Through a Universe Darkly

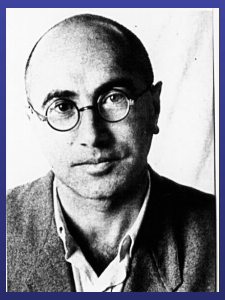
• BIG Q: What is the dark matter?

???

• more than 80 years after it was first postulated by Zwicky, this remains one of the great unsolved problems in science!

• But, by trial and error, we ve gained important clues

Yakov B. Zeldovich: Godfather of Soviet Physics



• 1914 - 1987

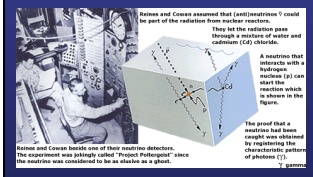
• `father' of Soviet Bomb (Atomic and Hydrogen)

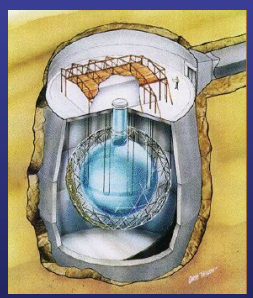
• great astrophysicist:
- **supermassive black holes**
- **no-hair theorem**

• `Zeldovich pancakes' :
- **top-down theory of galaxy formation**
- **neutrinos make up dark matter**

The Neutrino Universe

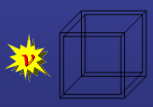
• neutrinos: - very elusive (weakly interacting)
- they are *known* to exist!





The Neutrino Universe

• neutrinos: - produced in Big Bang fireball
- travel (almost) with speed of light



1 cm^3

• n_ν~113 neutrinos plus anti-nu per flavor (e,μ,τ)

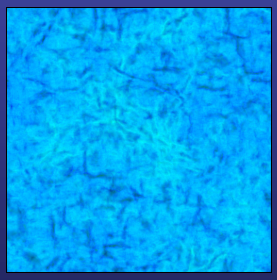
• *If* neutrinos had (tiny) rest-mass:

- total mass of neutrinos in universe huge:

Total Mass = N x mass_nu

The Neutrino Universe

- Briefly after Big Bang: Matter and energy is distributed very smoothly



- but not quite: there are tiny irregularities (`lumps')
- smallest lumps grow fastest under gravity
- What is their fate?

The Neutrino Universe

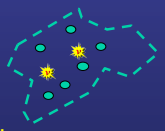
- Q: How much mass is needed to confine (coral in) neutrinos?
- Early on (first 10,000 years), neutrinos move (almost) with speed of light (thus: `Hot Dark Matter')

neutrino

Normal particles

Small mass

→ Small structures are `erased' by neutrino free-streaming!



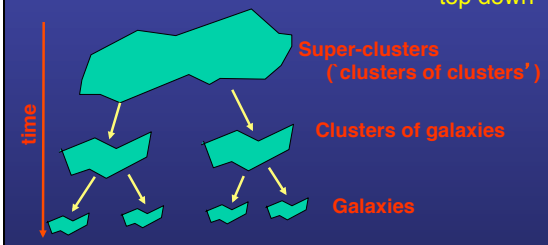
Large mass

~ 10^{15} solar masses

→ mass of a cluster of galaxies (e.g., Coma)

The Neutrino Universe

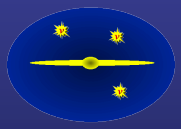
- Zeldovich pancakes: Galaxies form from the `top down'



- Prediction: clusters form *before* galaxies do!

The Neutrino Universe Undone

- early 1980s:
  - dwarf galaxies have dark matter halos, too!
  - clusters of galaxies form late in history of universe, after the galaxies themselves!



- The neutrino universe doesn't work!
- Again: What *is* the dark matter???

The Cold Dark Matter Model

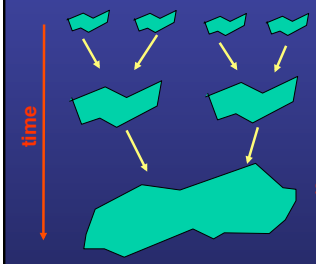
- 1984-86: postulate some mysterious particle that is massive, but only interacts weakly with ordinary matter other than through gravity
  (Blumenthal, Faber, Primack & Rees; Peebles)
- WIMPs = Weakly Interacting Massive Particles

Normal particle
WIMP

- small lumps survive!
- sub-galactic (million solar mass objects form first)!

The Cold Dark Matter Model

- Galaxies form from the `bottom up' (hierarchical)



Galaxies

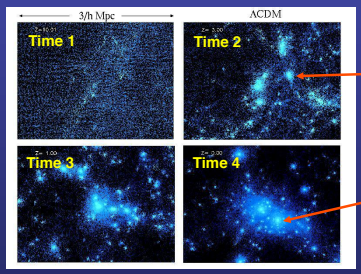
Clusters of galaxies

Super-clusters
(`clusters of clusters')

- Prediction: clusters form *after* galaxies do!

The Cold Dark Matter Model

- Structure forms from the `bottom up' (hierarchical)



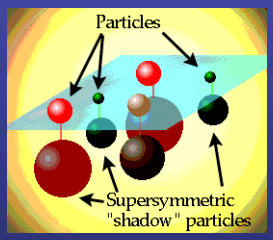
- Evidence: galaxies form before clusters!

The Cold Dark Matter Model

- But what is the WIMP really???
- Has not yet been directly detected!
- But there is a promising candidate:

  - the lightest supersymmetric particle (neutralino)

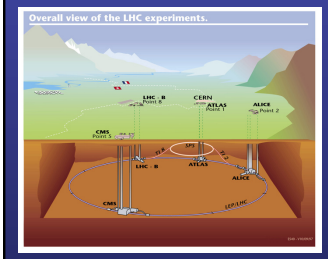
The Cold Dark Matter Model



- for every normal particle, there is a supersymmetric (`shadow') partner
- the lightest one (the neutralino) cannot decay, and would thus have survived from the very early universe!

Hunting down the WIMP:

→ CERN's new Large Hadron Collider (LHC)



- might be able to detect new particles predicted by supersymmetry