Physics beyond the standard model
Part II: Dark Matter

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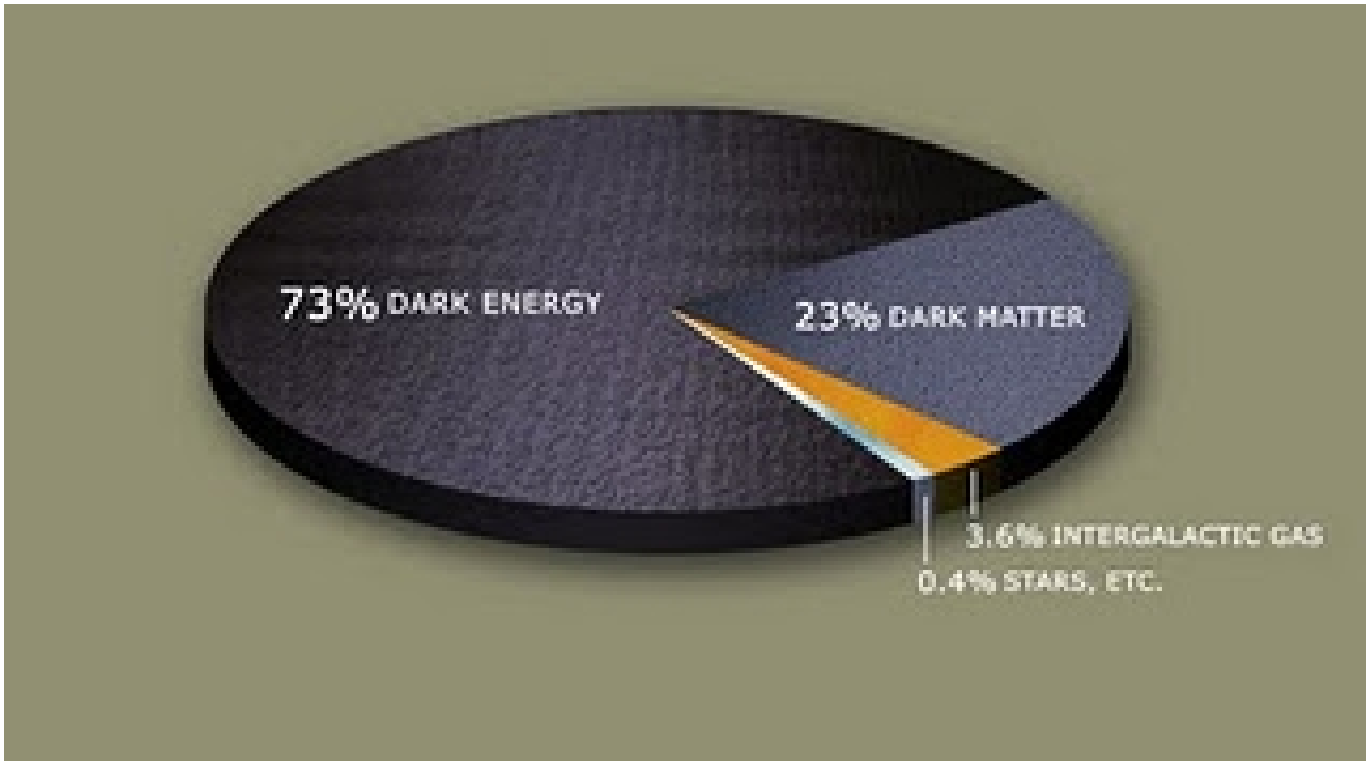
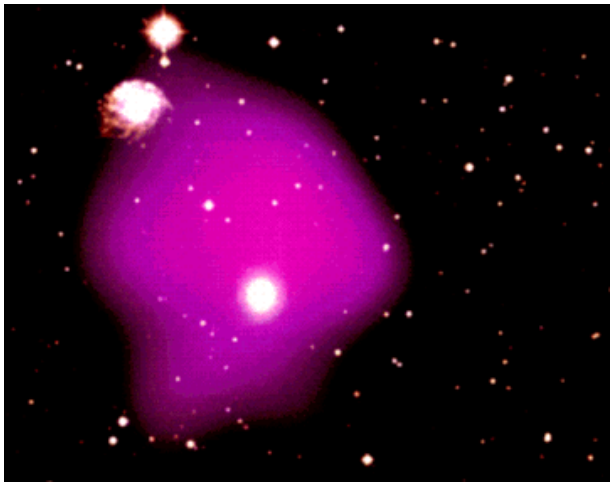
Outline

1. Evidence for Dark Matter
2. Dark Matter Candidates
    2.1 What Dark Matter is not
    2.2 WIMPs

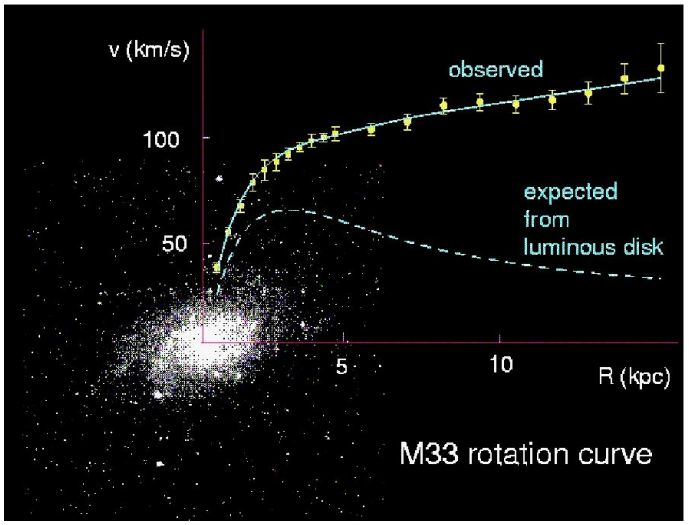


1. Evidence for Dark Matter

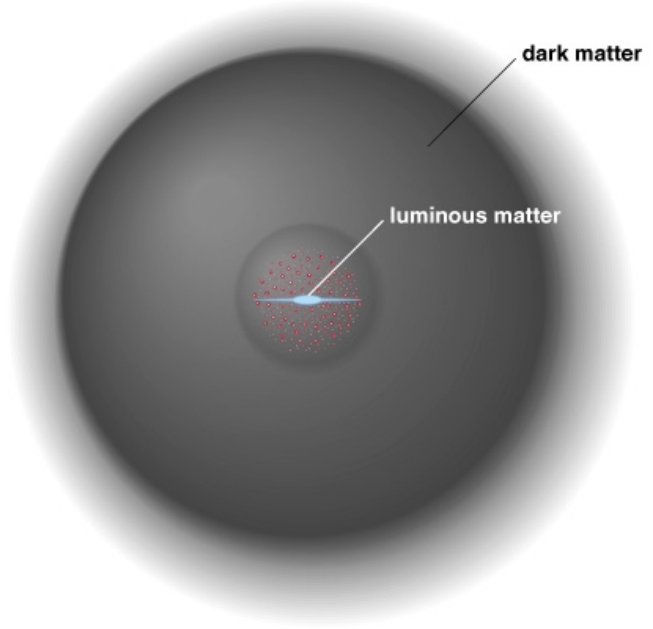
- "Missing mass" in galaxy clusters (Zwicky 1933)



- Rotation curves

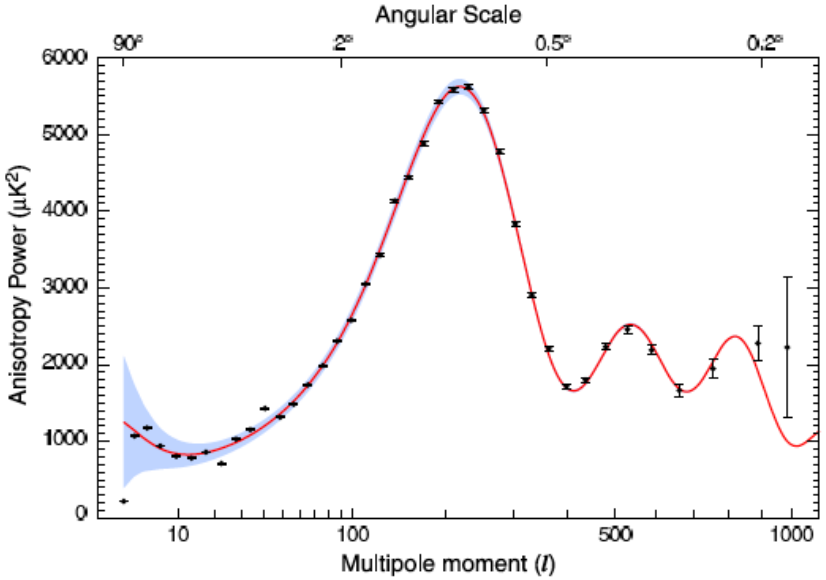


- Large scale structure

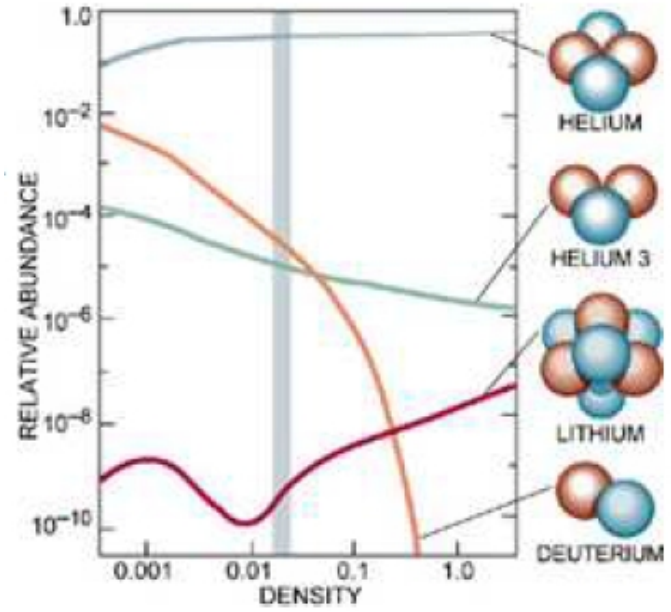


1. Evidence for Dark Matter

- Power spectrum CMB



- Big Bang Nucleosynthesis



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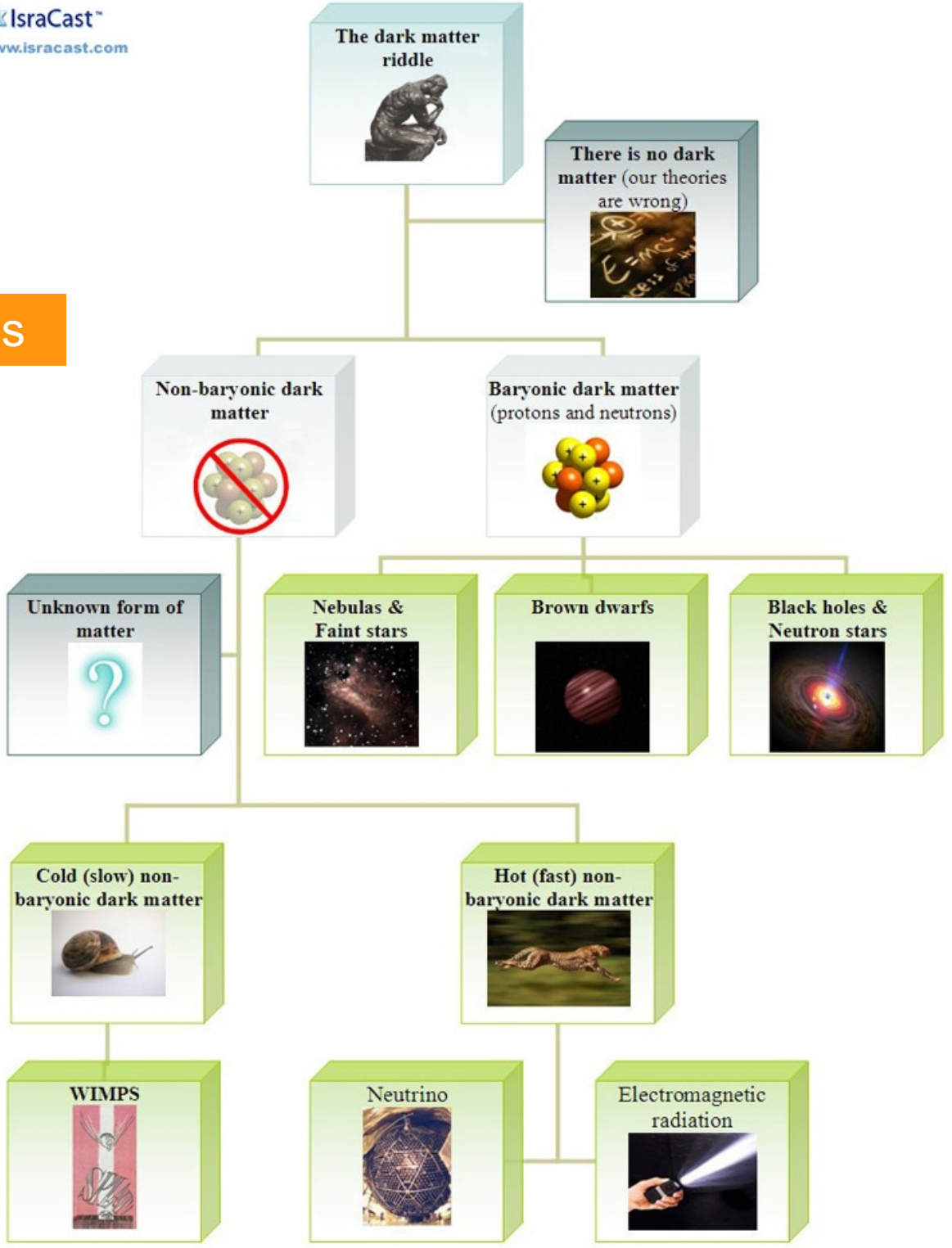
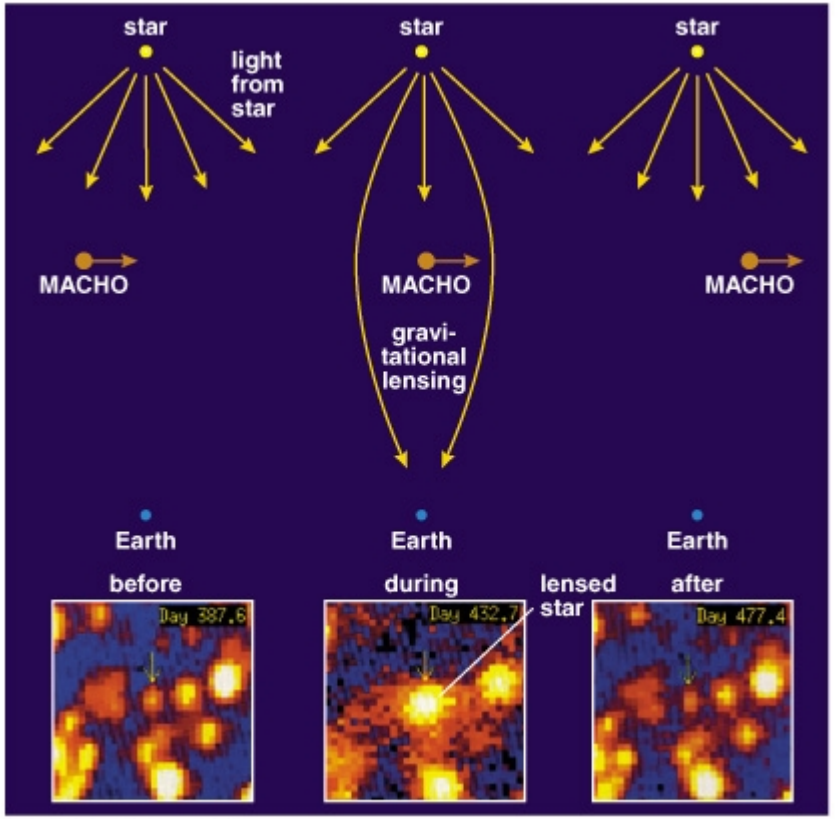
2. Dark Matter candidates



2.1 What Dark Matter is not

- MACHOs: Massive Compact Halo Objects
  - Jupiters
  - Brown dwarfs
  - (Primordial) Black holes

  → Microlensing:



not enough objects found

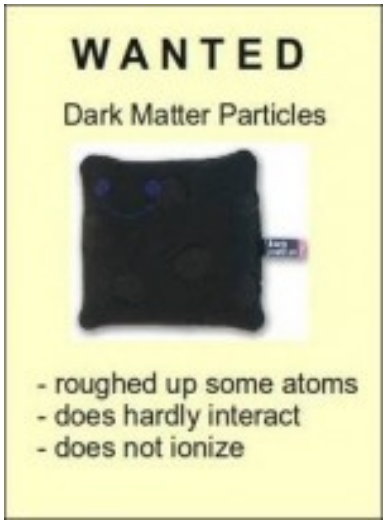
2.1 What Dark Matter is not

- Neutrinos
  - Finite mass
  - But:
    - upper mass limit
    - from Pauli exclusion principle: too massive
    - light and fast: erases small scale structure

What does a good candidate need then?

- Non-relativistic, slow moving at T~1 eV
- Massive particle
- Electrically neutral

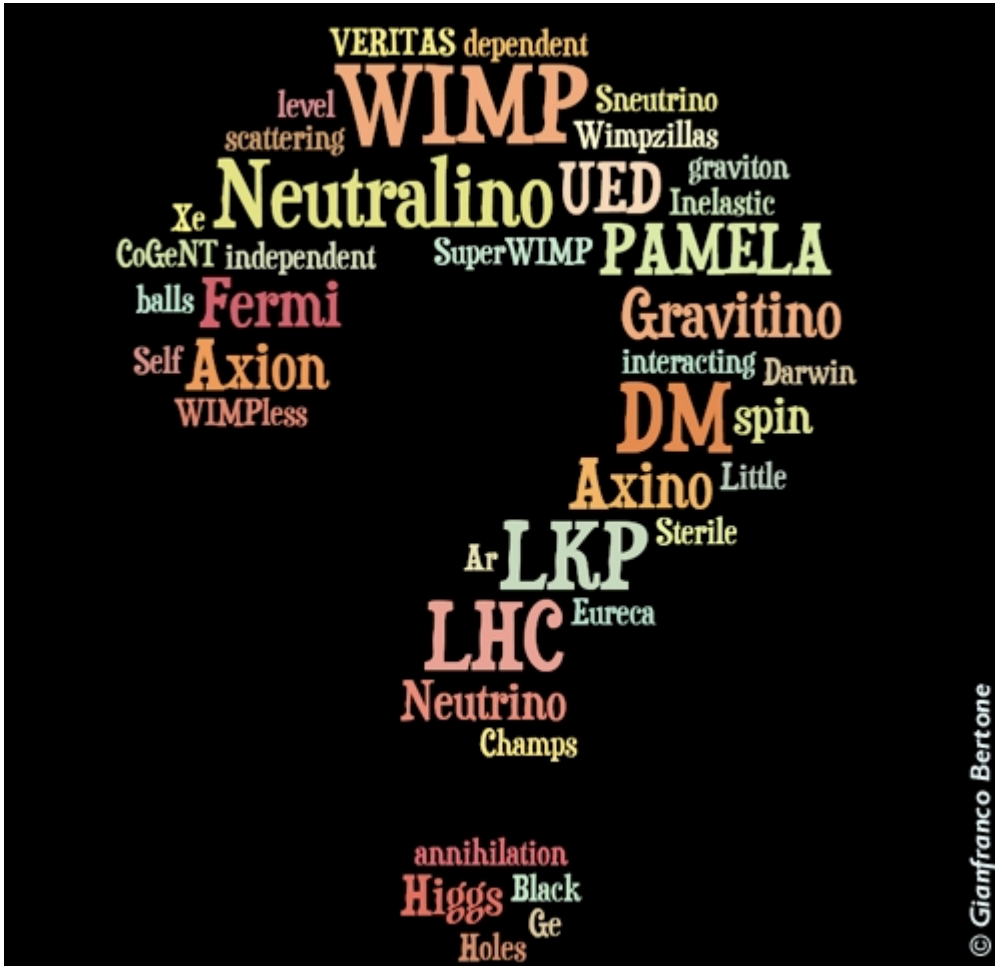
⇒ Cold Dark Matter: WIMP



2.2 WIMPs

Paradigm: WIMP (Weakly interacting massive particle)

- stable heavy elementary particle ✗ with mχ> 10^2 GeV
- Created in BB until T<mχ
- Only destroyed by annihilation
- Expansion until "freeze-out"
  ⟶ "thermal relics"



2.2 WIMPs

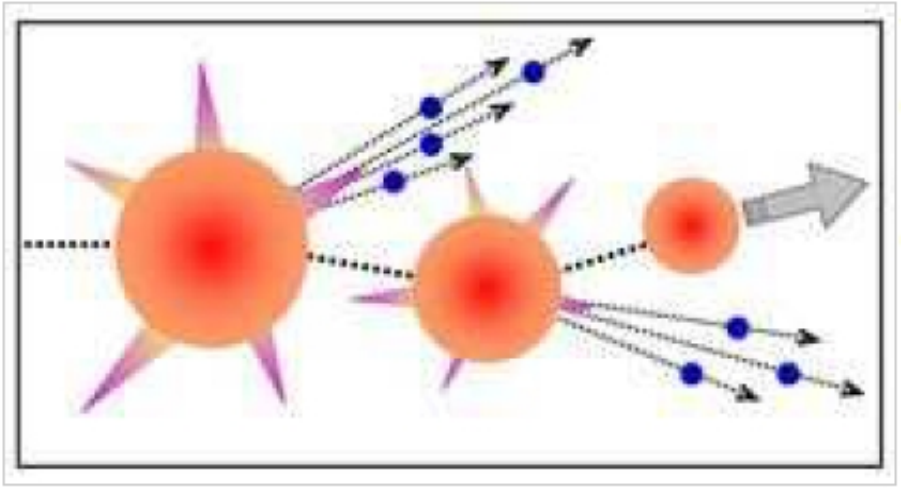
Supersymmetry:

- Proton longevity: τp> ~10^33 yr
- But: without R-parity, Supersymmetry allows for τp~10^-12s
- R-parity assigns:
  - even parity to all particles in SM
  - odd parity to superpartners
  - Example: light particles: 2,4,6
    heavy particles: 11,13,15
    Decay of 15:
    13+2, 15: 11+4, 15: 11+2+2
    an odd particle remains (here 11)

2.2 WIMPs

Supersymmetry:

- lightest supersymmetric particle (LSP) with odd parity cannot decay by definition
- Candidate for Dark Matter



2.2 WIMPs

LSP in Supersymmetry:

- neutralino:

  Photino, Zino, Higgsino (supersymmetric partner of: photon, Z-boson, Higgs-boson) (10-10000 GeV)

- gravitino

- sneutrino

2.2 WIMPs

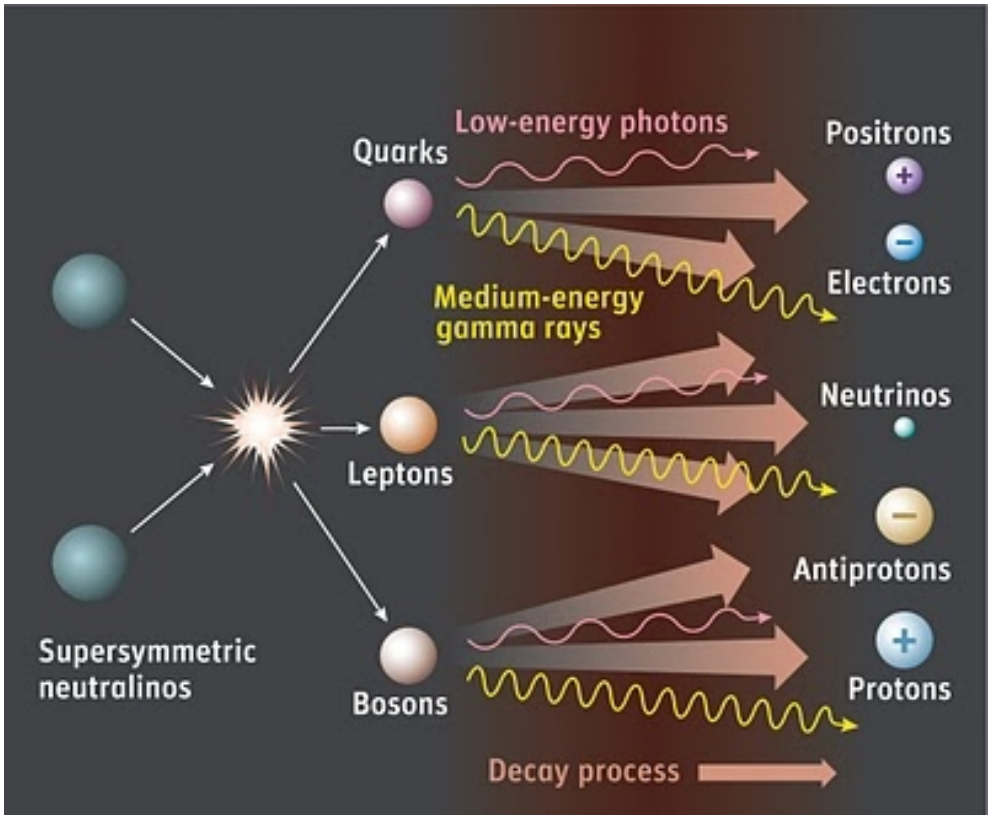
Extra dimensions:

- more spatial dimensions: a fourth one may be curled up very small
- as if each point in our familiar space were actually a tiny ring which a particle could run around
- particles moving around such rings would look like more massive versions of the Standard Model particles
- the lightest of these (the lightest Kaluza-Klein particle or LKP) is often stable as well

2.2 WIMPs

- Accelerator experiments

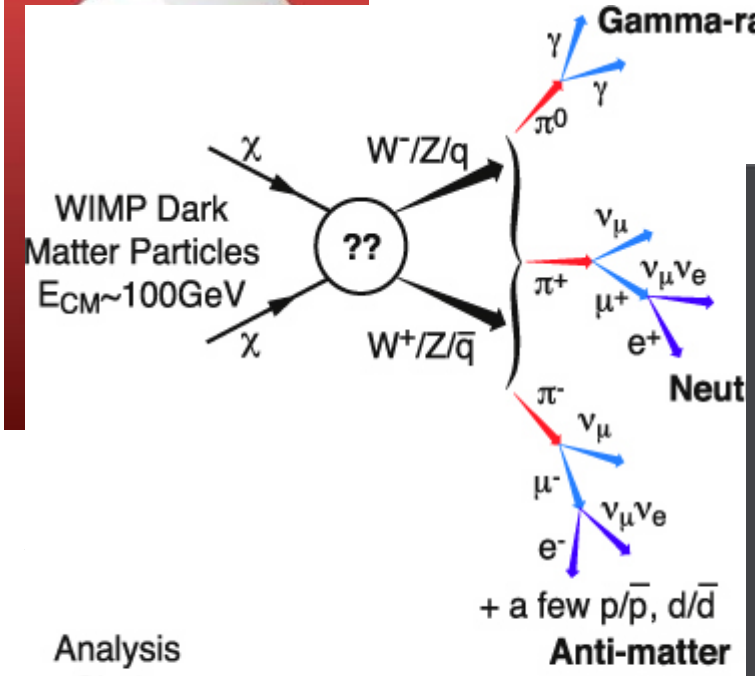
- Detection:
  - Direct
  - Indirect



Thank you for your attention

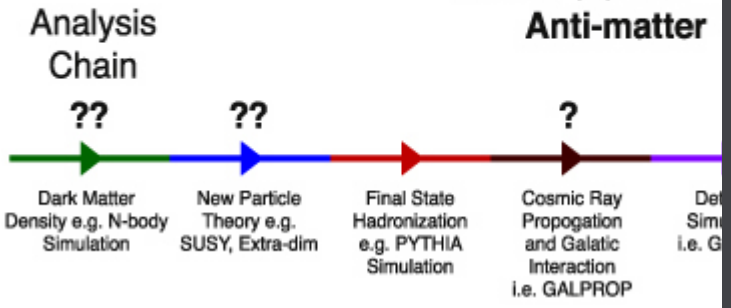
Next part: String Theory

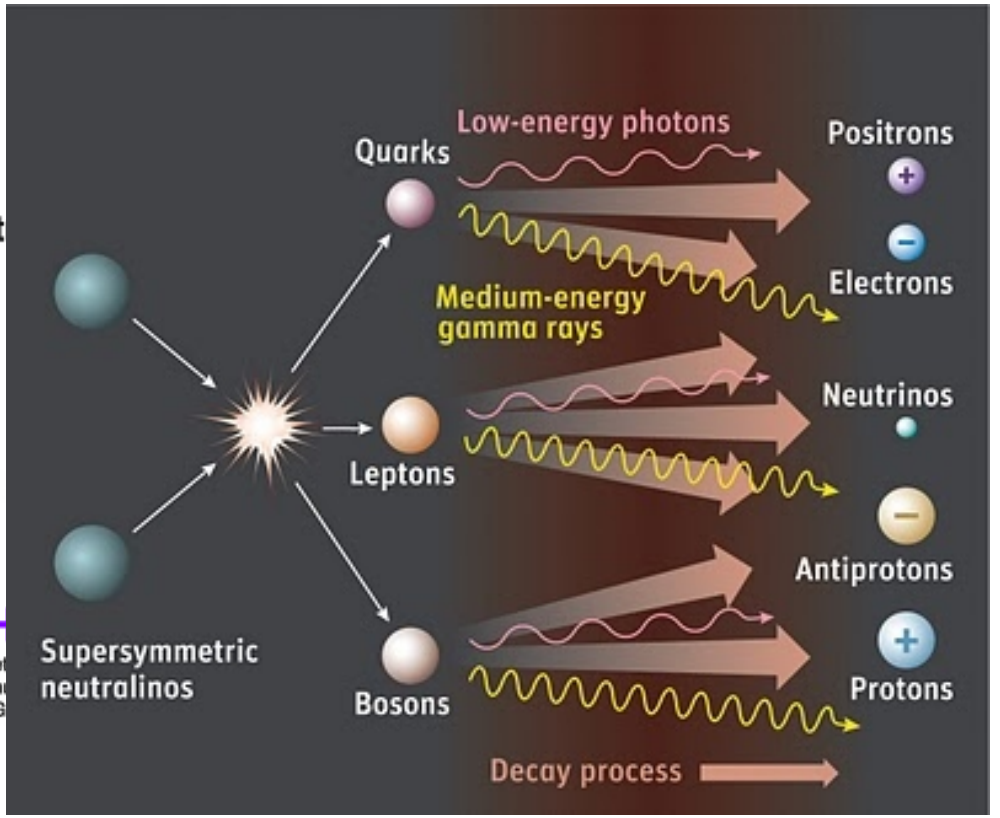
2.2 WIMPs


Gamma-rays
γ
γ
π0
χ
W-/Z/q
WIMP Dark
Matter Particles
ECM~100GeV
??
χ
W+/Z/q̄
νμ
π+
νμνe
μ+
e+
Neut
π-
νμ
μ-
νμνe
e-
+ a few p/p̄, d/d̄
Anti-matter

-

-


Analysis
Chain
??
??
?
Dark Matter
Density e.g. N-body
Simulation
New Particle
Theory e.g.
SUSY, Extra-dim
Final State
Hadronization
e.g. PYTHIA
Simulation
Cosmic Ray
Propogation
and Galatic
Interaction
i.e. GALPROP


Low-energy photons
Quarks
Positrons
Electrons
Medium-energy
gamma rays
Neutrinos
Leptons
Antiprotons
Supersymmetric
neutralinos
Bosons
Protons
Decay process