Dark Matter

ASTR 333/433
Spring 2024
TR 11:30am–12:45pm
Sears 552

http://astroweb.case.edu/ssm/ASTR333/

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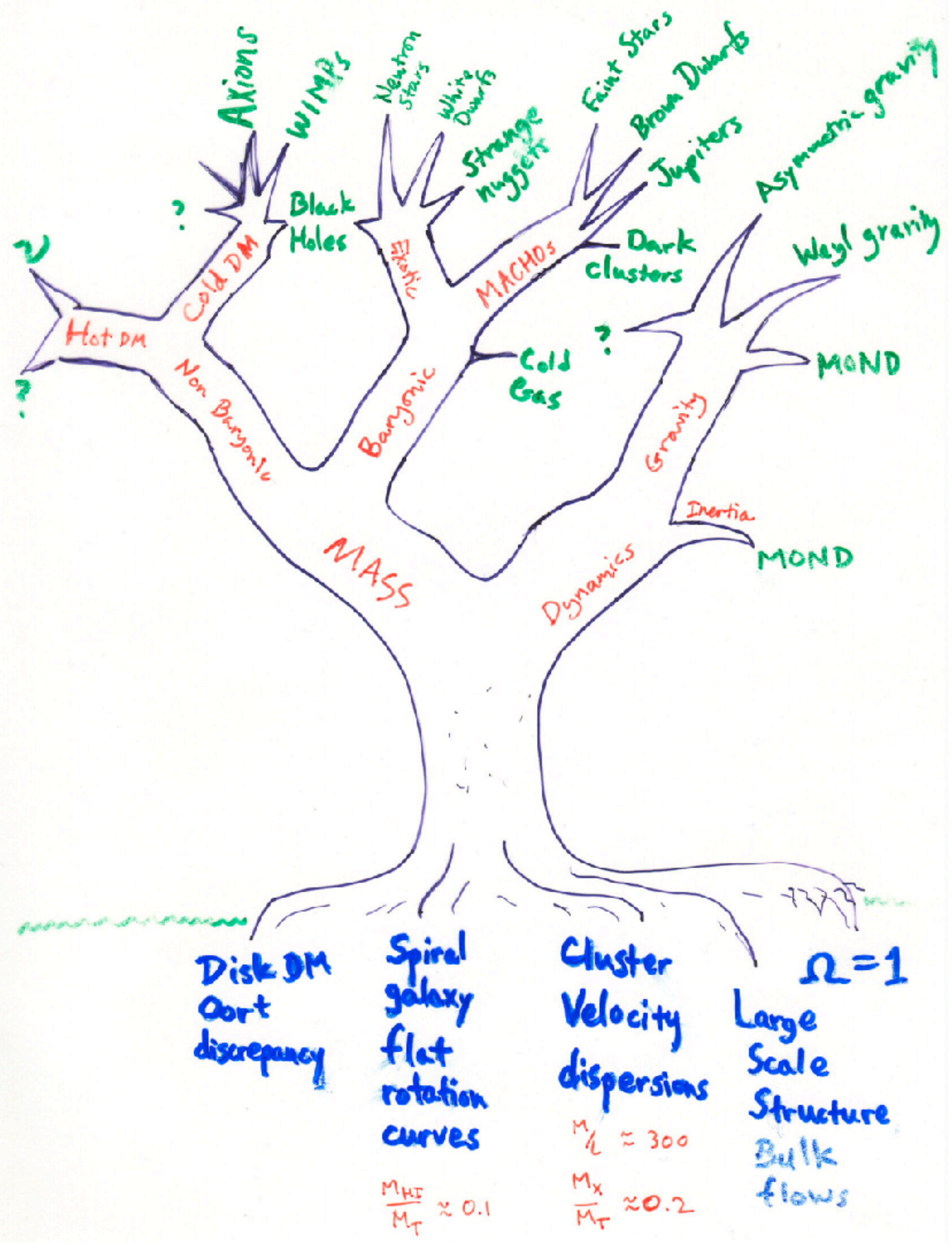


$\Omega_b \approx 0.05$ BBN baryon density

$\Omega_m \approx 0.30$ gravitating mass density

$f_b = \frac{\Omega_b}{\Omega_m}$ baryon fraction

There is a hierarchy of missing mass problems

$\Omega_b < \Omega_m$ cosmic missing mass problem
(not enough BBN baryons to explain all the gravitating mass in the Universe)

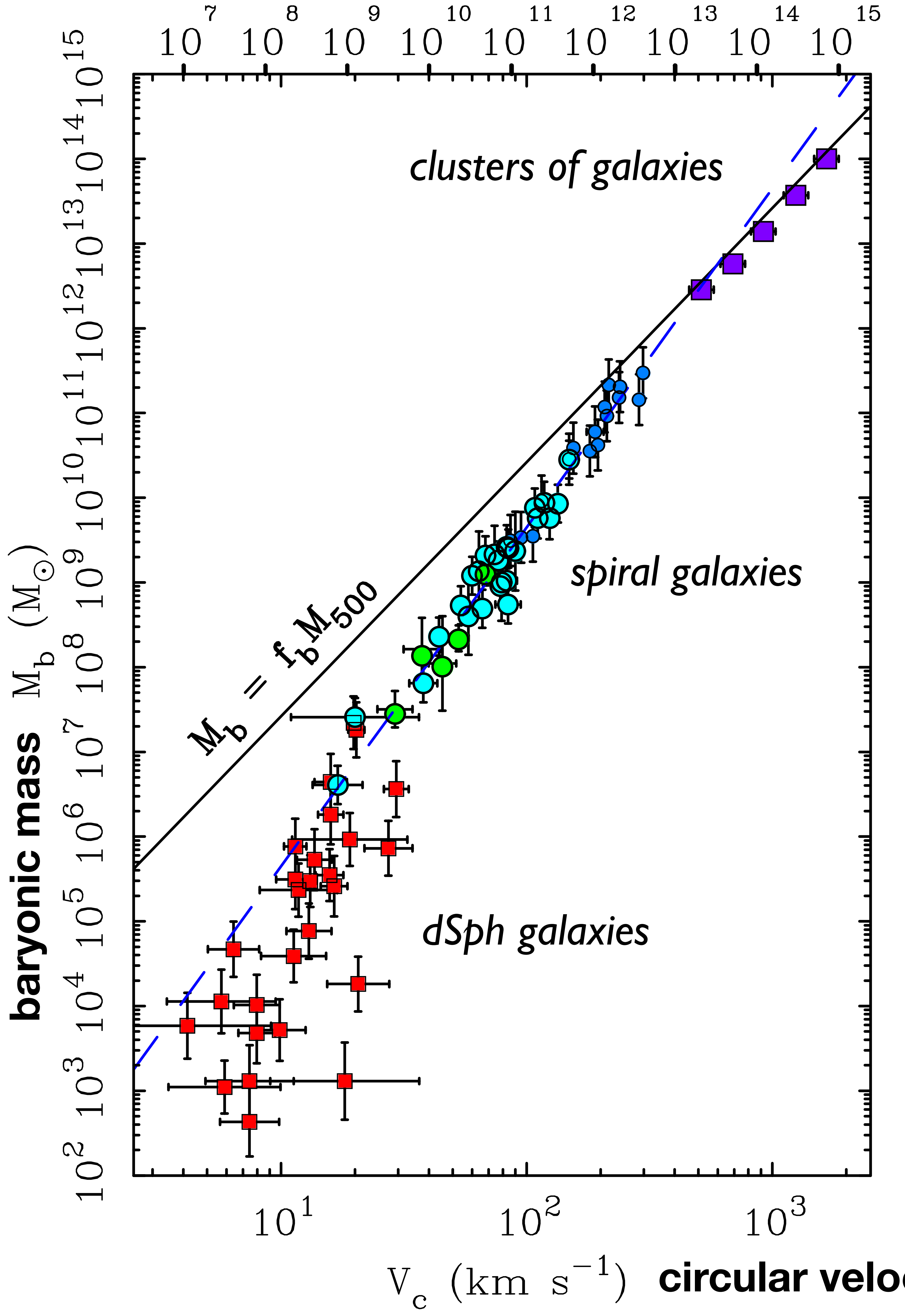
$\sum \Omega_b \text{ (observed)} < \Omega_b \text{ (BBN)}$ cosmic missing baryon problem
(not enough baryons for BBN)

$M_b < f_b M_{200}$ halo missing baryon problem
(not enough baryons in each DM halo)

Extended TF

Mass budget

Basically an accounting exercise: for every object, how much normal matter is there? How much total mass?



within an over-density $\Delta = 500$

Clusters
traced by **X-rays**
data are binned: many clusters per point; hides scatter

Spirals
traced by **circular velocity** extrapolated to R_{500}

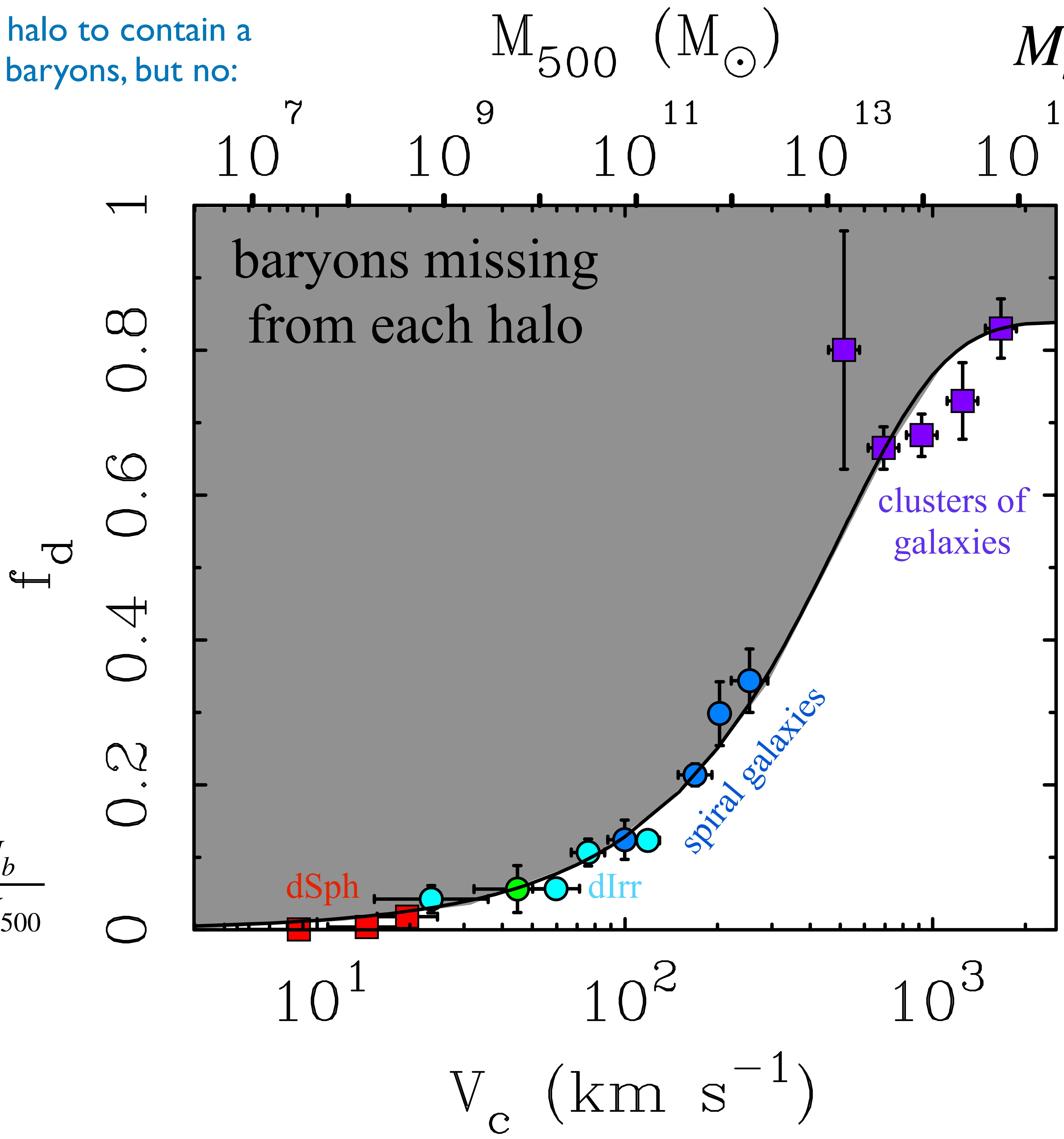
dwarf Spheroidals
traced by **velocity dispersion** extrapolated to R_{500}

McGaugh et al (2010)

The halo missing baryon problem

Expect each halo to contain a fair share of baryons, but no:

$M_b < f_b M_{200}$



detected baryon fraction

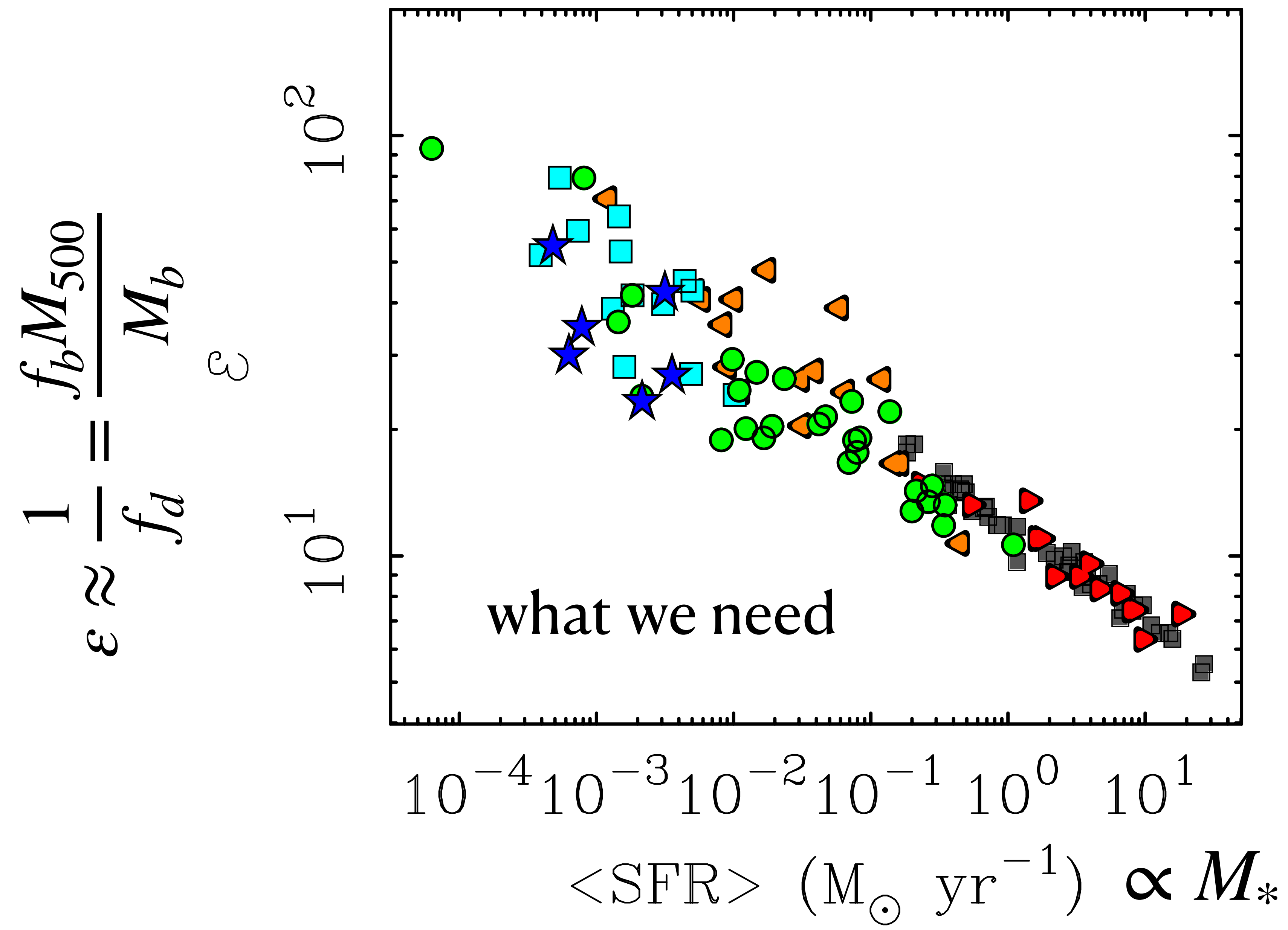
$$f_d = \frac{M_b}{f_b M_{500}}$$

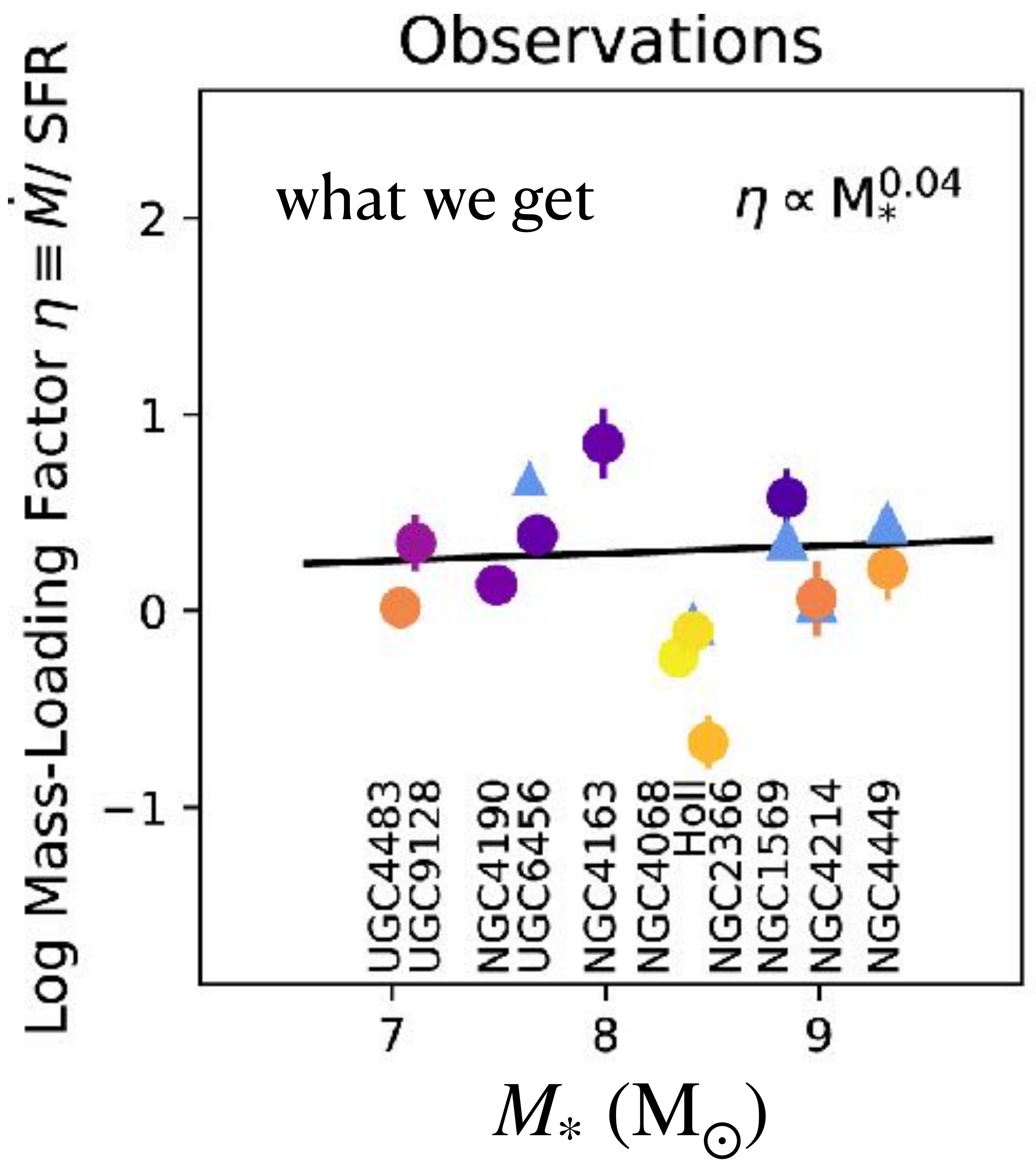
cosmic baryon fraction

$f_b = 0.17$

Feedback

invoked to explain cusp-core problem and missing baryon/missing satellite problem





The answer is unclear, but it is widely thought that either
(i) supernova feedback blows the excess baryons out of halos, or
(ii) feedback heats baryons so they don't dissipate into the disk

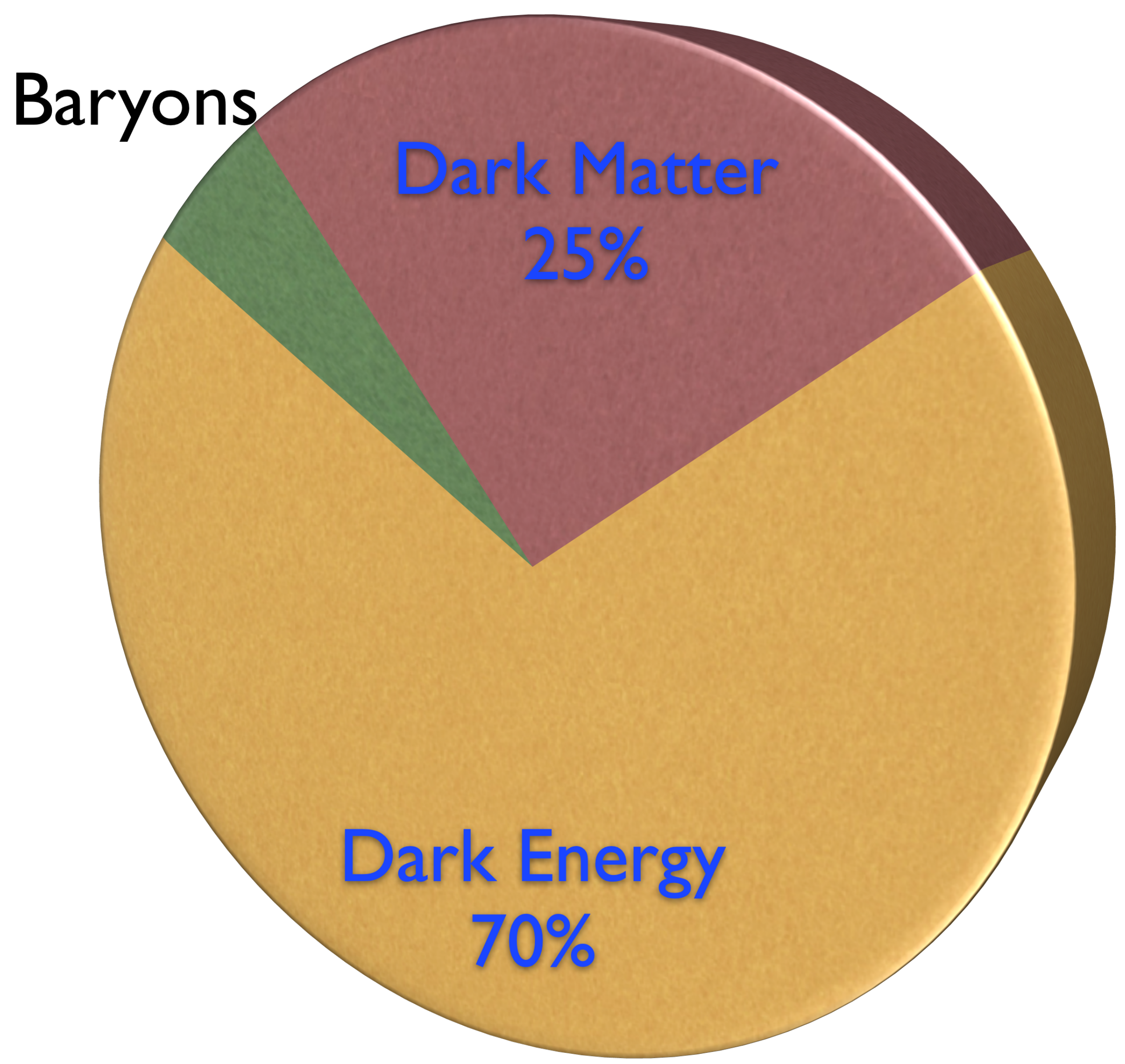
SN feedback is thought to be most effective in low mass galaxies with small potential wells that can't retain material that explodes outwards. It is not obvious that this works in practice.

Regardless of the cause, there is a missing baryon problem in individual dark matter halos (esp. low mass galaxies).

Empirical Pillars of the Hot Big Bang

1. Hubble Expansion
2. Big Bang Nucleosynthesis Ω_b
3. Cosmic Microwave Background

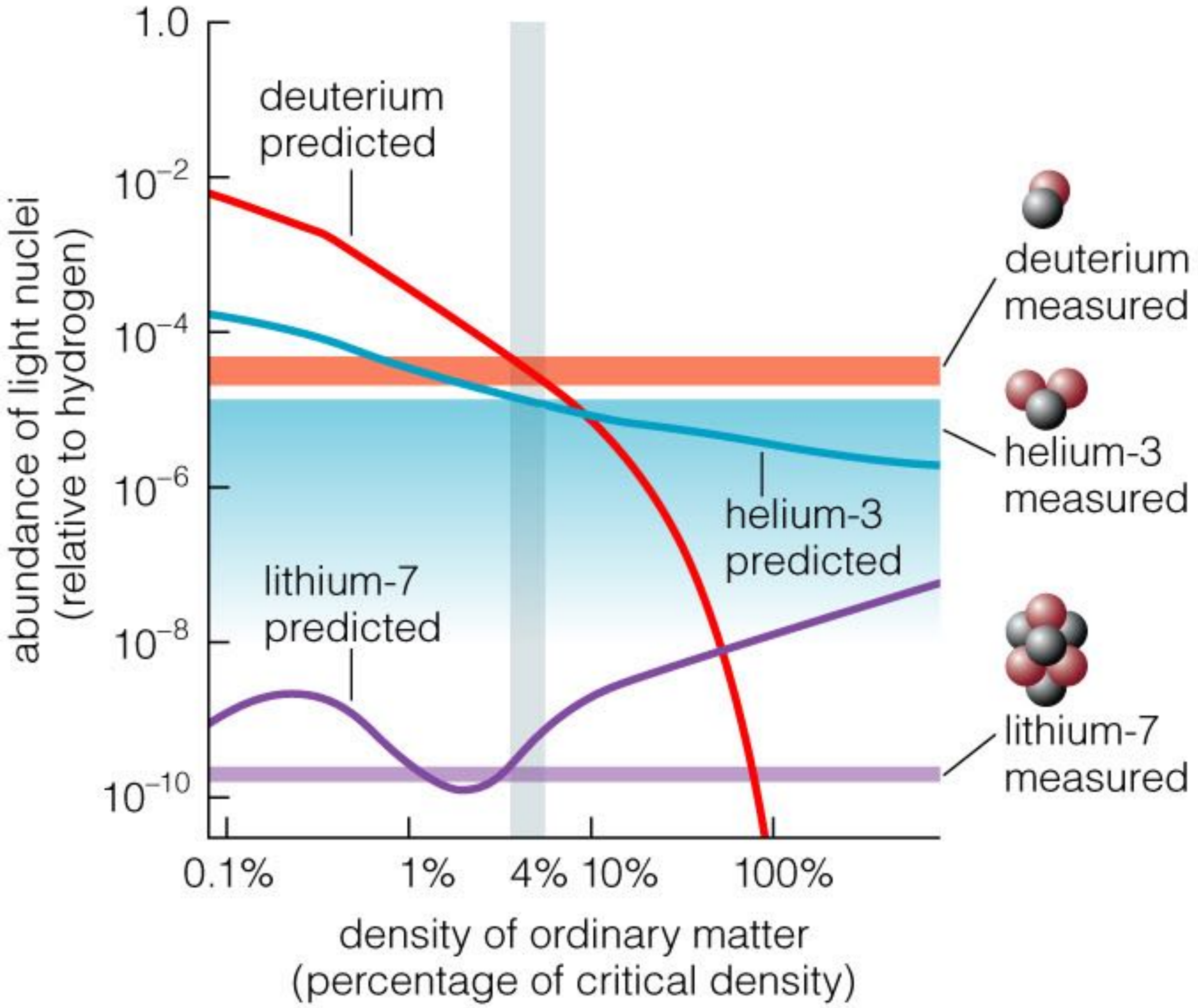
$$\Omega_m = \Omega_b + \Omega_{DM}$$



Auxiliary Hypotheses

- Dark matter Ω_{DM}
- Dark Energy Ω_Λ

Non-baryonic dark matter driven by $\Omega_m > \Omega_b$.
How do we know?

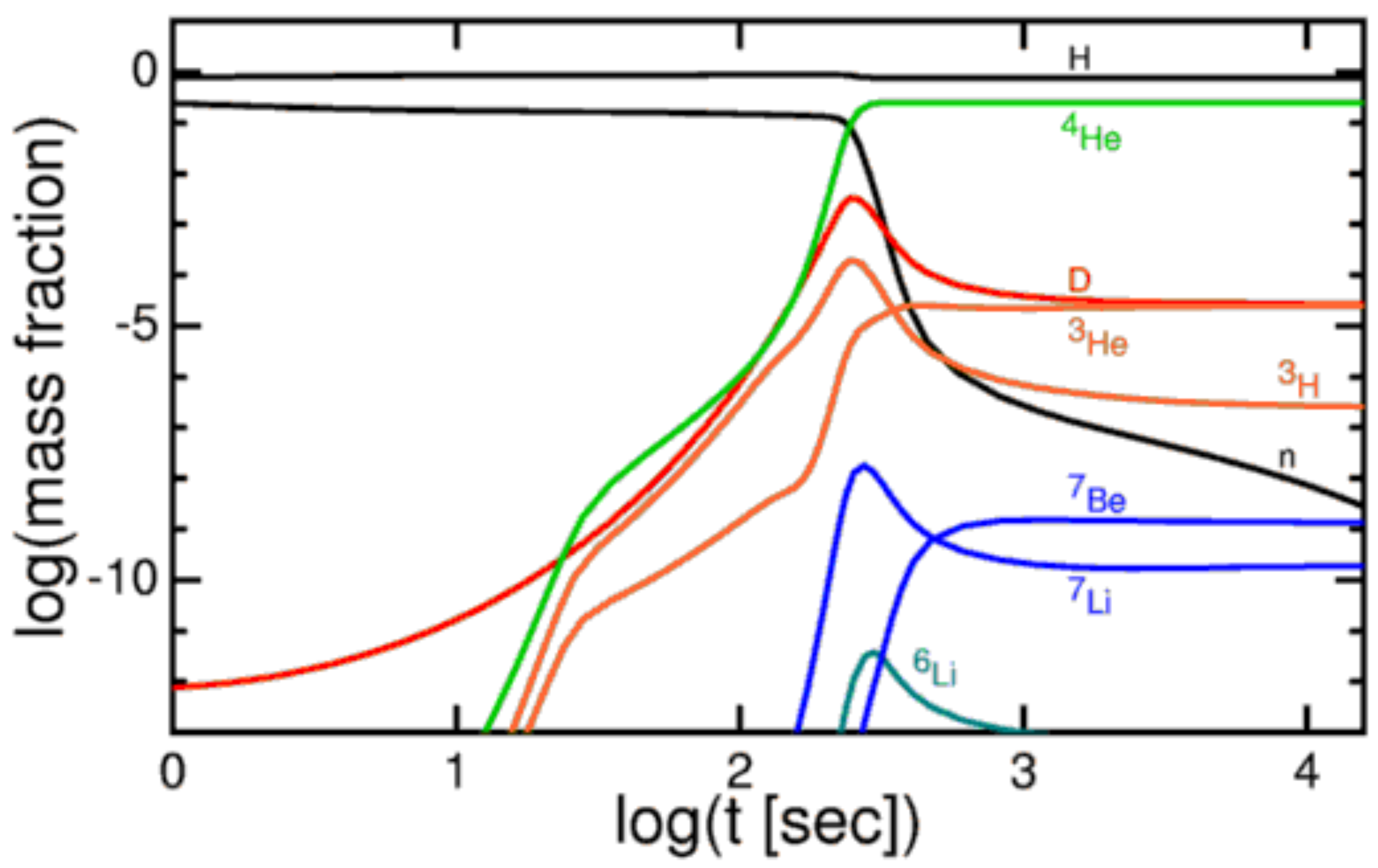


Ω_b

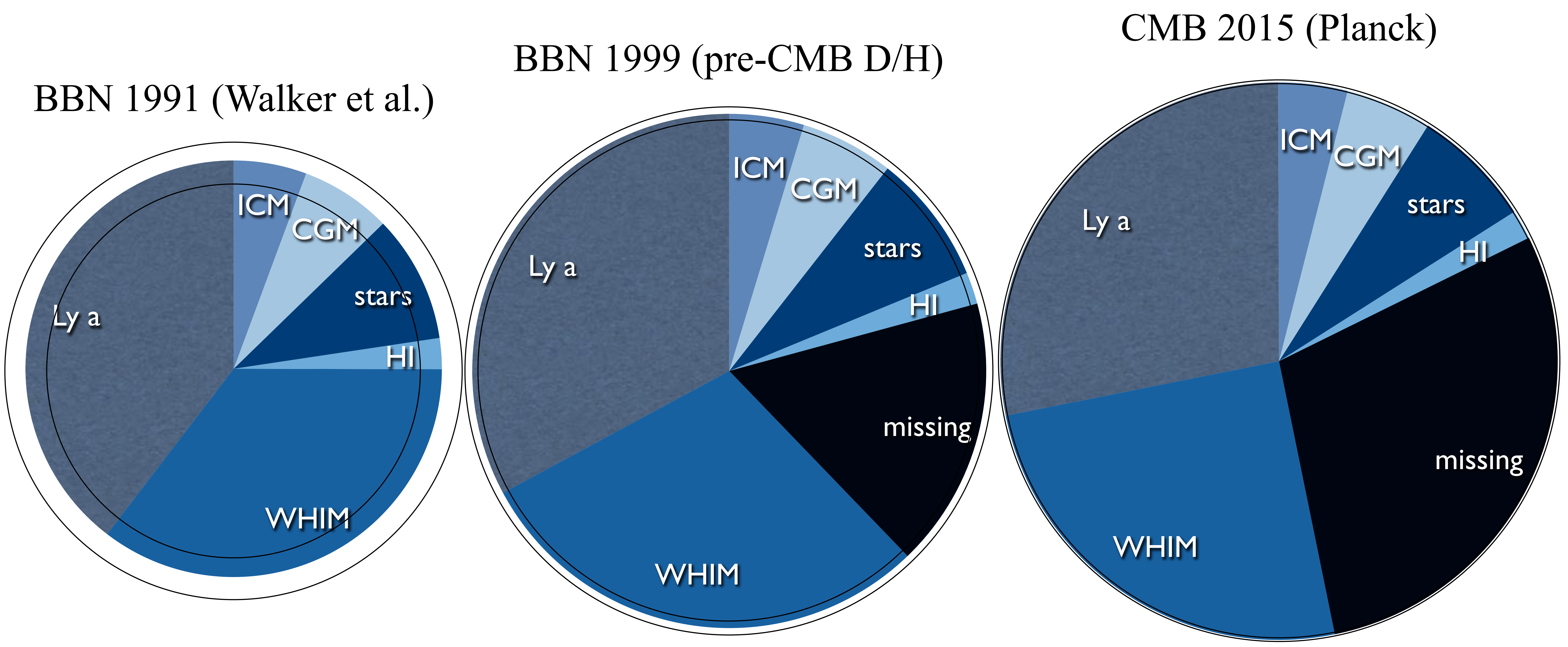
<u>How do we know?</u>

Theory: BBN in early universe

Observation: constraints on isotopic abundances of light elements



BBN estimates of Ω_b over time



$\Omega_b h^2 = 0.0125 \pm 0.0025$

$\Omega_b = 0.0255$

$\Omega_b h^2 = 0.019 \pm 0.001$

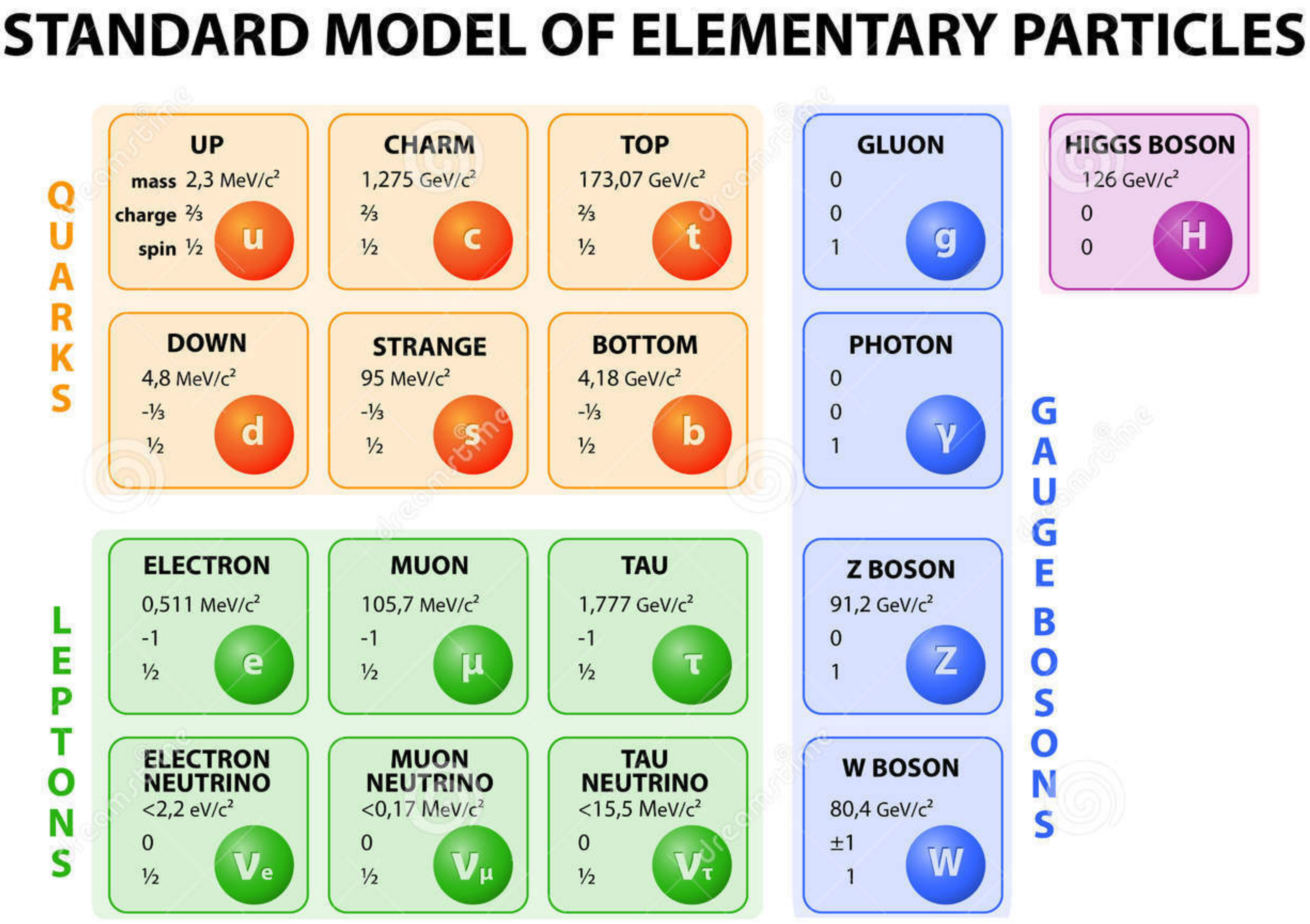
$\Omega_b = 0.0388$

$\Omega_b h^2 = 0.02230 \pm 0.00023$

$\Omega_b = 0.0455$ for $H_0 = 70$
$\Omega_b = 0.05$ for $H_0 = 66.8$
$\Omega_b = 0.04$ for $H_0 = 74.7$

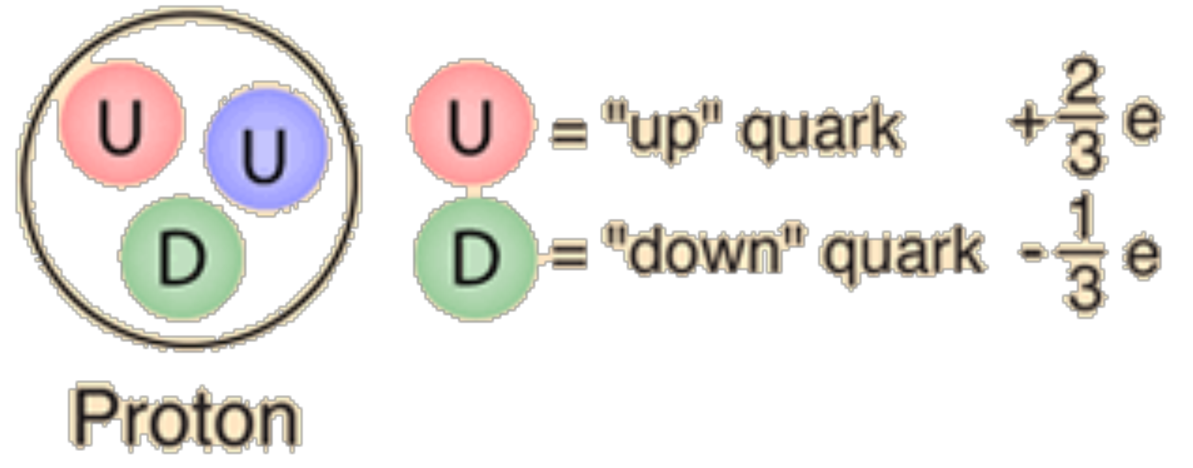
Our estimate of the baryon density Ω_b has grown over time.
The first step was in response to improved deuterium data;
the second was due to observation of the CMB acoustic power spectrum.

Whatever the non-baryonic dark matter is, it has to come from new physics beyond the standard model.

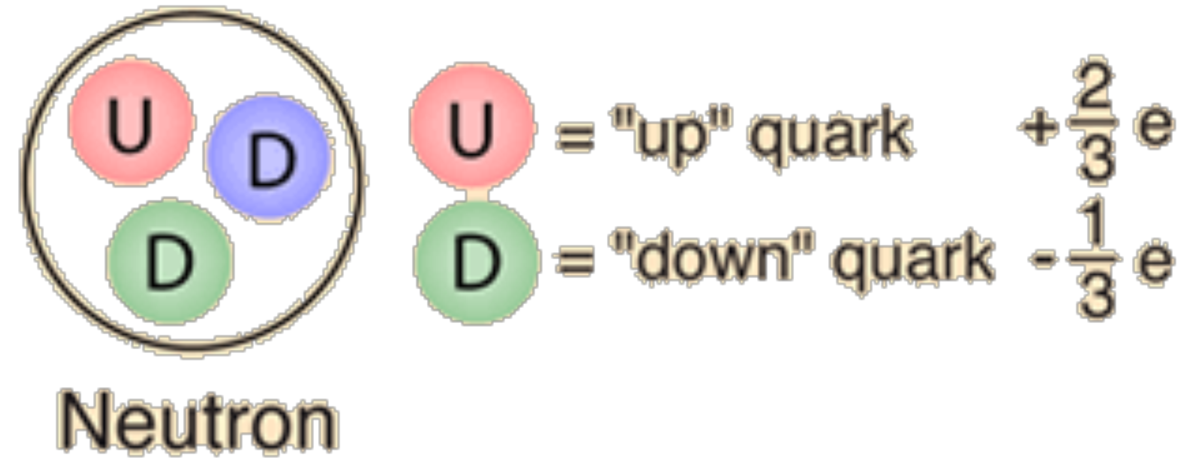


Baryons (3 quarks)

$m_p = 938.3$ eV

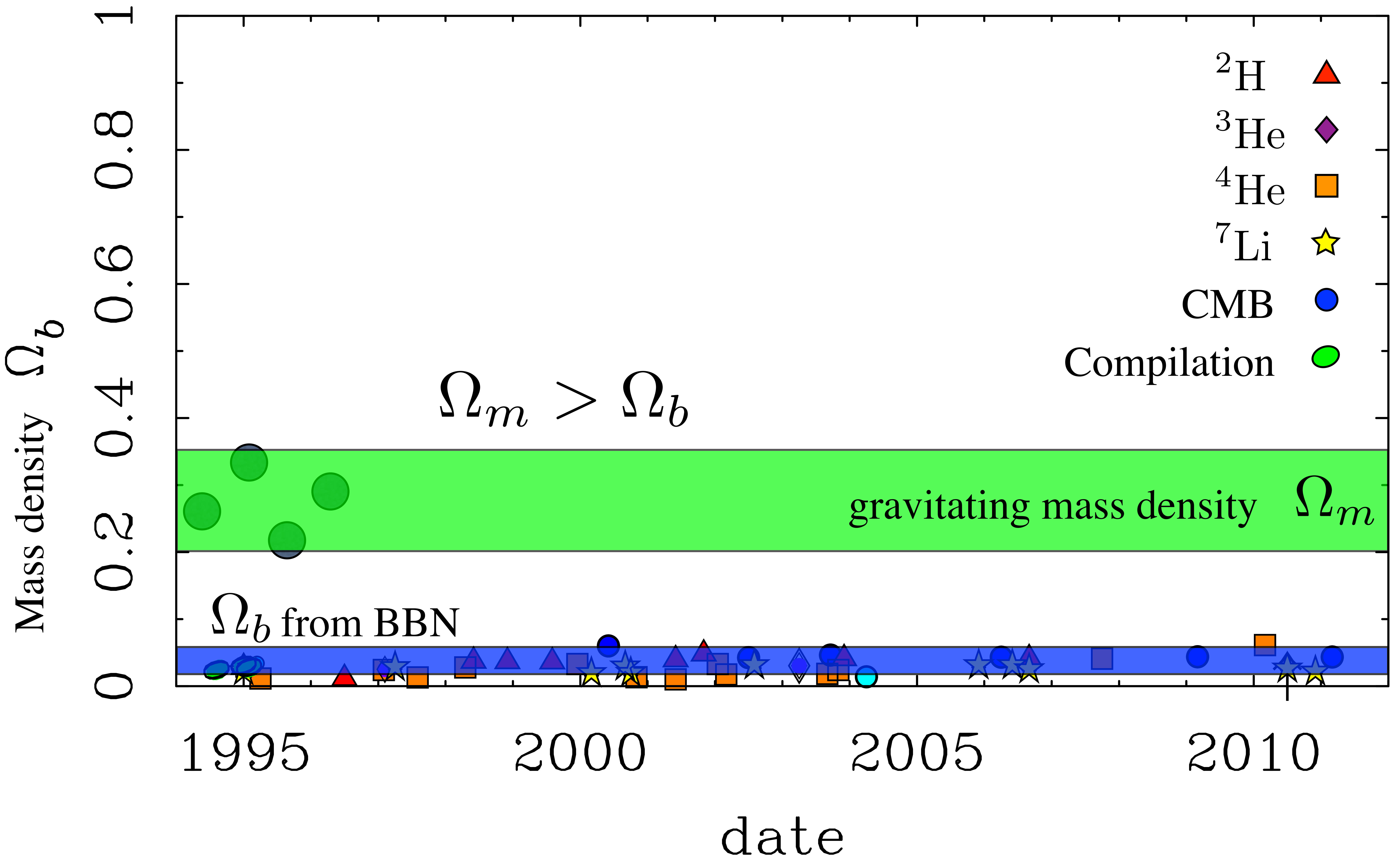


$m_n = 939.6$ eV



Up & down quarks are light: most of the rest mass is binding energy

There's more mass than BBN allows in baryons



Measurements of the gravitating mass density

- Cluster M/L
  - measure M/L of a cluster, combine with measured luminosity density of universe.
- Weak lensing
  - measure shear over large scales
- Peculiar Velocity Field
  - measure deviations from Hubble flow
- Power spectrum of galaxies
- CMB fits

Measurements of the gravitating mass density

- Cluster M/L
  - measure M/L of a cluster, combine with measured luminosity density of universe.
  - j from integrating the luminosity function of galaxies:

$$\rho_m = \left(\frac{M}{L}\right) j$$

  - Also, cluster baryon fractions:

$$f_b = \frac{M_b}{M_{tot}} = \frac{\Omega_b}{\Omega_m}$$

  - both assume clusters are representative of the whole.

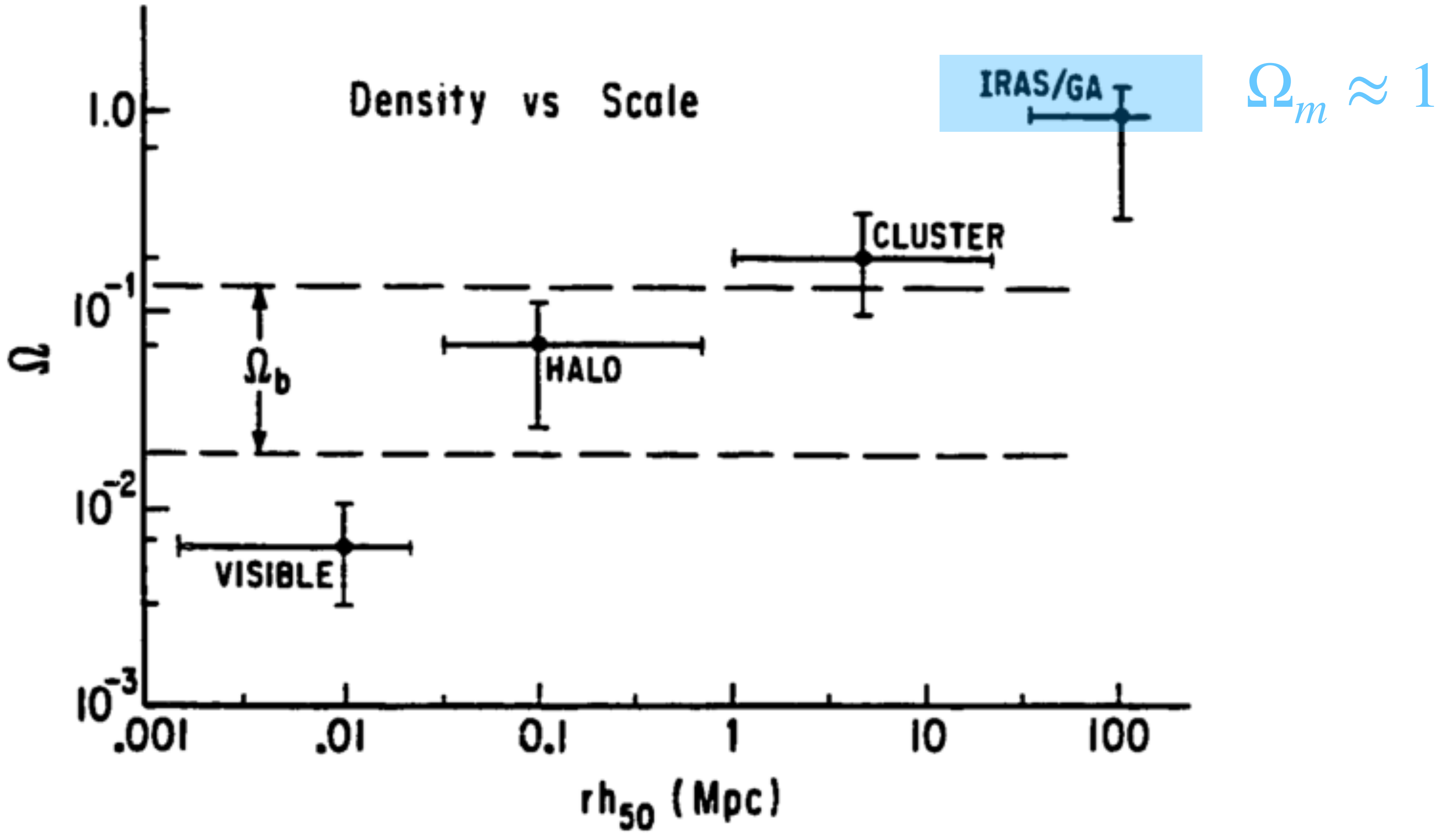


Figure 2. Implied densities versus the scale of the measurements.

Schramm (1992)

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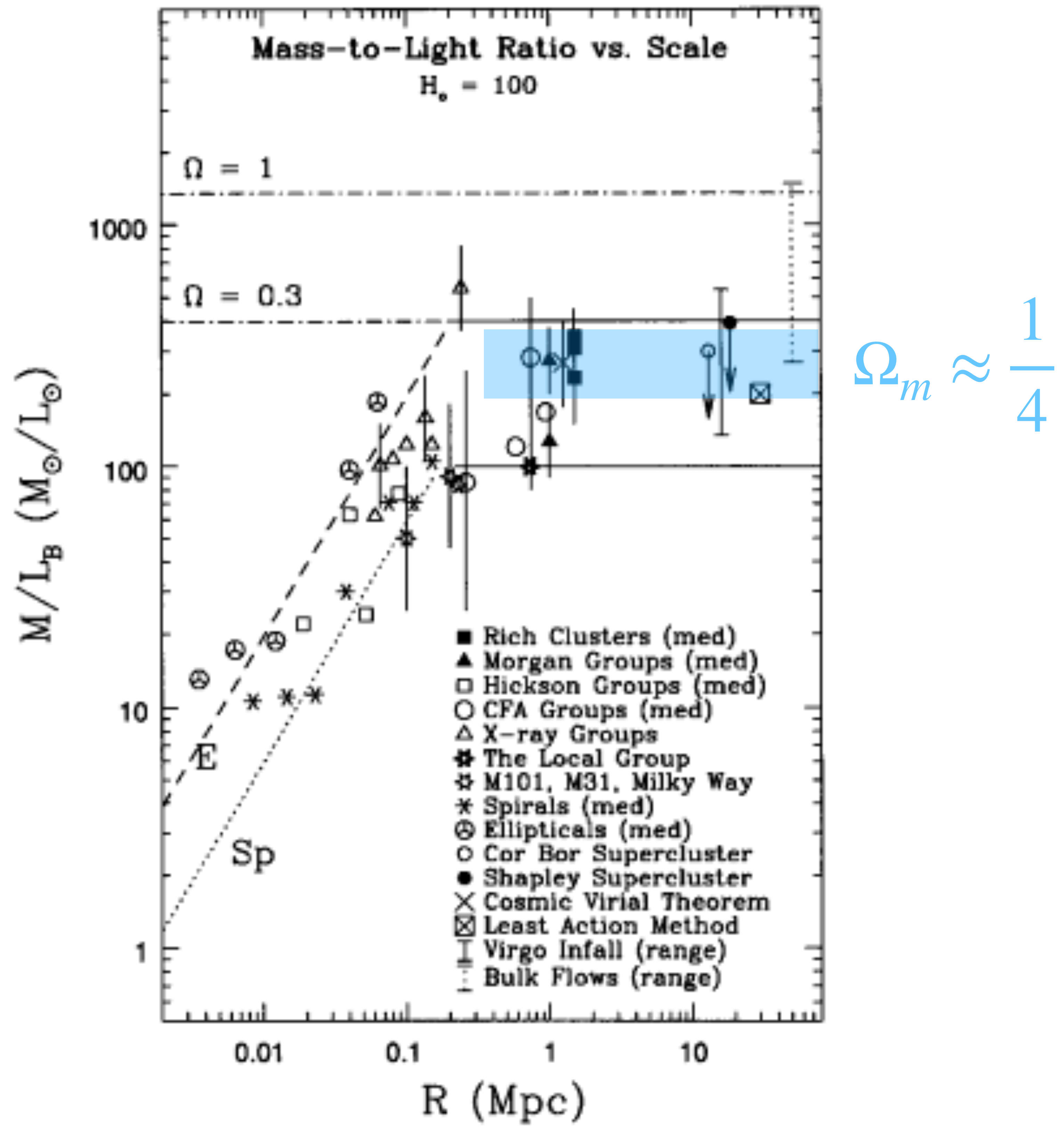

FIG. 2.—Composite mass-to-light ratio of different systems—galaxies, groups, clusters, and superclusters—as a function of scale. The best-fit $M/L_B \propto R$ lines for spirals and ellipticals (from Fig. 1) are shown. We present median values at different scales for the large samples of galaxies, groups and clusters, as well as specific values for some individual galaxies, X-ray groups, and superclusters. Typical 1 σ uncertainties and 1 σ scatter around median values are shown. Also presented, for comparison, are the M/L_B (or equivalently Ω) determinations from the cosmic virial theorem, the least action method, and the *range* of various reported results from the Virgocentric infall and large-scale bulk flows (assuming mass traces light). The M/L_B expected for $\Omega = 1$ and $\Omega = 0.3$ are indicated.

Bahcall, Lubin, & Dorman (1995)

– cluster baryon fractions

$$f_b = \frac{M_b}{M_{tot}} = \frac{\Omega_b}{\Omega_m}$$