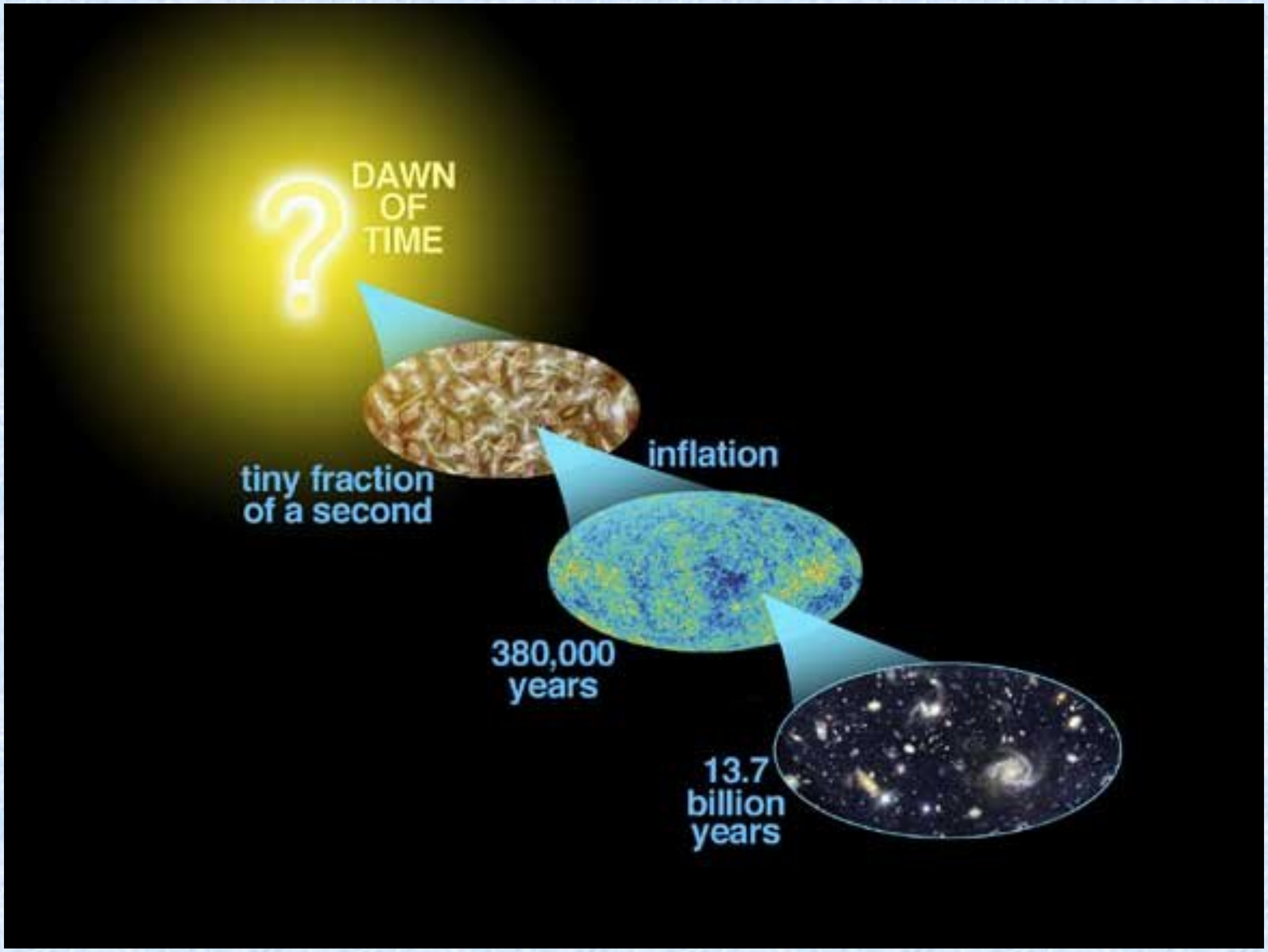
Physics 133: Extragalactic Astronomy and Cosmology



Lecture 11; February 19 2014

Previously:

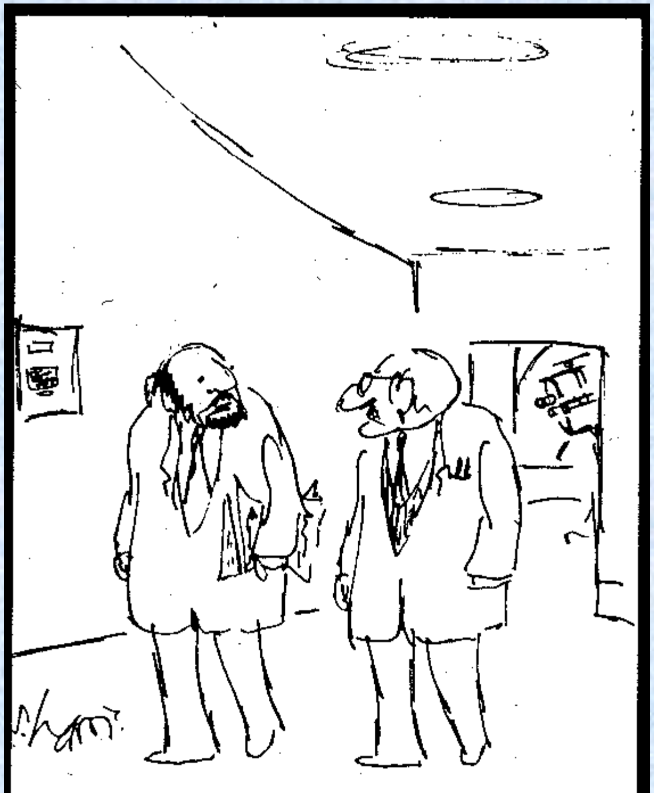
- Luminous and Dark Matters:
  - Luminous and baryonic matter
  - Dark matter in galaxies
  - Dark matter in clusters
  - Virial Theorem
  - Hydrostatic Equilibrium

Outline:

- What’s the matter?

What's the matter?

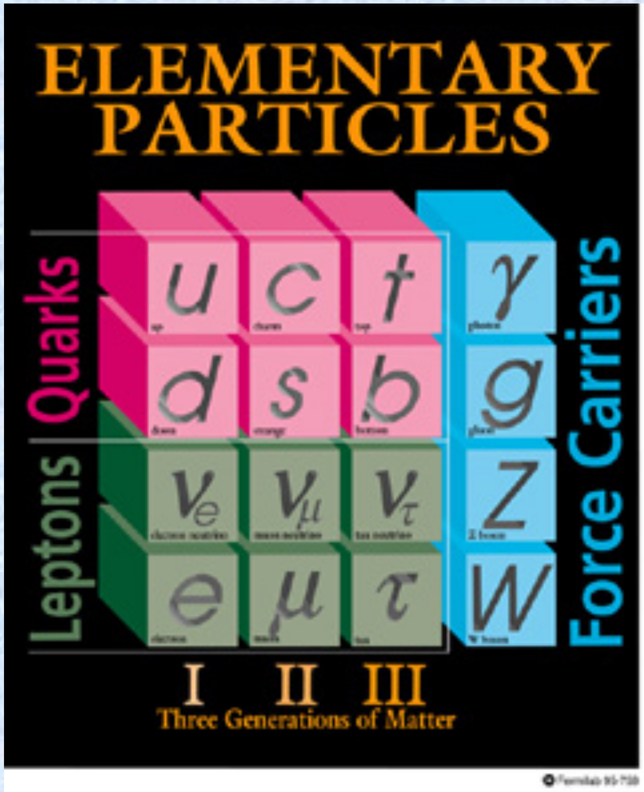
- Dark matter is non baryonic (primordial nucleosynthesis/CMB)
- But what is it?



"Vacuums, black holes, anti-matter — it's the elusive and intangible which appeals to me."

What's the matter? Or what is "normal" matter

- Ordinary matter is made of protons and neutrons, i.e. quarks up and down.
- Ordinary matter is baryonic matter
- Neutrinos should not have mass in the standard model, but if they do, they could explain at least part of dark matter

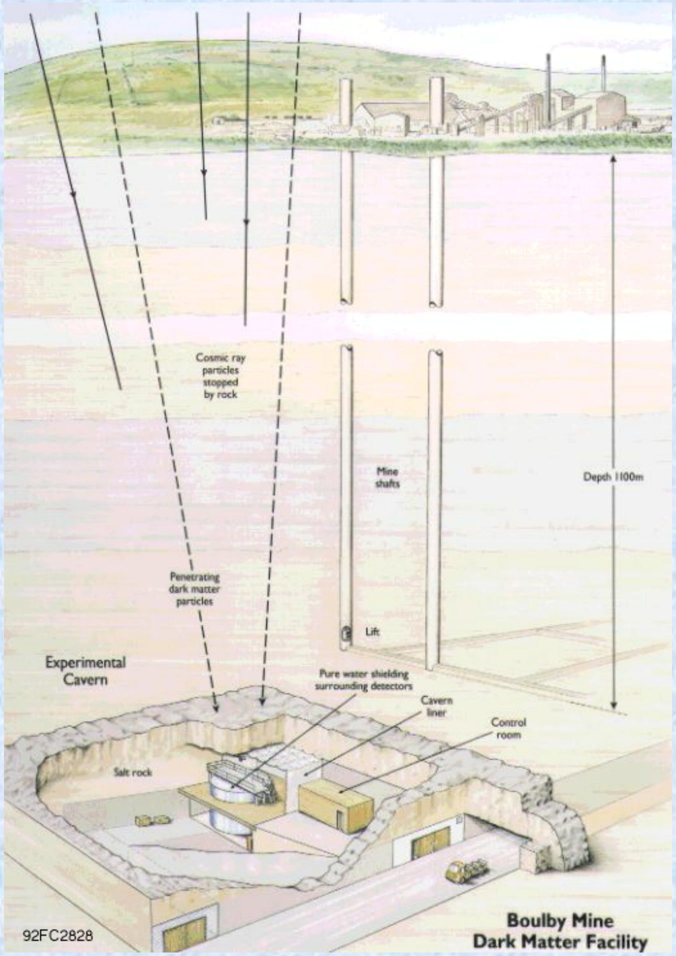


Non baryonic dark matter

1. Massive particles that interact only weakly, i.e. no electromagnetic interaction, called WIMPS, for weakly interacting massive particles. "Cold" dark matter
2. Massive neutrinos. "Hot" dark matter.
3. Sterile neutrinos or other kev scale particles. "Warm" dark matter

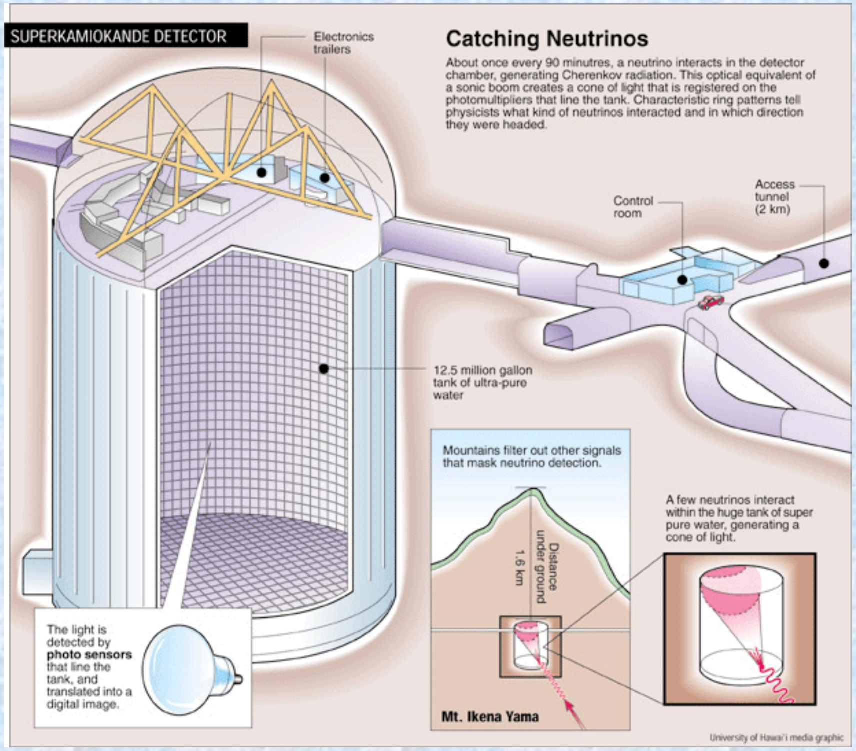
What is dark matter? WIMPS?

- Findings WIMPS in a lab is very hard, because they interact only weakly
- The main difficulty is that you have to filter out all sort of particles that are not of cosmic origin (e.g. Earth's natural radioactivity)
- Such searches for dark matter have so far been inconclusive…



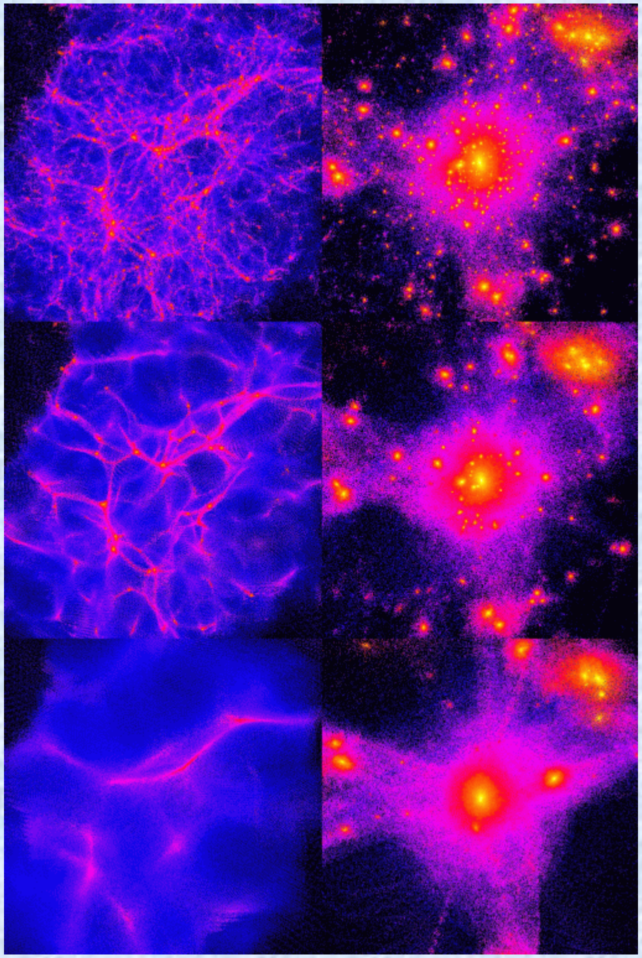
What is dark matter? Neutrinos?

- There are three distinct families of neutrinos
- It is observed that neutrinos change family (oscillations)
  - Solar neutrinos
  - Ground based experiments
- The probability of neutrino oscillations sets a limit on the difference in mass
- Neutrinos are a form of hot dark matter, but not enough to account for all the observed dark matter [homework]



What is dark matter?
Dark matter cannot be hot

- Hot dark matter escapes easily from overdensities, smoothing out large scale structure
- This would not match the observed large scale structure
- So we can rule out hot dark matter.
- Astrophysical upper limit on SUM of neutrino masses ~0.3eV



COLD

WARM

HOT

Warm Dark Matter

- Intermediate case. E.g. sterile neutrinos
- Generically distribution function can be described by

$$f(v) \propto \frac{\beta}{e^{pc/\alpha k T_\gamma} + 1}$$

$$\mathrm{Neutrino\ HDM:}\ \ \alpha = (4/11)^{1/3}, \beta = 1$$

$$\mathrm{CDM:}\ \ \alpha \to 0 m \to \infty$$

$$\mathrm{thermal\ WDM:}\ \ \alpha < 1$$

$$\mathrm{non-thermal\ WDM:}\ \ \beta < 1$$

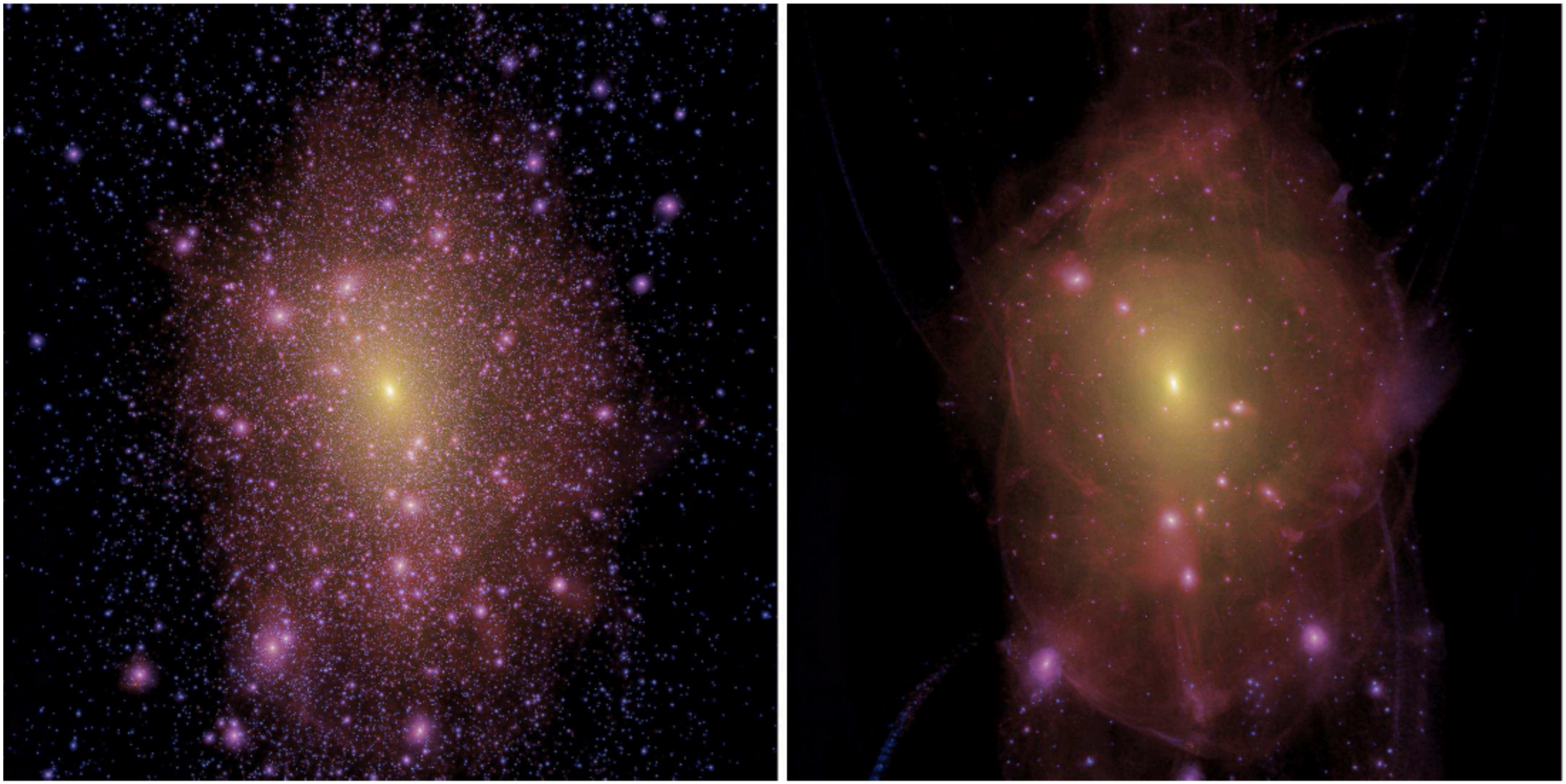
Warm Dark Matter

- Since WDM decouples when it's relativistic its abundance is given by

$$\Omega_{\rm WDM} h^2 = \beta \left(\frac{\alpha^3 11}{4} \right) \left(\frac{m_{WDM}}{93eV} \right)$$

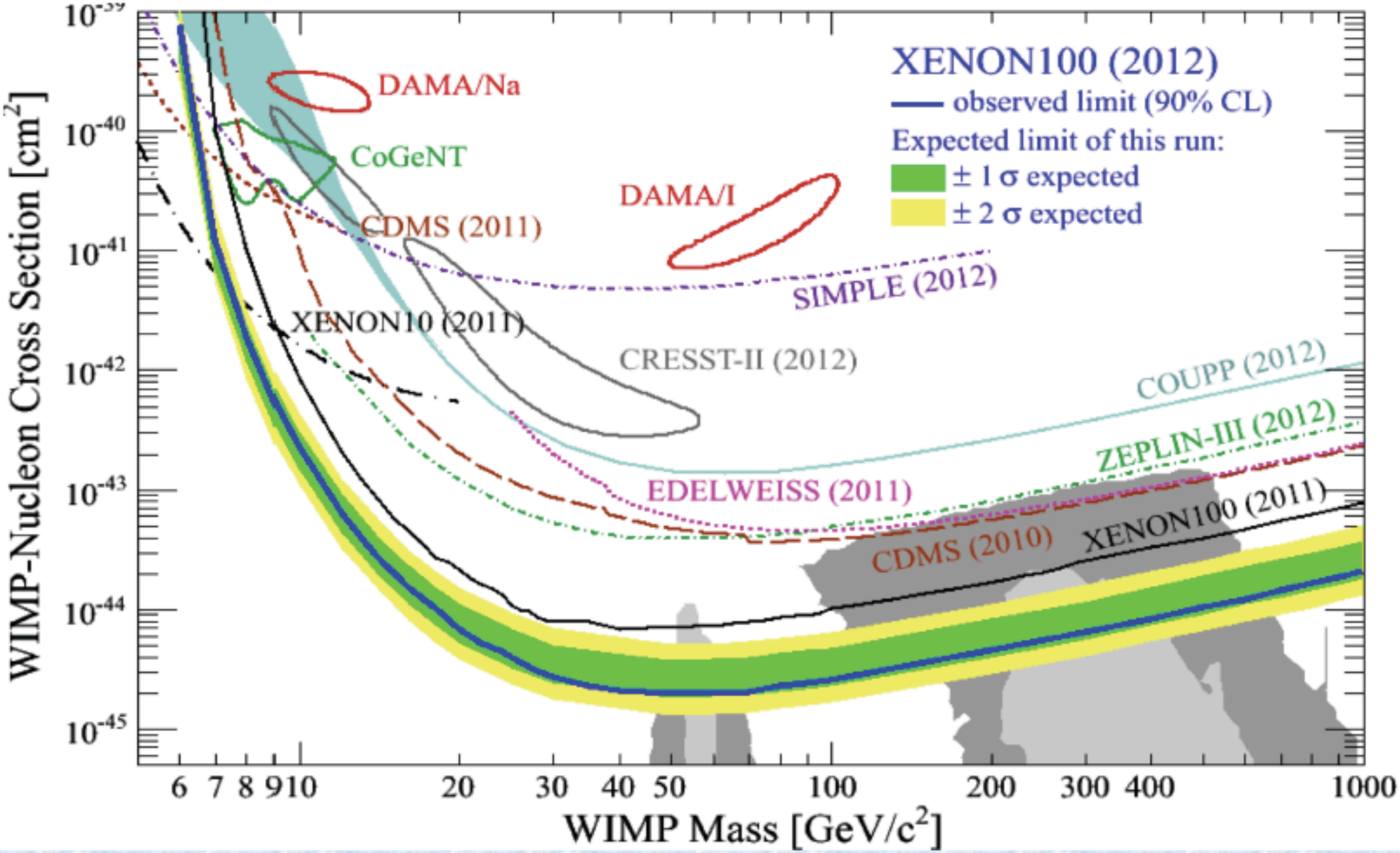
- Thermal relic is for beta=1 and T can be much lower than TCMB if decoupling happens early on

Warm Dark Matter

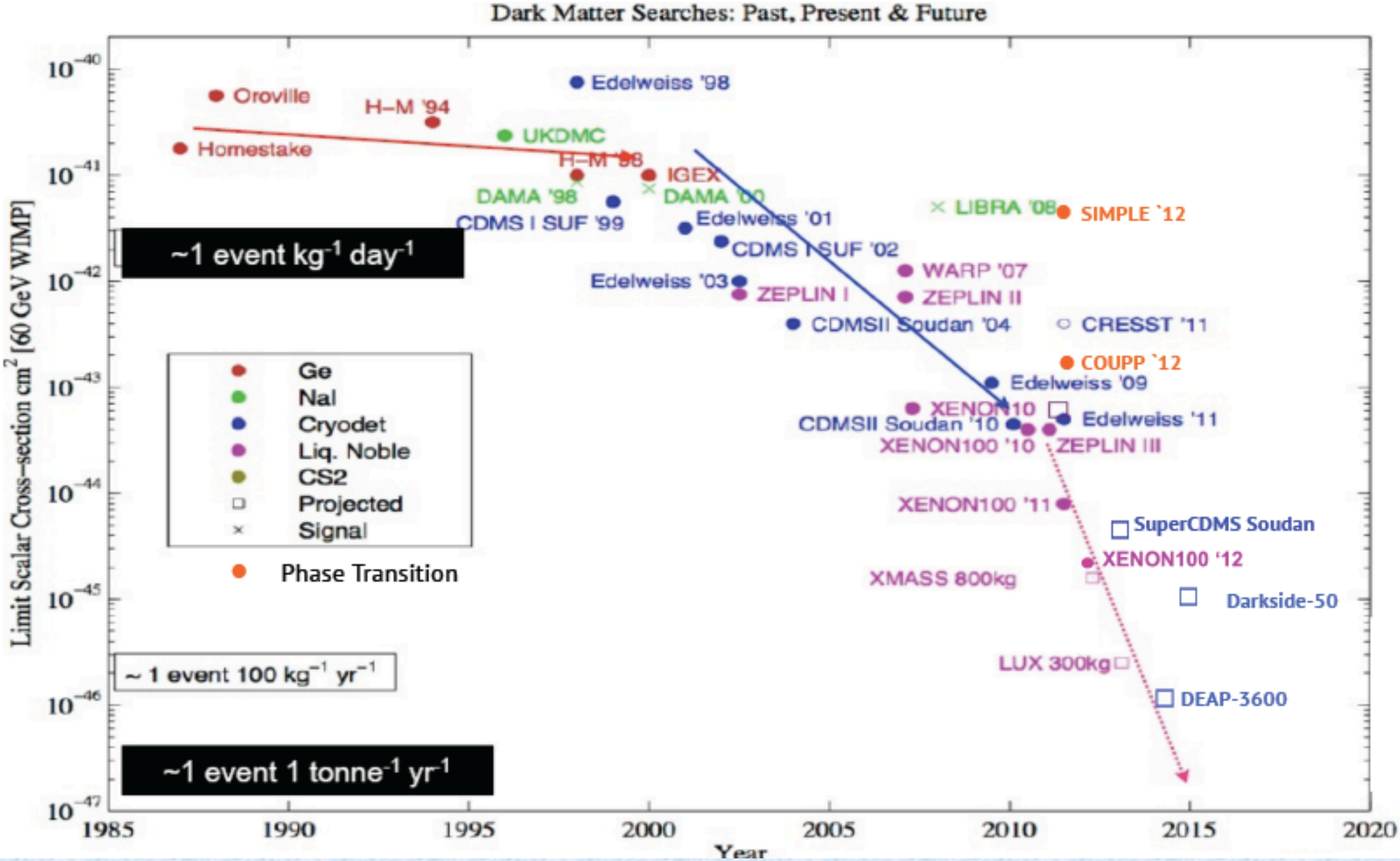


Lovell et al. 2012

WIMP SI Parameter Space "race to the bottom"



From Harry Nelson's talk at DAMASC

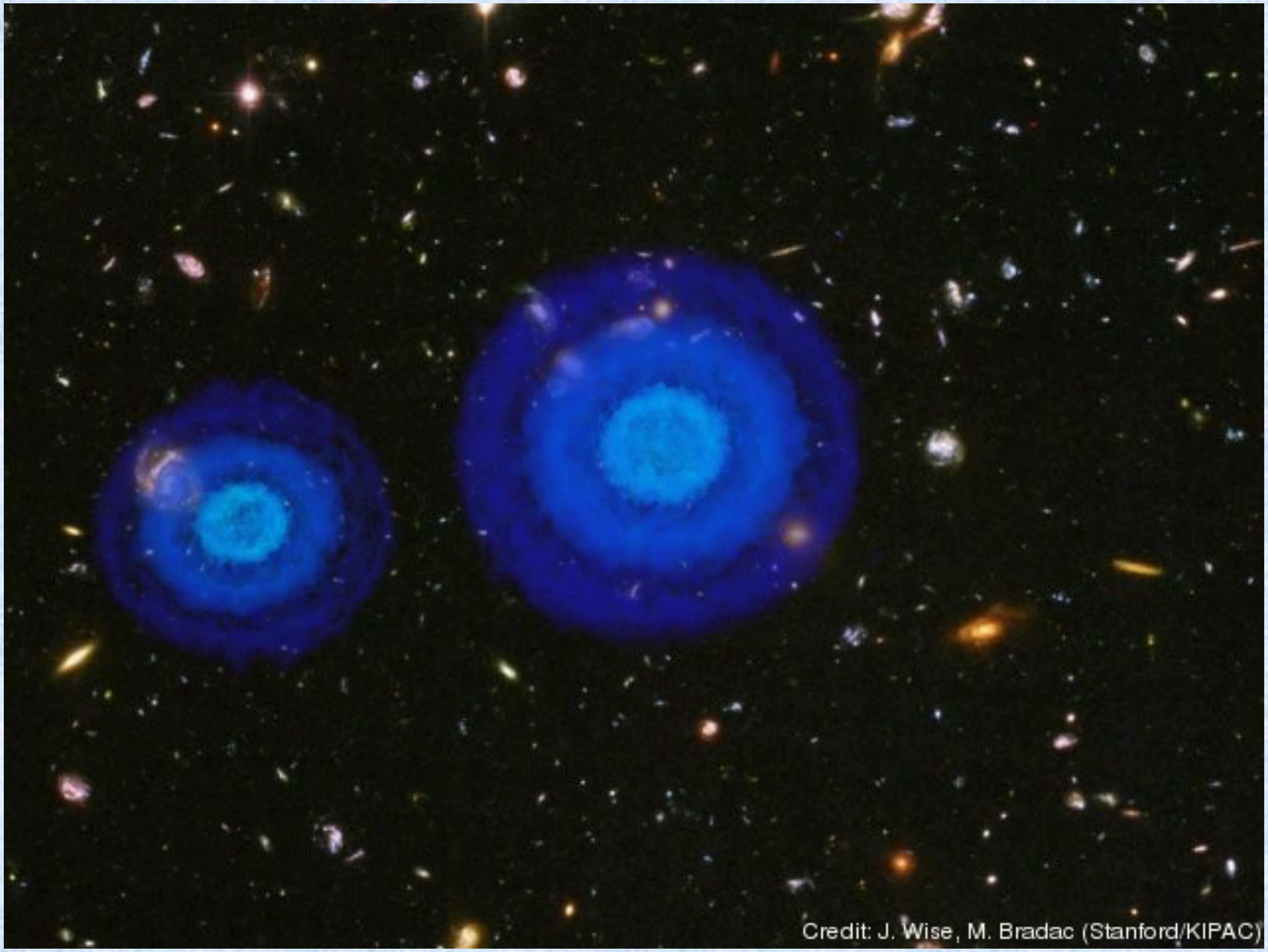


From Harry Nelson's talk at DAMASC

Other limits on dark matter

- LHC
- Astronomical limits on self-interaction cross-section (claim of a marginal detection; Dawson et al. 2012)
- Limits on cross section for self-annhilation and decay into standard model particles, e.g. from Fermi Gamma Ray Telescope. Recent claim of line detection at ~130 GeV

One example



Summary

- There is dark matter:
  - Galaxies – rotation curves
  - Clusters – virial theorem and hydrostatic equilibrium
- We do not know what it is:
  - It cannot be hidden baryons [BBN + CMB say no]
  - It could be new exotic particles..

The End

See you on monday