Dark Matter Models

Soorya Narayan

(I would like this to be an interactive session. PS I’m looking at particle physicists)

Dark Matter

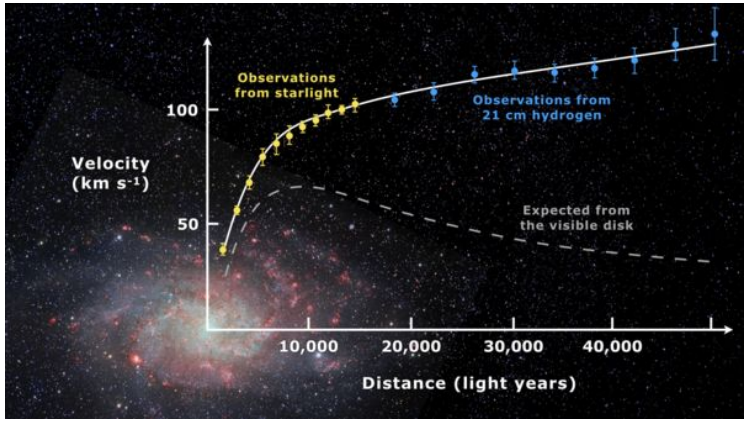
Evidence - galaxy rotation curves (Jan Oort and Fritz Zwicky in 1930s; Vera Rubin and Kent Ford in 1970s), gravitational lensing, Large-Scale Structures, stability of galaxy clusters and groups, and the CMB.

Research shows that DM is concentrated in halos around galaxies and galaxy clusters

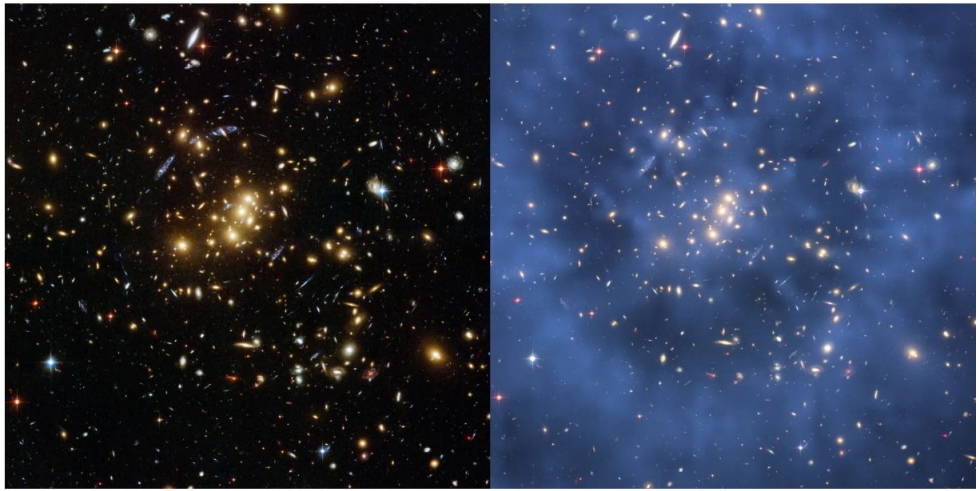
Various Models - CDM, WDM, SIDM, DDM

DM interacts with standard model particles only through gravity (at least that should be your stand point for this talk)

Evidence for Dark Matter



Extended rotation curve and DM halo of M33[2]



The massive galaxy cluster Cl 0024+17 (ZwCl 0024+1652). The left view is in visible light. The right image holds added blue shading that indicates the location of invisible dark matter. The shape and position of the gravitationally lensed galaxies we see in the left-hand image, mathematically requires the presence of this dark matter.
NASA, ESA, M.J. Jee, and H. Ford (Johns Hopkins University)[3]

Cosmology 101

The universe is 13.7 Billion years old

Big Bang ► Inflation ► Expansion

Super hot ► hot ► cold ► freezing ► absolute zero

Thermal Equilibrium ► Decoupled

Jargon, but you need it, sadly

Pair production, annihilation, standard model interactions, BSM interactions

Decoupling - Ex. We can “see” the universe only from a redshift of ~1100 (to a distance of 40 Gly, today)

1. Very hot, very small universe; electron-photon interaction
2. Universe expands and cools; electrons get trapped by protons (H); mean free path of EVERYTHING increases
3. Rate of electron-photon < rate of expansion

Freeze out - When the interaction rates of a particle becomes lesser than the expansion rate of the universe.

$$\Gamma = \langle \sigma_{\text{ann}} v \rangle n_{\text{eq}}$$

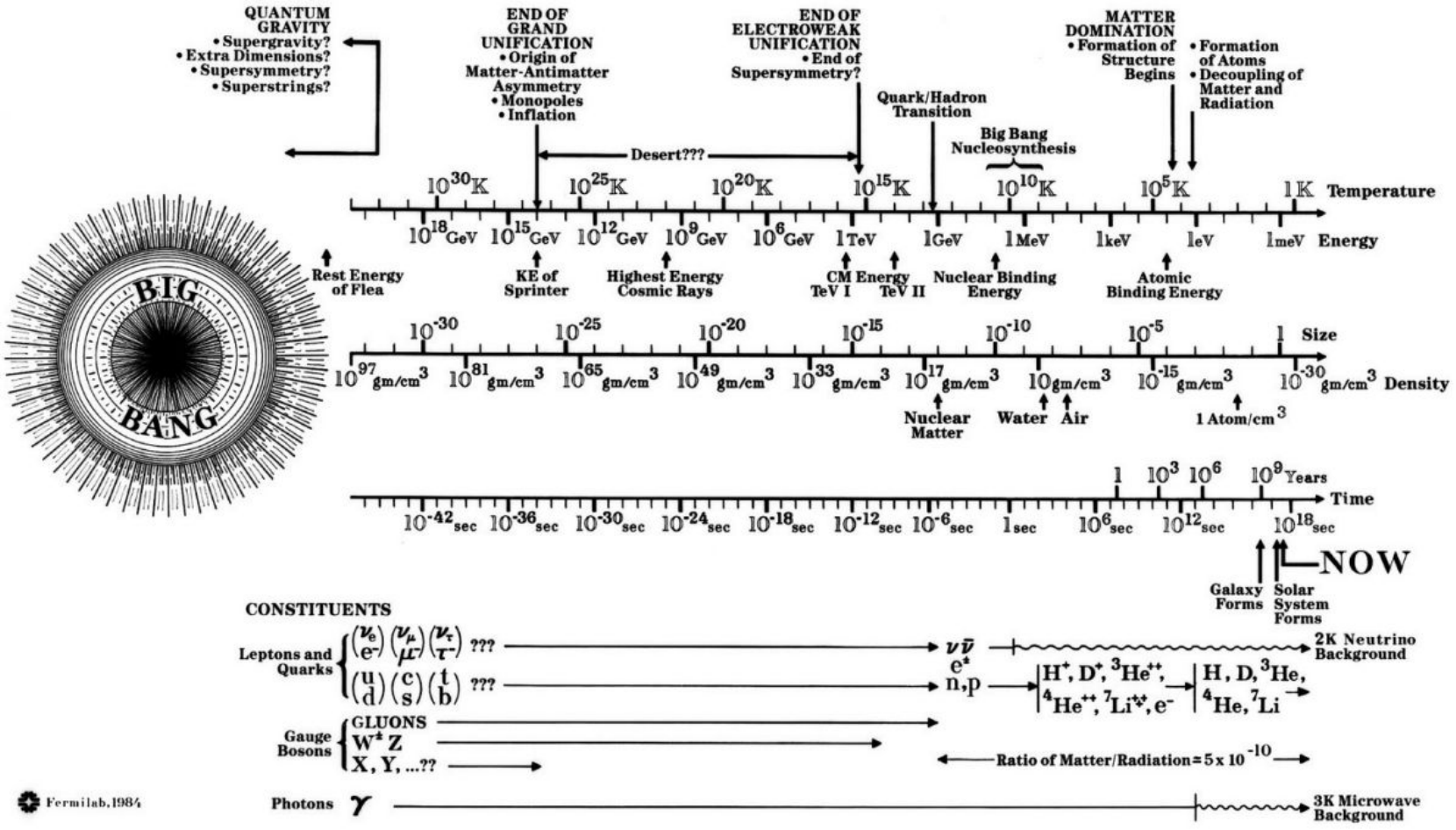
Jargon Pt II, again, you need it

Big Bang Nucleosynthesis [BNN] (t ~ couple of mins) - The temperature of the universe fell so low that He^{2+}, Li^{3+} and other smaller elemental nuclei could start forming.

Thermal Production in the early universe - Much before BNN (ik, the modifier is used ironically) everything interacted with everything else. YES, the BSM dream.

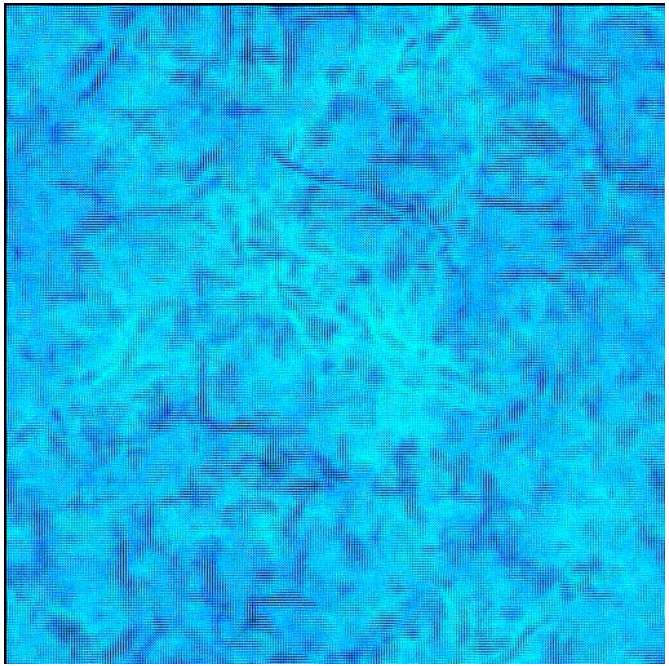
Thermal Production of DM in the early universe - Roughly the same time point as “much before BNN”, DM particles were in equilibrium through annihilation reactions

$$\chi\overline{\chi} \leftrightarrow e^+e^-, q\overline{q}, W^+W^-, Z^0\overline{Z}^0, HH, \ldots$$


QUANTUM GRAVITY
• Supergravity?
• Extra Dimensions?
• Supersymmetry?
• Superstrings?
END OF GRAND UNIFICATION
• Origin of Matter-Antimatter Asymmetry
• Monopoles
• Inflation
END OF ELECTROWEAK UNIFICATION
• End of Supersymmetry?
Quark/Hadron Transition
Big Bang Nucleosynthesis
MATTER DOMINATION
• Formation of Structure Begins
• Formation of Atoms
• Decoupling of Matter and Radiation
Desert???
BIG BANG
Temperature
Energy
Rest Energy of Flea
KE of Sprinter
Highest Energy Cosmic Rays
CM Energy TeV I
TeV II
Nuclear Binding Energy
Atomic Binding Energy
Size
Density
Nuclear Matter
Water
Air
1 Atom/cm3
Time
NOW
Galaxy Forms
Solar System Forms
CONSTITUENTS
Leptons and Quarks
???
Gauge Bosons
GLUONS
W± Z
X, Y, ...??
Photons
2K Neutrino Background
Ratio of Matter/Radiation = 5 x 10-10
3K Microwave Background
Fermilab, 1984

LCDM Simulation

This shows a portion of the universe that collapses into a galaxy cluster. Comoving coordinates are used i.e., Hubble expansion is factored out.



Courtesy - Paul Bode

Warm Dark Matter (WDM) - Sub GeV particles

Semi-relativistic at freeze out. Structure formation is **bottom-up for scales > free streaming scale** and **top-down for scales < free streaming scales.**

Promising candidate - sterile neutrinos with mass in keV range. These can decay into SM neutrinos producing X-Rays.

Why in consideration - around 2014-15 we found a peculiar, narrow 3.5 keV X-Ray line in spectra of Andromeda.

How to confirm - Find proof that DM halos < **M** is suppressed. Identify Halo mass profile.

Self Interacting Dark Matter (SIDM)

Energy and momentum **exchange** within the dark sector. Scattering cross section of around $1\ \mathrm{cm}^2\,\mathrm{g}^{-1}$ best explains our observations.

Promising candidate - “dark photon” mediated self interactions

Why in consideration - Can explain the diversity and uniformity of galaxy (and cluster) rotation curves. We have logical data from said curves that constrain the cross section in various velocity ranges.

How to confirm - DM halos form cores instead of cusps. Profile is distinctly different depending on the amount of visible matter. Prove DM acoustic oscillation in CMB.

Lambda CDM (LCDM)

Non relativistic as freeze out.

Promising candidate - WIMPs (~100 GeV)

How to observe - Lensing, CMB and inferred halo profiles. We can consider slight modifications like self annihilation into SM particles and then look for those particles.

Why consider - Best explains all observations (except at smallest scales)

Thank you