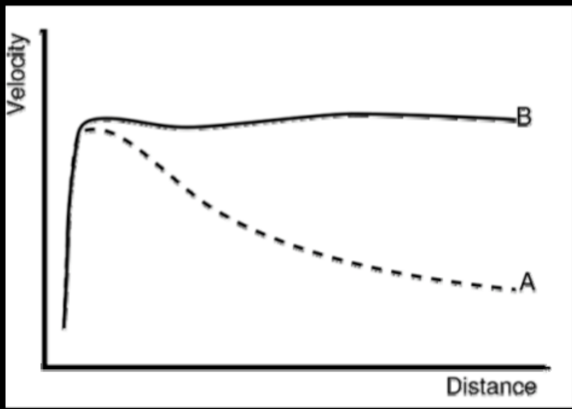


Jan Oort

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

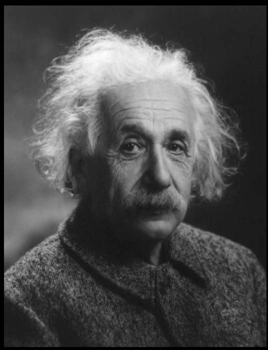
1936: Fritz Zwicky applied the Virial theorem to the velocities of galaxies in the Coma cluster and finds very high $\Upsilon = M/L$ for them to remain bound ($\Upsilon_{coma}/\Upsilon_{sun} \sim 500 \gg 2 - 10$ for galaxies).

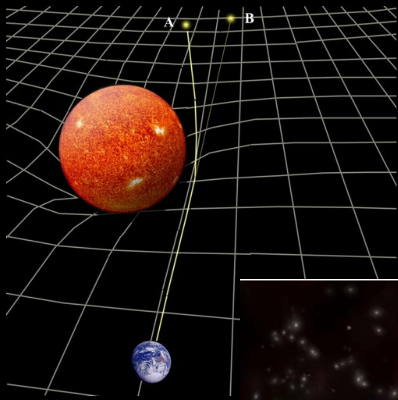
- Viral theorem (for gravitationally relaxed systems): $2\bar{E}_k + \bar{E}_p = 0$
- Mass from the virial theorem: $M_V = \langle v^2 \rangle \langle R \rangle / G$
- Visible (luminous) Mass: $M_L = N_g \, R_{ML} \, L_g$

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

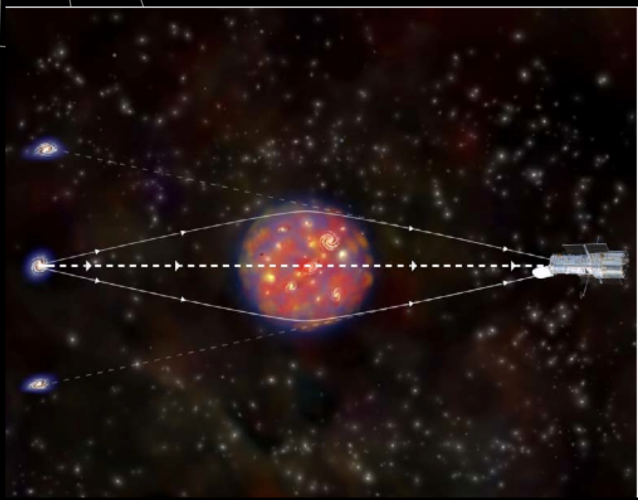
Dark Mater: Observational evidences

lensing effects: weak and strong lensing





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



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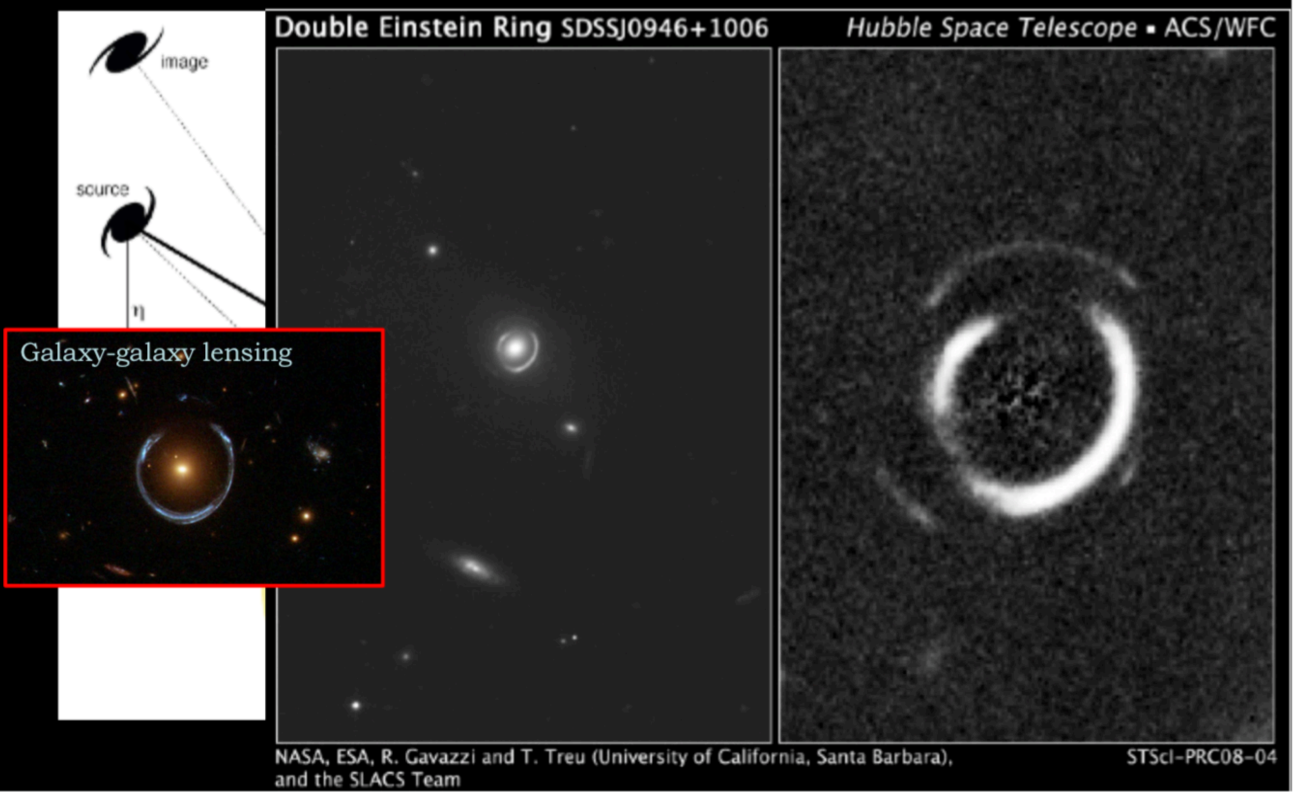
Dark Mater: Observational evidences

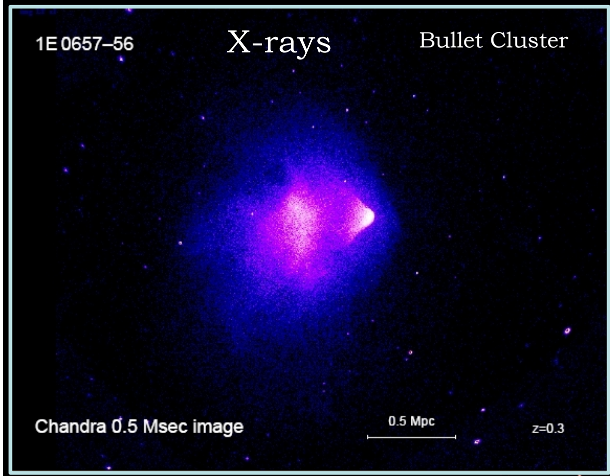
lensing effects: strong lensing

Einstein Rings

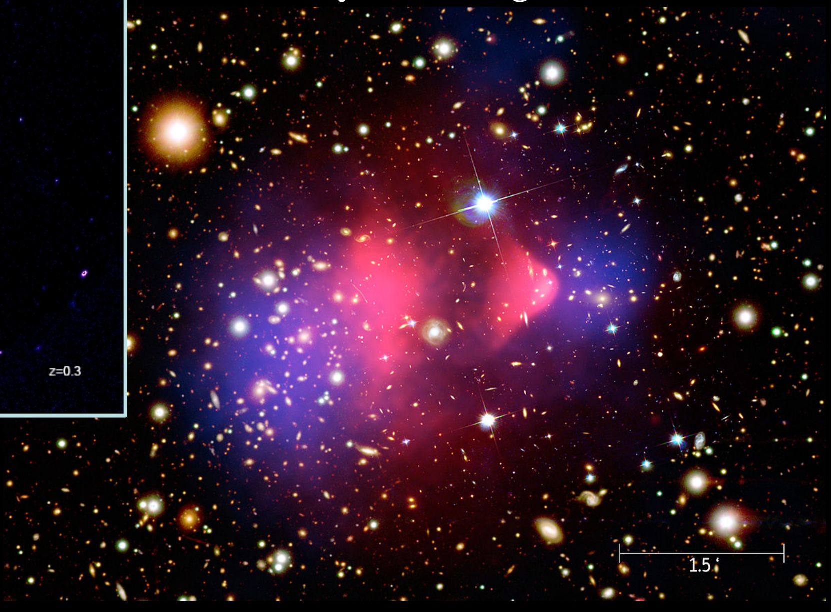


Dark Mater: Observational evidences

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"



X-rays + lensing + visible



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

Types of "Dark Matter"

Some definitions:

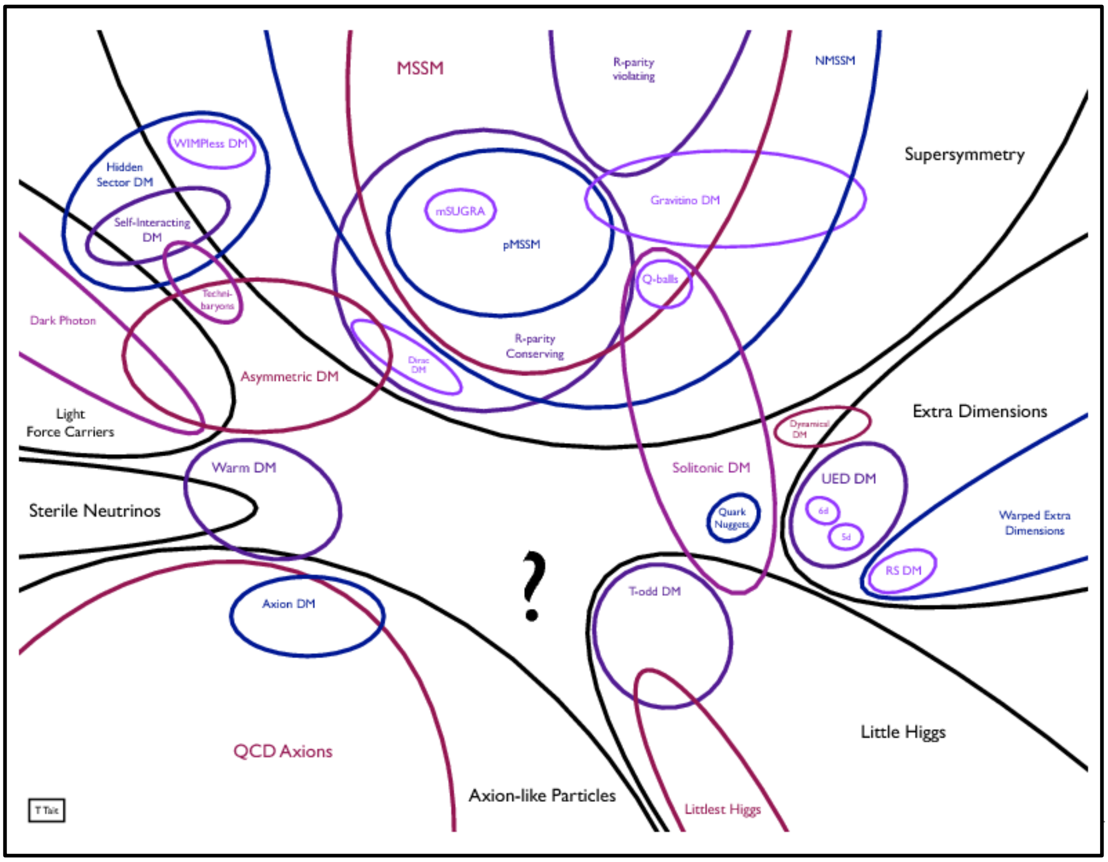
Dark matter **is not non-luminous** (invisible) ordinary matter!

Non-luminous baryonic "dark matter":
- White dwarfs
- Neutron stars
- Black holes
- MACHOS (Massive Compact Halo Objects)
- ...

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

Types of "Dark Matter"

Model candidates:



Dark Matter relics: WIMP Freeze out

Weakly Interactive Massive Particles:

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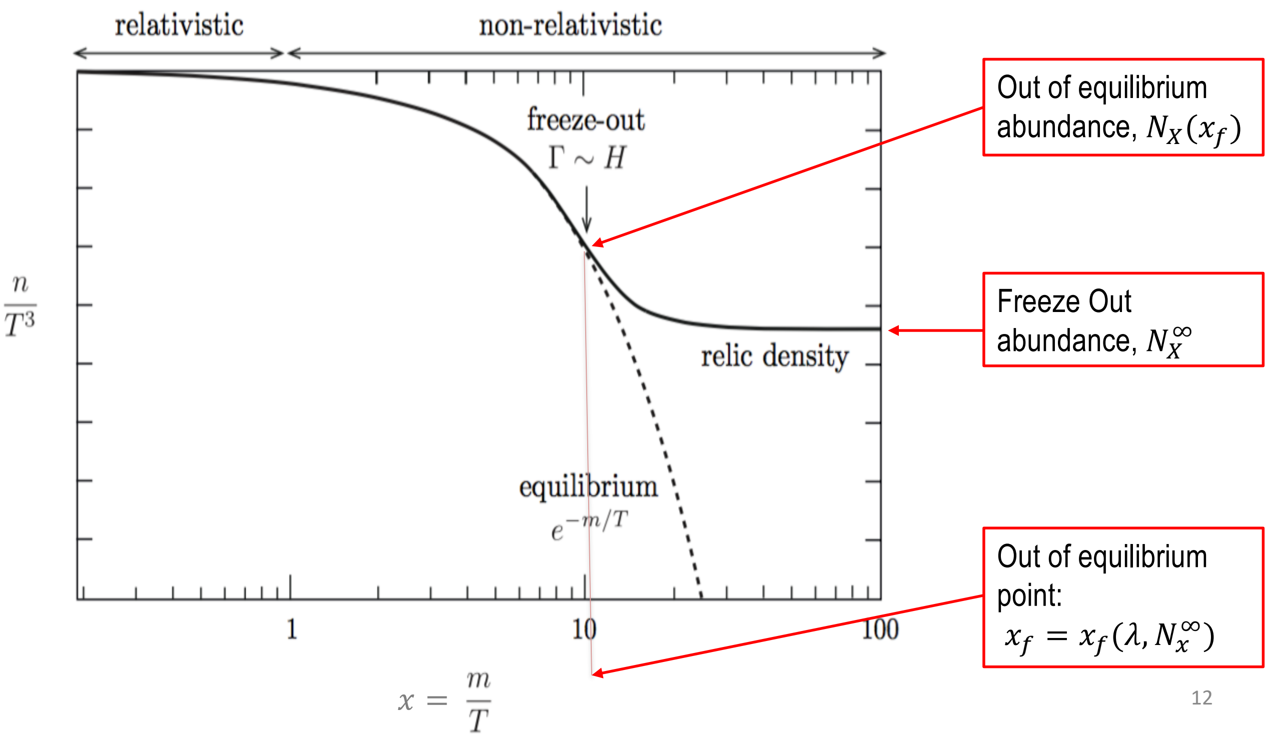

Dark Matter relics: WIMP Freeze out

Ricatti Equation:

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Dark Matter relics: WIMP Freeze out

WIMP miracle:

Black board lecture

Dark Matter relics code packages

Example 1:

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

MicrOMEGAs: a code for the calculation of Dark Matter Properties including the relic density, direct and indirect rates in a general supersymmetric model and other models of New Physics

Geneviève Bélanger, Fawzi Boudjema, Alexander Pukhov and Andrei Semenov

MicrOMEGAs 5.0 (Generic Model)

- Introduction
- Documentation
- Download and Install
- Previous versions
- Registration and Mailing list
- History: version 1.1
- Help and Contact
- Feedback: Comparisons
- CalcHEP
- LanHEP

Micromegas v_4 for the calculation of
Relic density
Direct detection rates
Indirect detection rates

Code to calculate the properties of one or two stable massive particles in a generic model. First developed to compute the relic density of a stable massive particle, the code also computes the rates for direct and indirect detection rates of dark matter. It is assumed that a discrete symmetry like R-parity ensures the stability of the lightest odd particle. All annihilation and coannihilation channels are included in the computation of the relic density. Specific examples of this general approach include the MSSM and various extensions. Extensions to other models can be implemented by the user. The New Physics model first requires to write a new CalcHEP model file, a package for the automatic generation of squared matrix elements. This can be done through LanHEP. Once this is done, all annihilation and coannihilation channels are included automatically in any model.
The cross-sections for both spin dependent and spin independent interactions of WIMPS on protons are computed automatically as well as the rates for WIMP scattering on nuclei in a large detector.
The neutrino flux and the induced muon flux from DM captured in the Sun and the Earth are computed as well as the exclusion from IceCube22.
Annihilation cross-sections of the dark matter candidate at zero velocity, relevant for indirect detection of dark matter, are also computed automatically. The propagation of charged particles in the Galactic halo is handled with a new module.

The decay widths of all particles in the model as well as the cross-sections for production of any pair of new particles at colliders are computed automatically as well as the production of a pair of dark matter particles with a jet.

Dark Matter relic code packages

Example 2:

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

SuperIso Relic

By Alexandre Arbey, Farvah Nazila Mahmoudi & Glenn Robbins

SuperIso
- Description
- Manual

SuperIso Relic
- Description
- Manual

Download
- SuperIso
- SuperIso Relic

AlterBBN

Links

Calculation of flavour physics and dark matter observables

SuperIso Relic is a mixed C - Fortran code which computes the dark matter observables in the MSSM and NMSSM. SuperIso Relic is an extension of SuperIso and therefore gives access to many flavour observables at the same time.

The computation of the relic density requires the calculation of thousands of annihilation and coannihilation Feynman diagrams. In SuperIso Relic, all these diagrams have been analytically computed at tree level using FeynArts/FormCalc. They are then calculated numerically during execution. The widths of the Higgs bosons are also computed using FeynHiggs or Hdecay. The necessary libraries are included in the SuperIso Relic packages.

From the cosmological point of view, SuperIso Relic performs the relic density calculation in the cosmological standard model, but also offers the possibility to alter the equation of state of radiation or modify the density and entropy content of the pre-BBN Universe. BBN constraints to check the validity of the altered model are automatically computed using the AlterBBN code included in the package.

Since its version 4, SuperIso Relic also includes routines to compute observables related to dark matter direct and indirect detections, and incorporates in particular experimental constraints from FERMI-LAT, AMS-02, XENON1T, PANDA-X and PICO60.

For any comment, question or bug report please contact Alexandre Arbey, Nazila Mahmoudi or Glenn Robbins.