# Neutrino Ocillations and Astroparticle Physics (4)

John Carr
Centre de Physique des Particules de Marseille (IN2P3/CNRS)

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## Dark Matter Searches

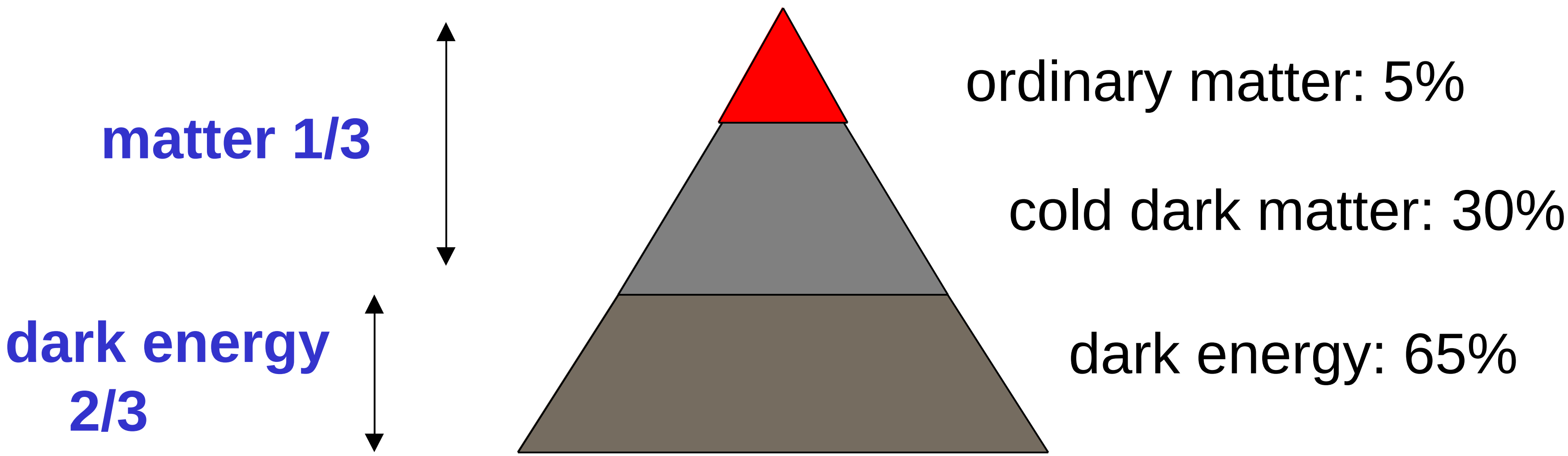
### Evidence for Matter Density

- Galaxy Dynamics
- Strong Gravitational Lensing

### Searches

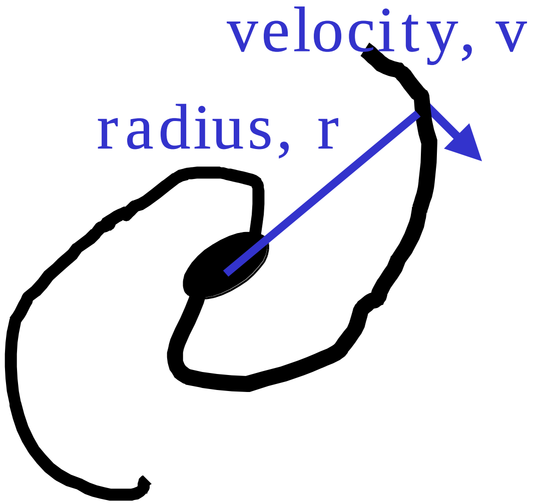
- Astronomy Dark Matter Candidates (Baryonic)
  - Brown Dwarfs
  - White Dwarfs
- Particle Dark Matter Candidates
  - Neutrinos
  - Axions
  - Neutralinos: Direct and Indirect Searches

# Composition of Universe




Universe flat: average density = critical density

# Galaxy Rotation

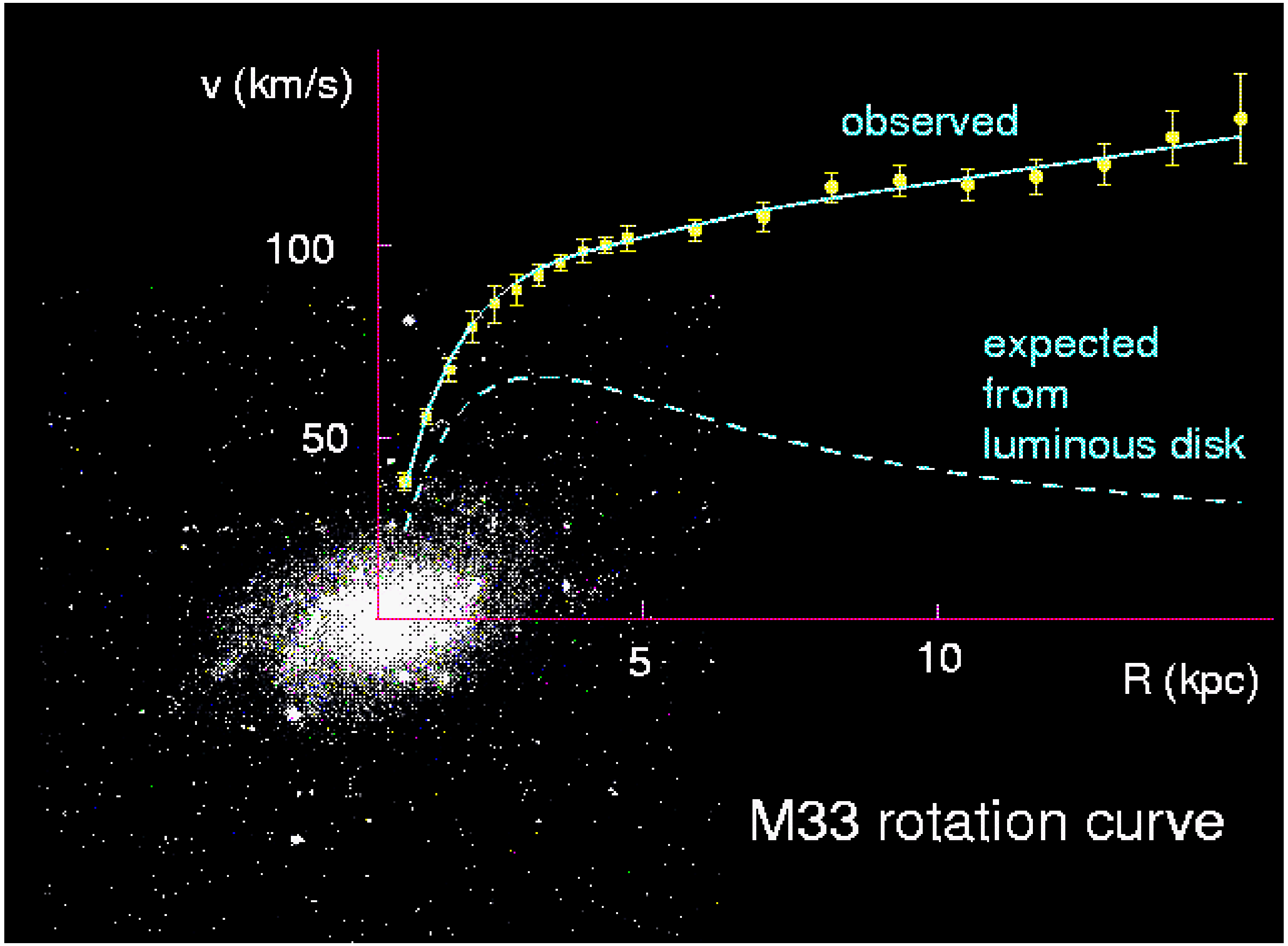



Gravity:

$G\,M(r) \,/\, r^2 = v^2 \,/\, r$

enclosed mass:

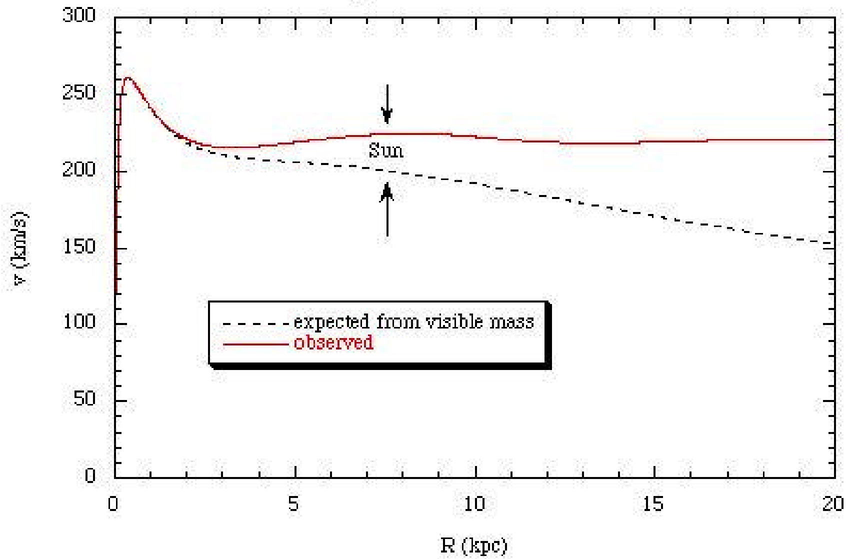
$M(r) = v^2\, r \,/\, G$



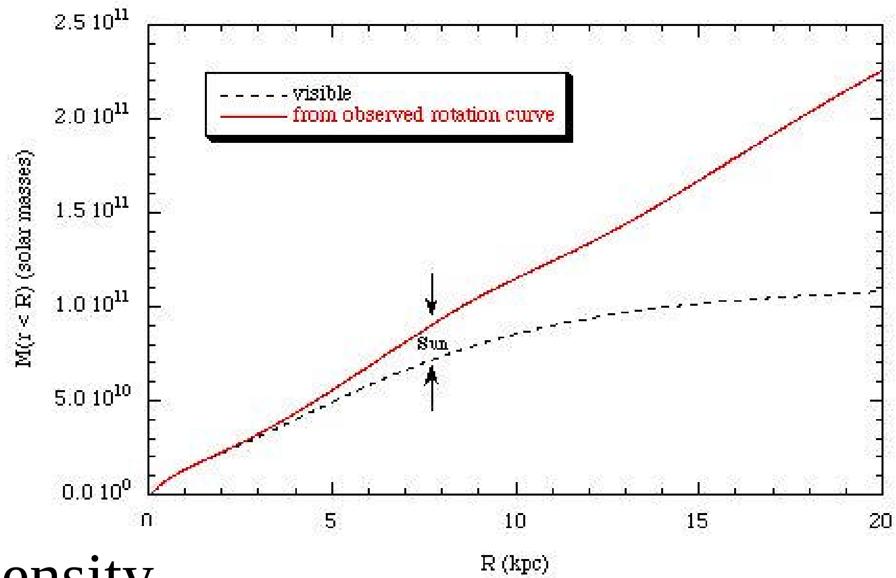

Luminous stars only small fraction of mass of galaxy

# Mass in a typical galaxy

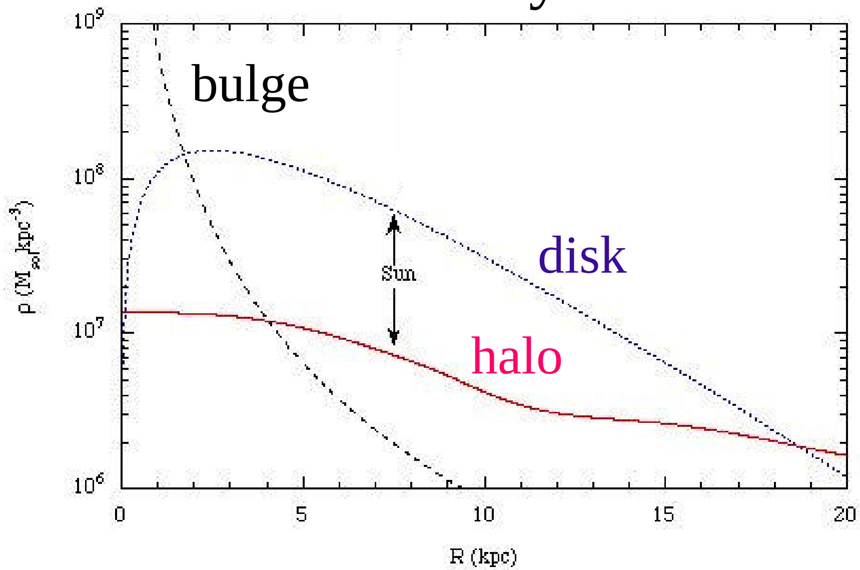
Rotation curve




Mass from rotation curve



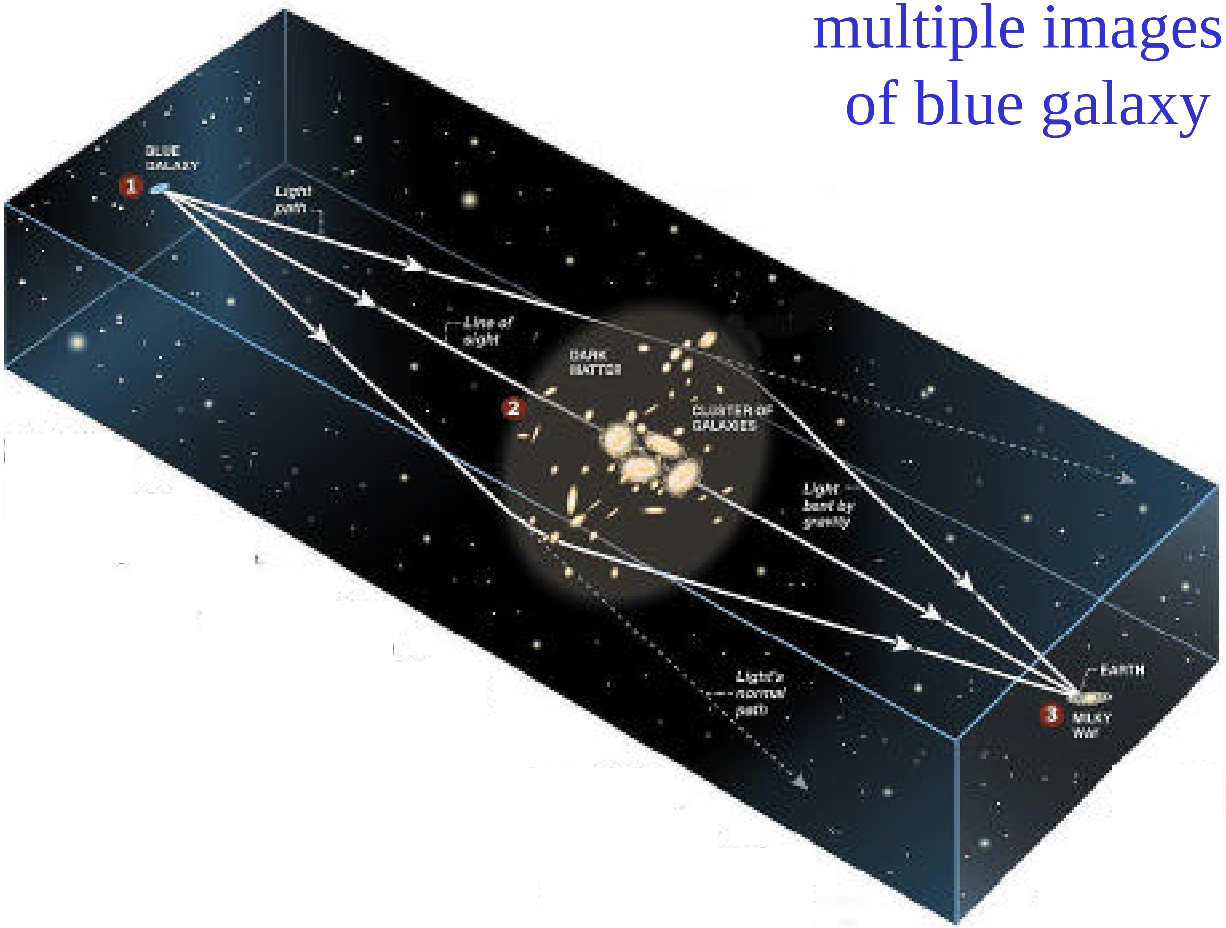

Density



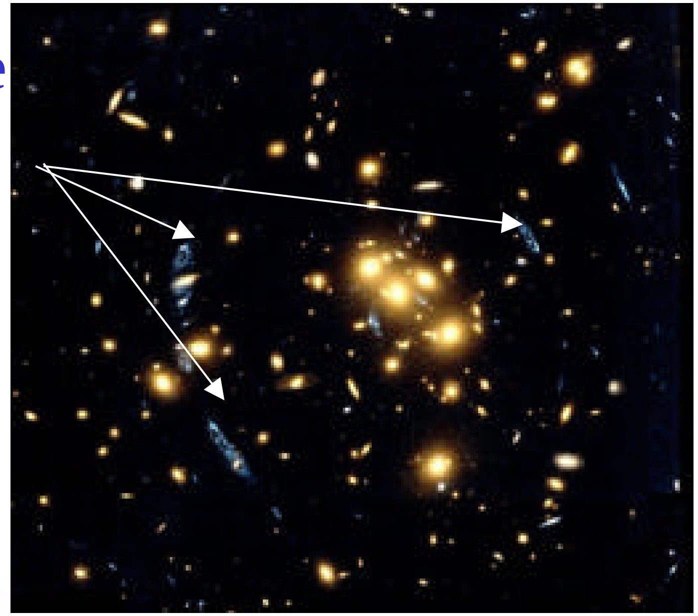

Dark matter
in halo

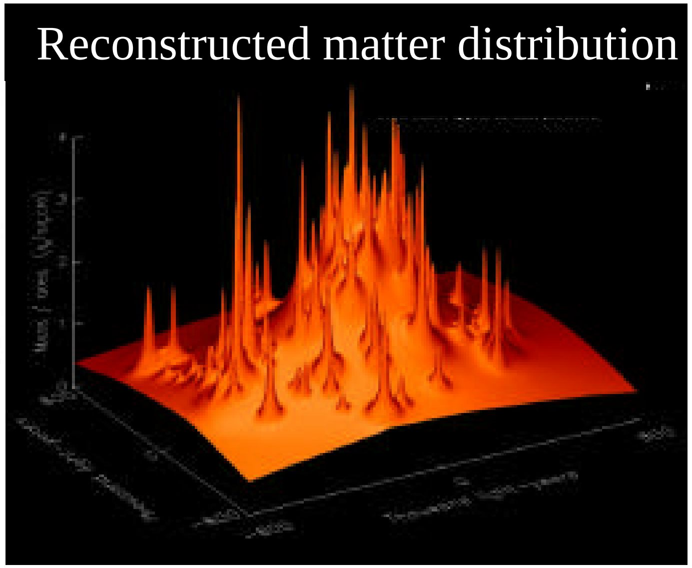
but
detailed
distribution?

# Gravitational Lensing by Dark Matter

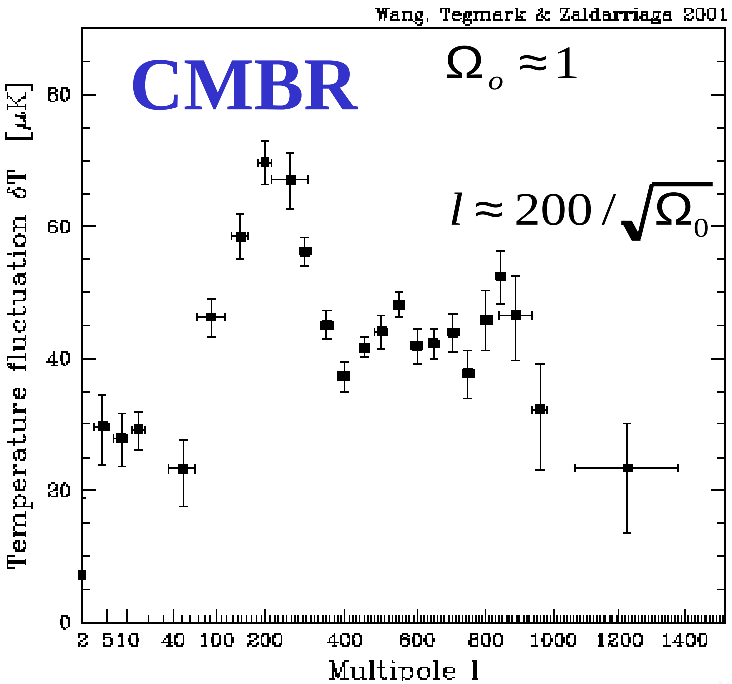



Hubble Space Telescope
multiple images
of blue galaxy

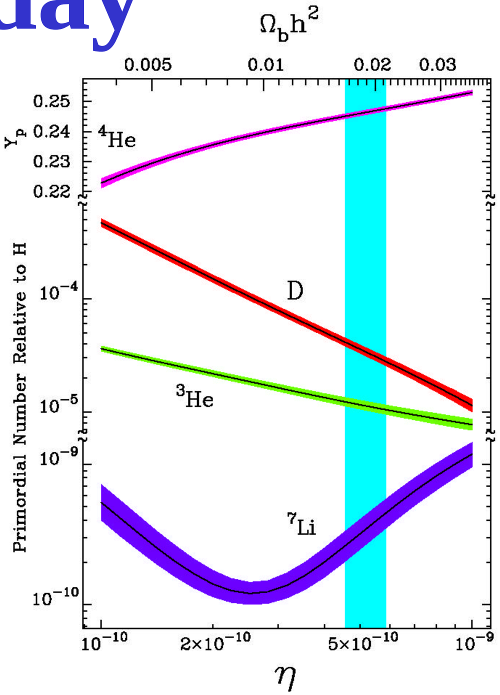


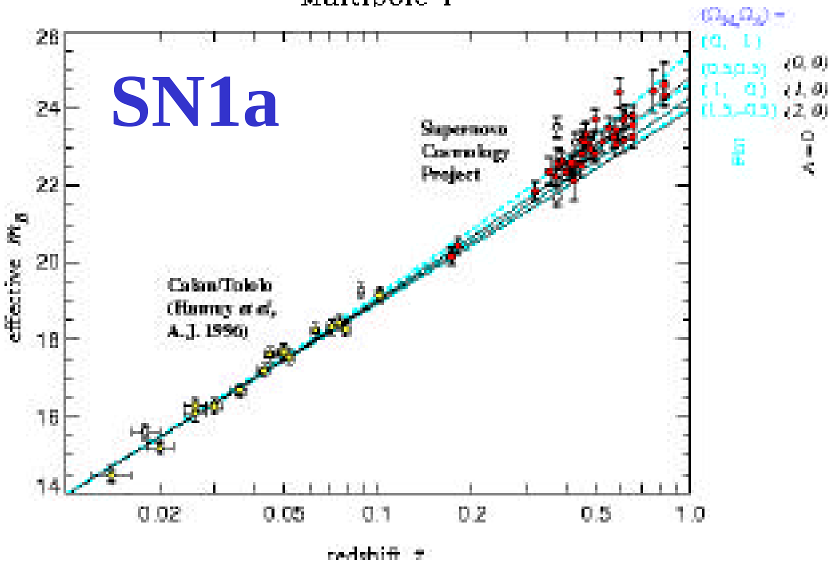

Reconstructed matter distribution

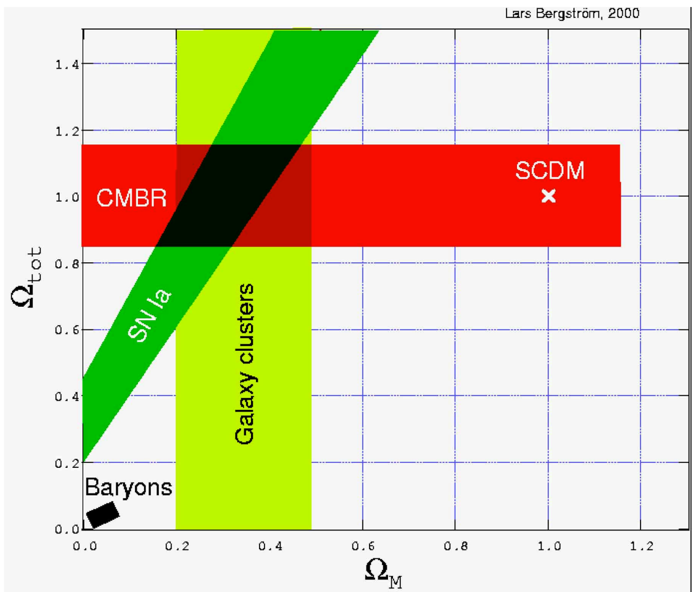
# Evidence seen yesterday




BBNS

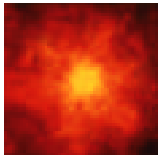


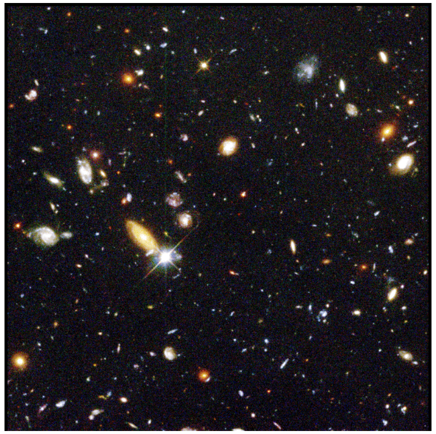
# Dark Matter and Structure Formation

Big Bang



**gravity**

Present Structures



Dark Matter is dominant matter in universe :

so dominates gravitational interactions in structure formation

Two extreme forms of dark matter possible: hot and cold

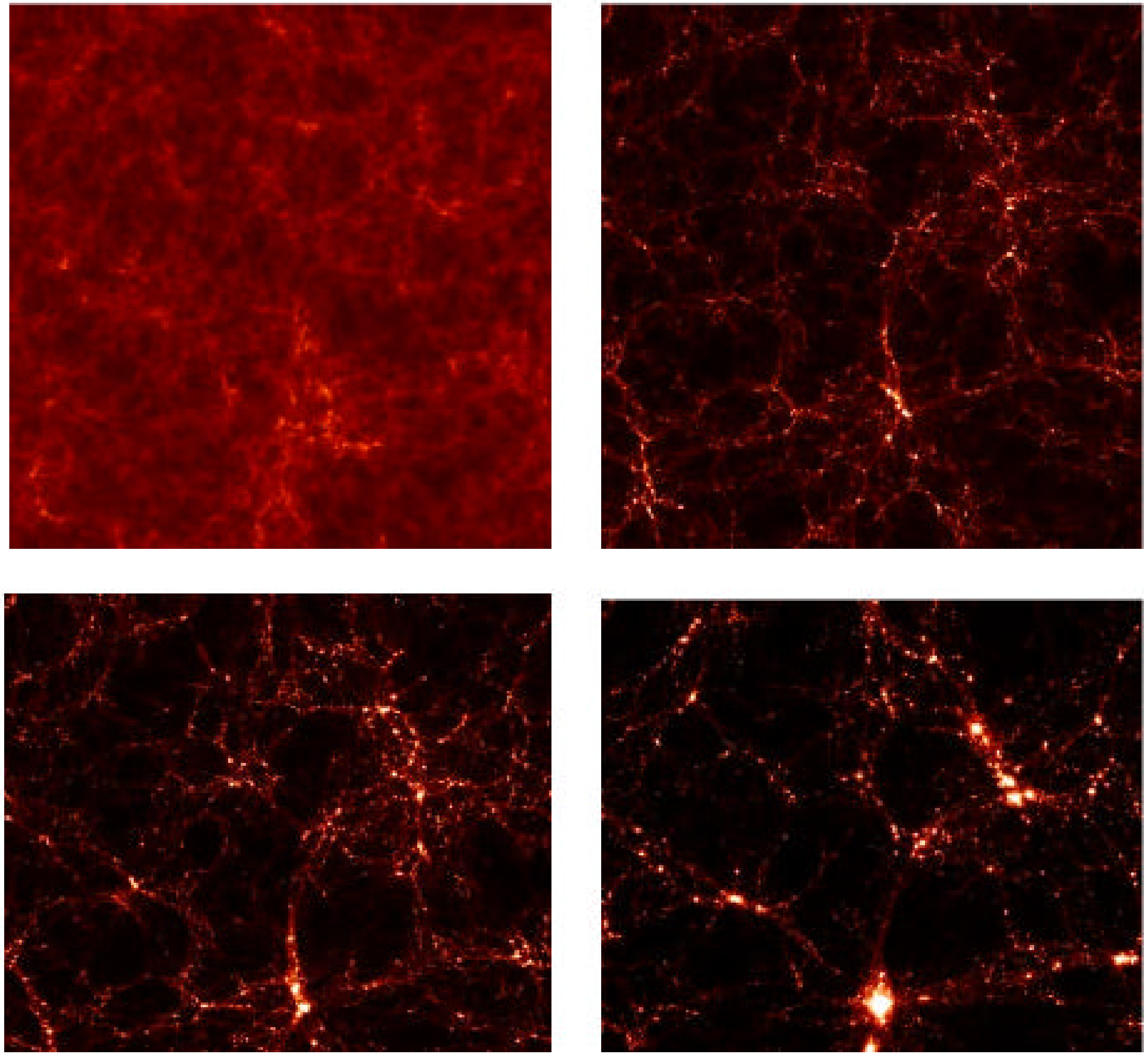
hot dark matter ( eg. Neutrinos ) relativistic

cold dark matter ( eg. Neutralinos ) non-relativistic

Relativistic particles escape from structure formation: no galaxies form !

Simulation indicate most dark matter in cold form : CDM

# Simulations of Structure Formation



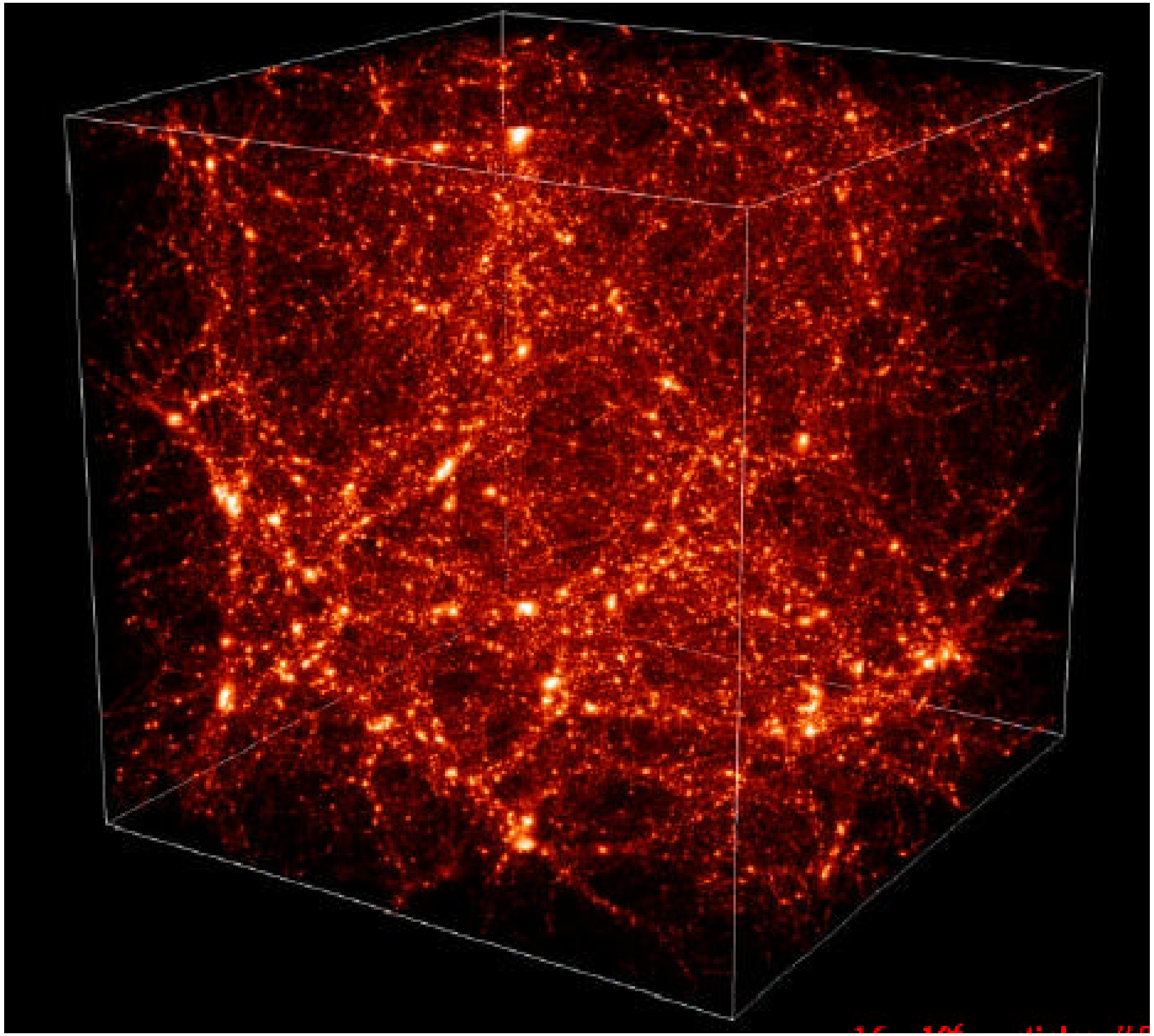
Z=11

Z=2

Z=1

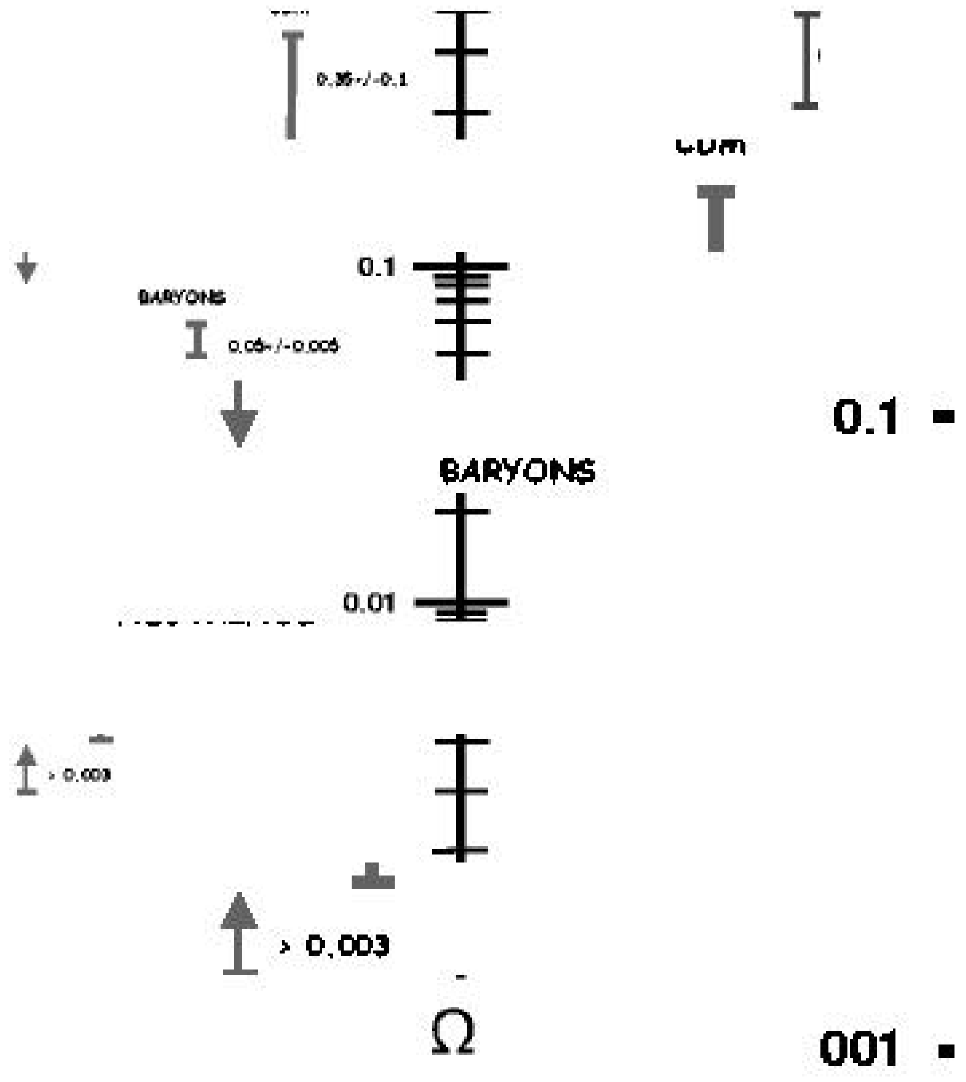
Z=0, now

# Simulations of Structure Formation



3D Simulation
with ‘ΛCDM’
scale 150 Mpc

# Matter/Energy in the Universe




$\Omega_{total} = \Omega_M + \Omega_\Lambda \quad 1$

matter  dark energy

Matter:

$\Omega_M = \Omega_b + \Omega_\nu + \Omega_{CDM} \quad 0.35$

baryons  neutrinos  cold dark matter

**Baryonic matter :**

$\Omega_b \quad 0.05$

stars, gas, brown dwarfs, white dwarfs

Neutrinos:

$\Omega_\nu \quad 0.002$

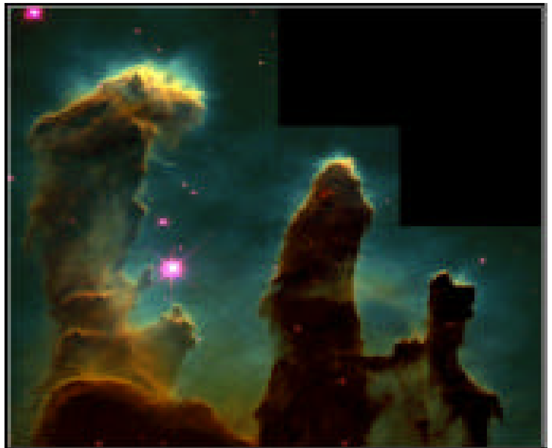
if $M(\nu)$  0.1eV as from oscillations

Cold Dark Matter :

$\Omega_{CDM}$ **0.3**

**WIMPS/neutralinos, axions**

# Dark Matter: Astrophysical Candidates



Brown Dwarfs (stars mass $<0.1\ M_{sun}$ no fusion)

- some but not enough

White Dwarfs ( final states of small stars)

- some but not enough

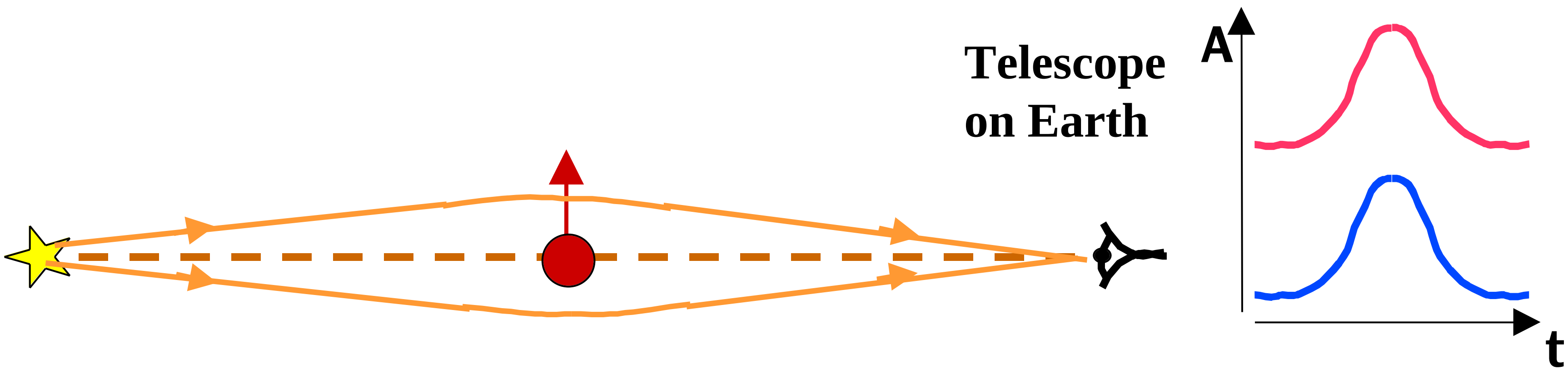
Neutron Stars/Black Holes ( final states of big stars)

- expected to be rarer than white dwarfs

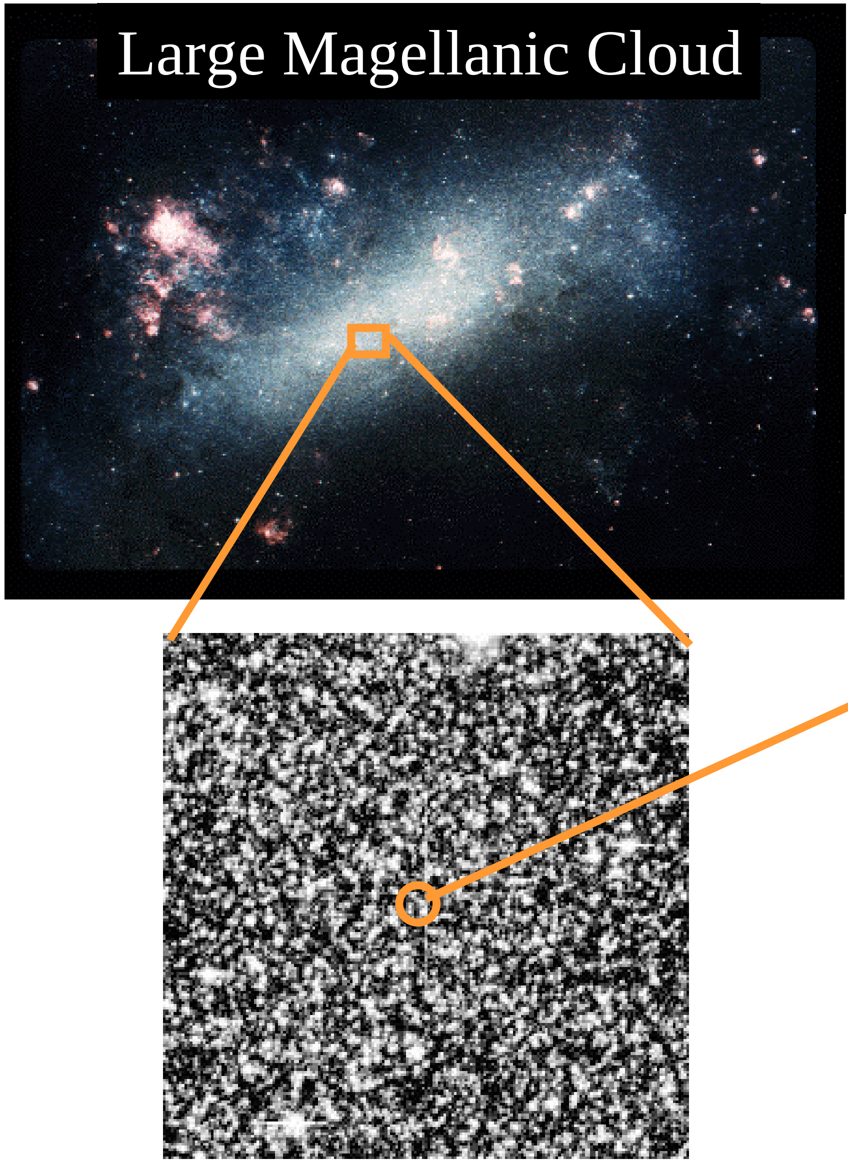
Gas clouds

- 75% visible matter in the universe, but observable

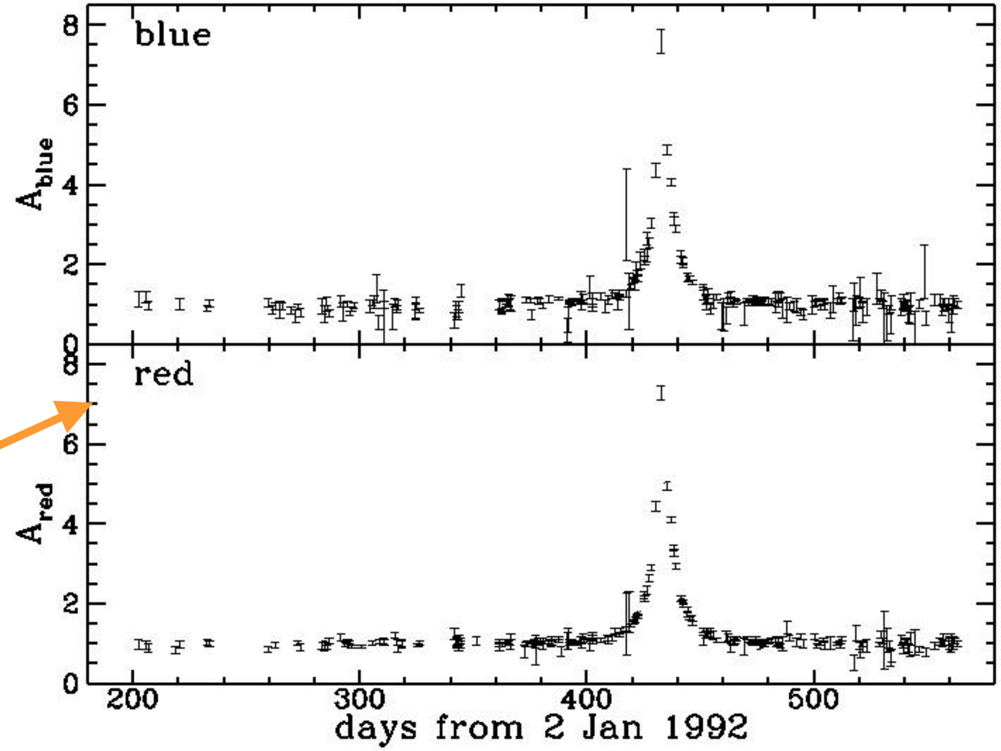
# Gravitational Lensing Searches for Brown Dwarfs

# Gravitational Microlensing



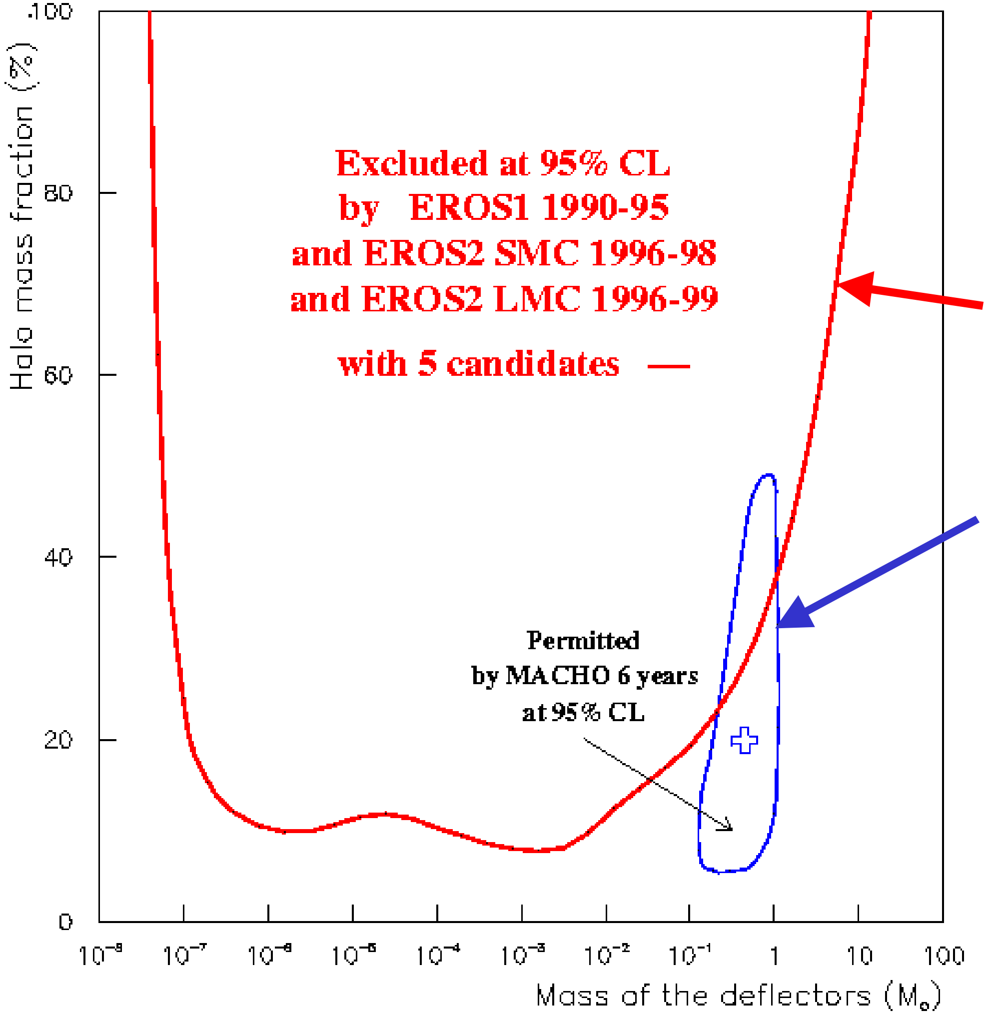

Two colours to eliminate variable stars



# Search for Brown Dwarfs

## (Massive Compact Halo Objects)

Small stars not burning, Jupiter-like objects




**For a standard spherical halo:**

**= 4 $10^{11}$**

**EROS experiment:**

**excludes 30% halo fraction $10^{-7}$ to**

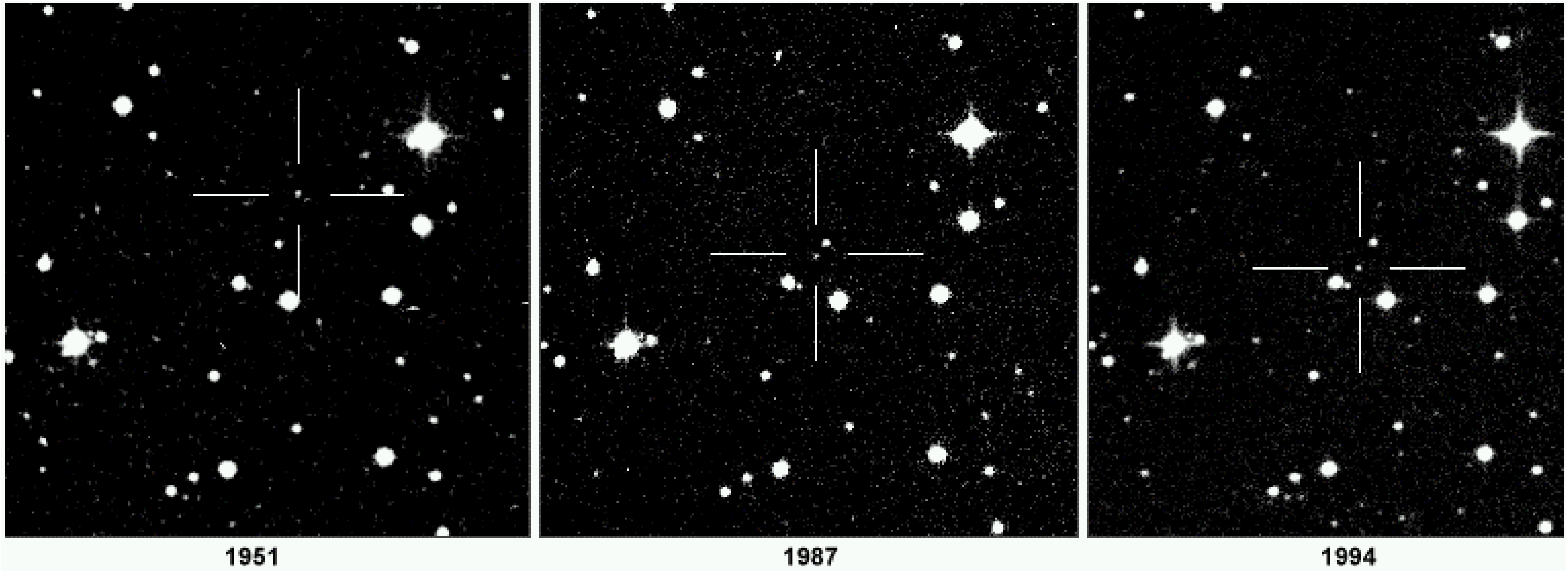
**MACHO experiment:**

**allows 10% to 50% halo fraction 0.**

**Brown Dwarfs are part of baryonic dark matter in the**

# White Dwarfs

## Final state of small stars




38 white dwarfs recently found in old plates :

fast moving => belong to the halo population

old (i.e. cold) => first population of stars in our Galaxy

White dwarfs may compose 3% to 35% of the halo

# Dark Matter: Particle Candidates

## Neutrinos

Expectes to exist as Big Bang fossil 300 / $cm^3$

$\Omega_\nu = 0.002$ if $m \sim 0.1eV$ ( as much mass as visible stars )

Could not explain all DM because escape during galaxy formation

## Axions

Invoked to clean up ‘Strong CP Violation’ problem in SM

Can be Dark Matter if $10^{-5} < m_a < 10^{-2}$ eV

Tough to detect

## WIMPS (Weakly Interacting Massive Particles )

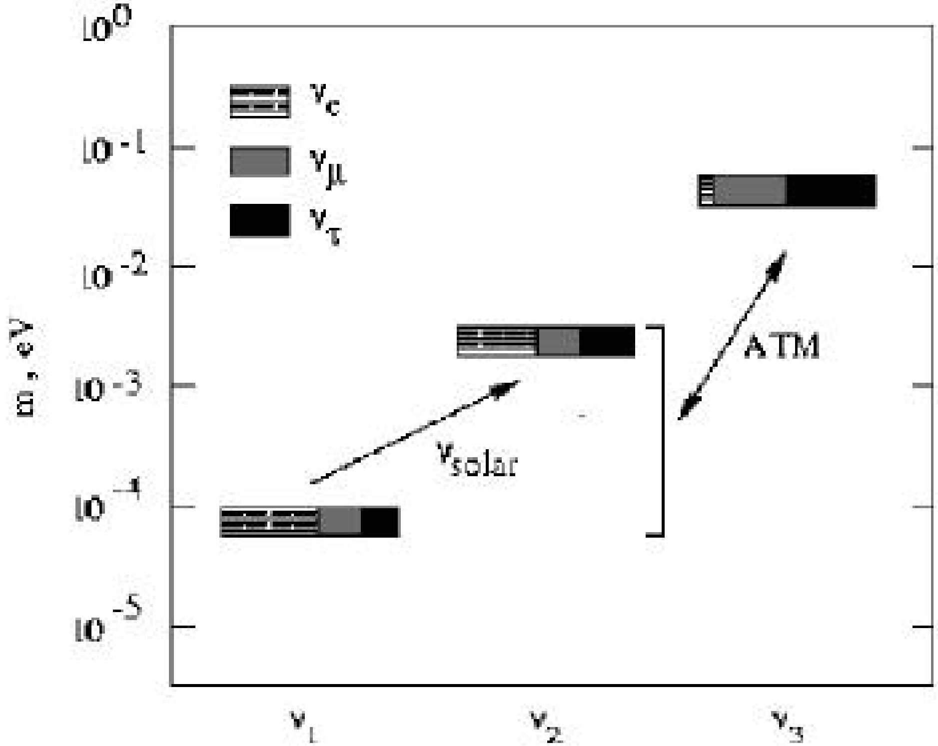
Neutralino : lightest super-symmetric particle

Many searches

# Neutrinos as Dark Matter

**Neutrino contribution to density fraction: $\Omega_\nu \approx \Sigma$ m / 46 eV**

Neutrino Oscillation : most likely solution




**So $\Omega_\nu \approx 0.002$**

# Axions

CP is not an exact symmetry

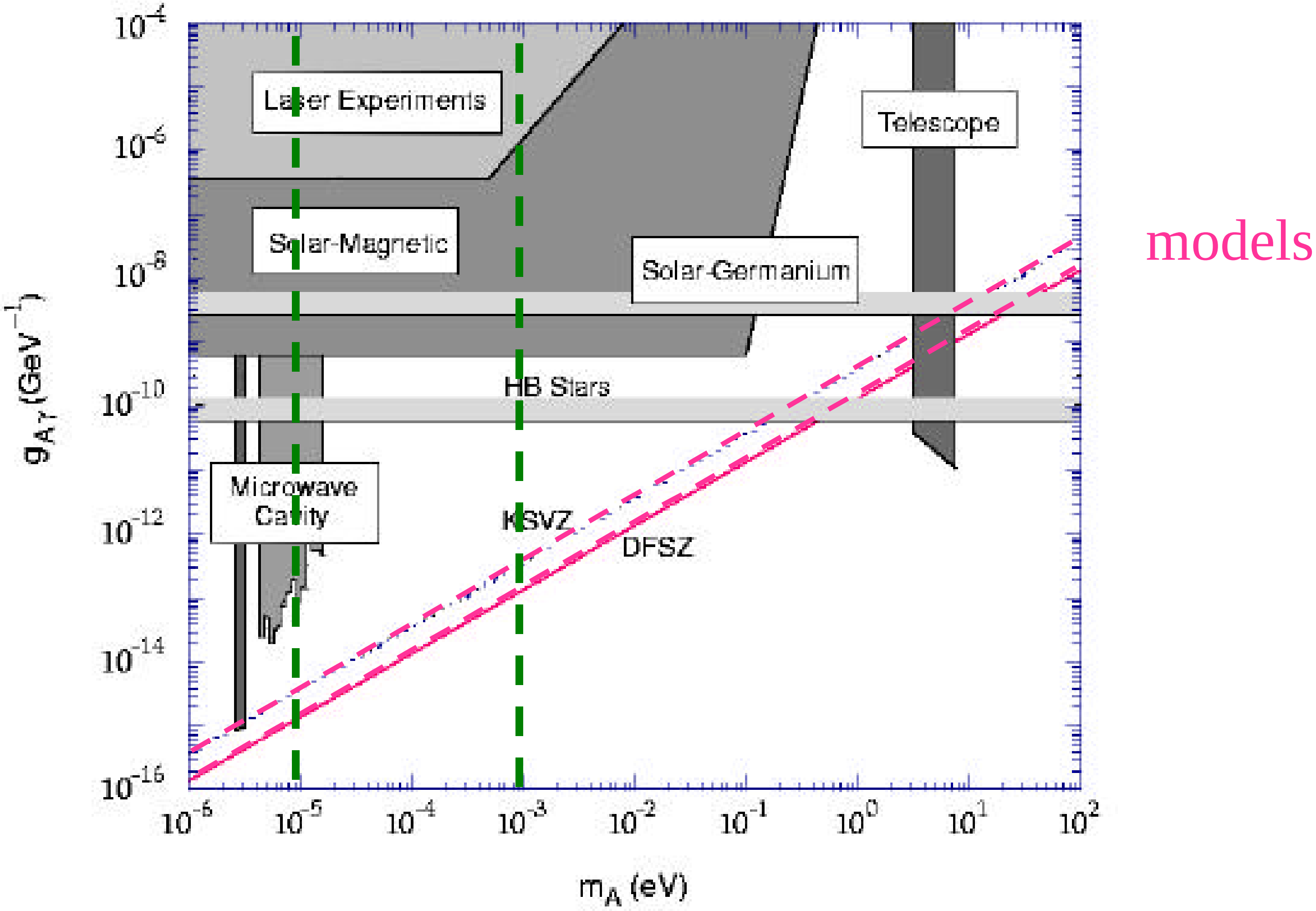
Violated in weak interaction : observed in $K^0$ and B systems
- theory can predict it after experimental discovery

Unfortunately QCD predicts violation in strong interactions
- not observed, limits from electron dipole moment
- Peccei and Quinn propose another U(1) symmetry
- Goldstone boson of this U(1) is the axion

Searches for decades but not found must be very light $m_a < 0.01$ev
Couples so weakly to other particles so it behaves like Cold Dark Matter

Experiments still looking in mode: $a \rightarrow \gamma\gamma$

# Existing limits on axions




**Axion contribution to density fraction: $\Omega_a \approx (5\ 10^{-6}\ \mathrm{eV}/\ m_a)^{1.2}$**

**Masses $10^{-5}$ to $10^{-3}$ interesting as dark matter**

# US Large Scale Axion Search

## Microwave Cavity