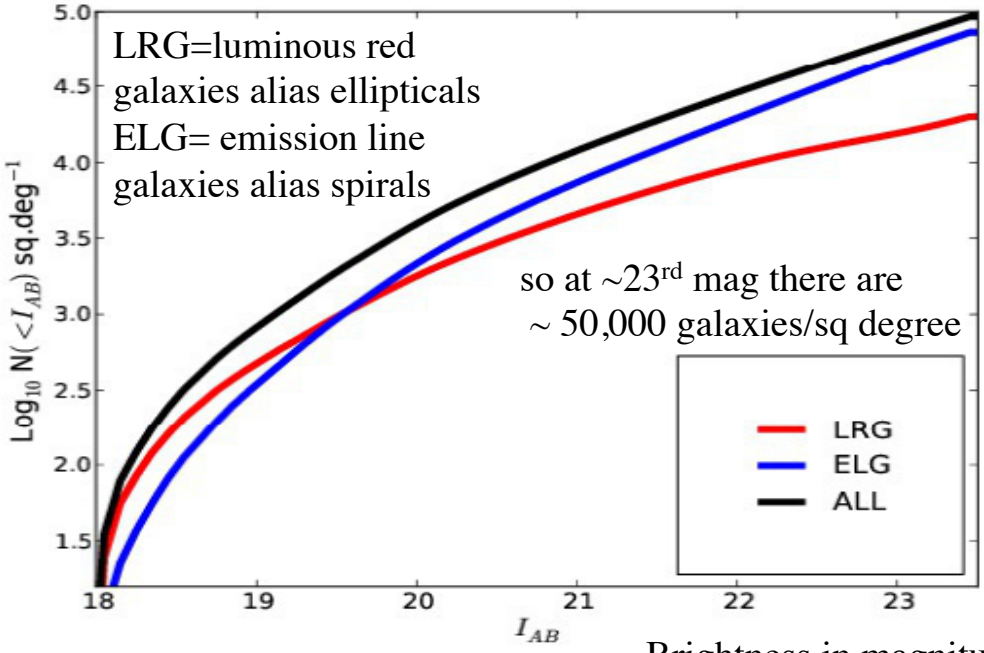
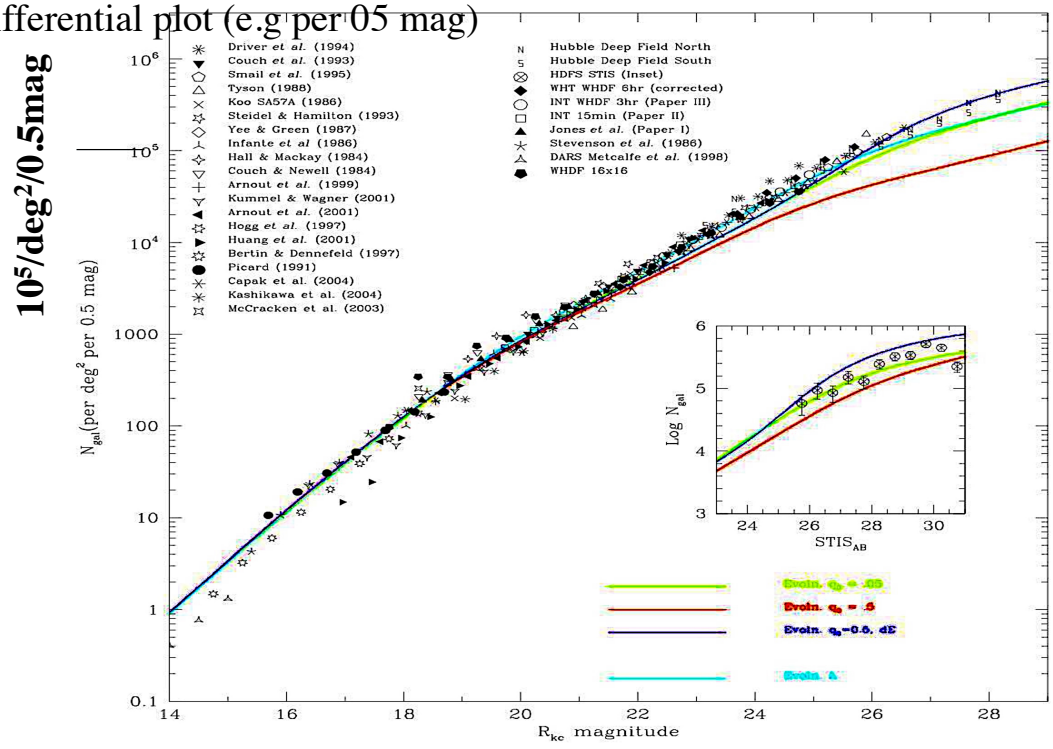
How Many Galaxies ?
Number of Galaxies of "Each" type

- LRG= red galaxies, ELG= **blue** galaxies- this is an *integral* plot



Brightness in magnitudes

Galaxy surface density vs. mag even fainter- a differential plot (e.g per 05 mag)

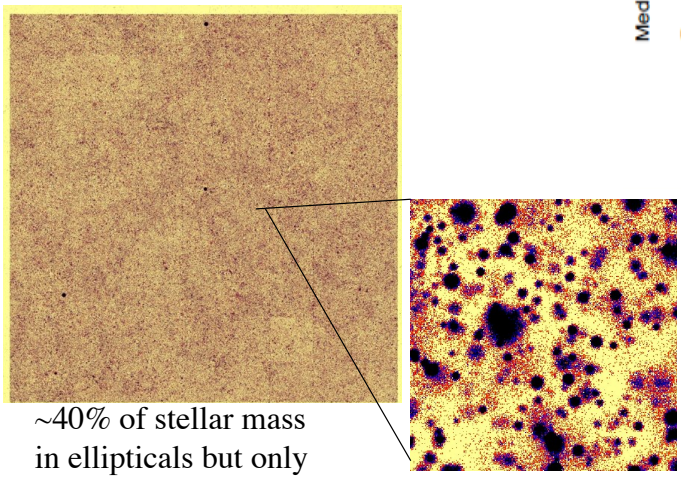


magnitudes

How Many Galaxies are There?

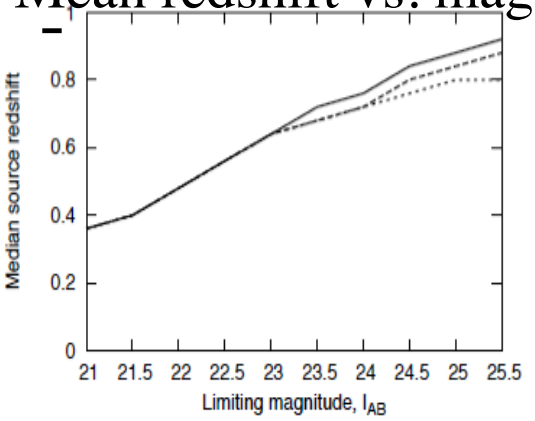
~50 galaxies/sq. arc min at m~25.5, rising slowly to ~175 at m~29 e.g $2x10^{10}$ all sky

The median redshift at a given magnitude increases slowly (https://www.nasa.gov/feature/goddard/2016/hubble-reveals-observable-universe-contains-10-times-more-galaxies-than-previously-thought)



~40% of stellar mass in ellipticals but only 5% by number

Mean redshift vs. mag



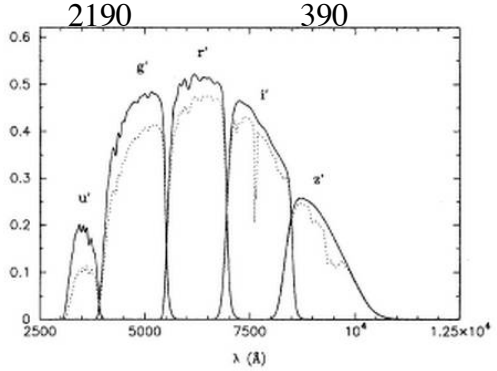
'small' m means **apparent magnitude,**
big M means **absolute magnitude**
'I_{AB}' refers to the color and mag system (more later)

Warning!!

- I assume you have read and understand S&G sec 1.1.5 "Stellar photometry: the magnitude system"
- We will be using magnitudes

A Bewildering Variety of Bands and Names

Name	wavelength nm	Δλ
U	365	66
B	445	94
G	482	140
V	551	99
R	658	138
I	806	149
z	900	140
Y	1020	120
J	1220	213
H	1630	307
K	2190	390



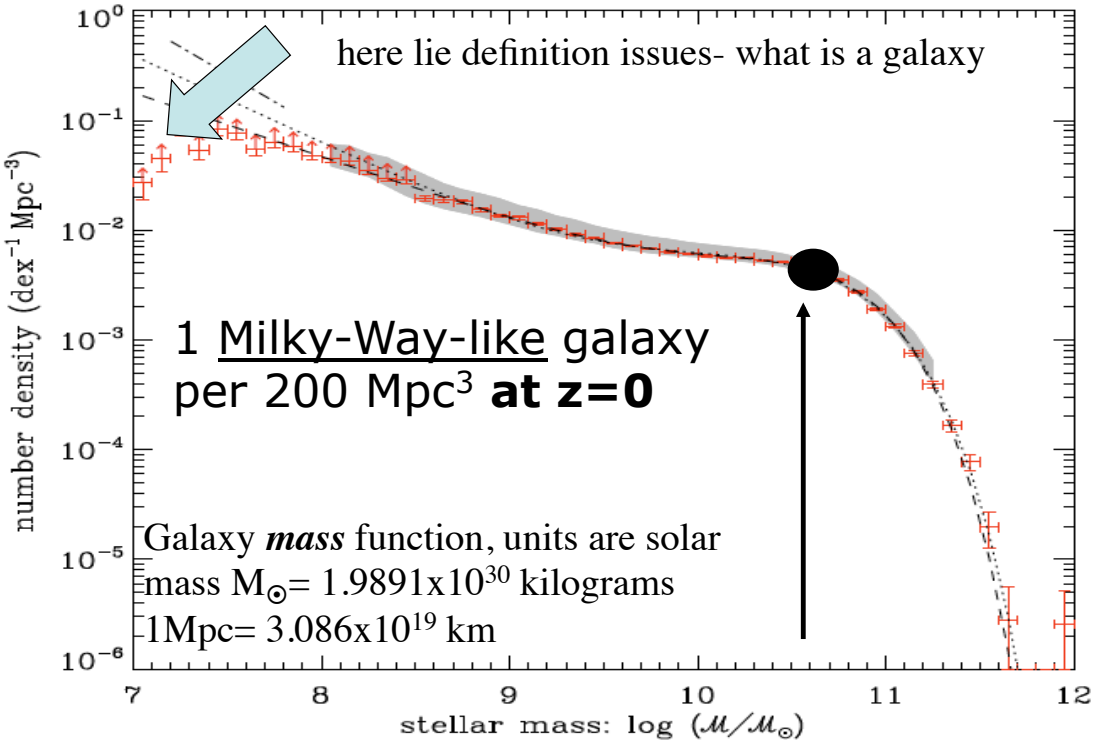
There are 2 different magnitude systems!

AB system (Oke & Gunn 1983), a object with a flat energy distribution (F_ν=constant) has the same mag in all colors; 3631 Jy=mag 0 (how bright Vega is in the V band!)
Absolue mag of sun in SDSS filter set u;g;r;i;z 6:80; 5:45; 4:76; 4:58; 4:51

The **Vega** system by definition, Vega's magnitudes are 0.0 in all filters.

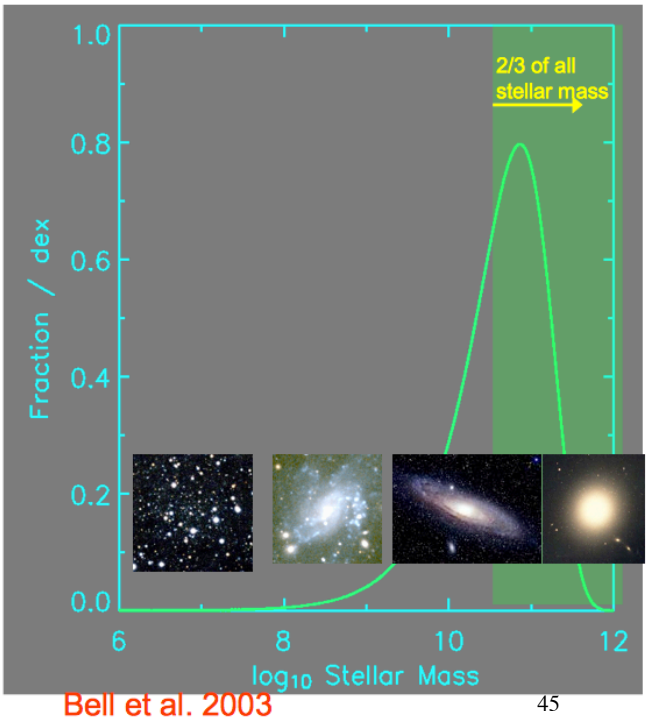
there are many other filter 'sets' each based on different needs
(e.g. the UBV data set was developed for use with photographic plates, the SDSS set for use with CCDs circa 1995 technology)

How Many Galaxies are There ?



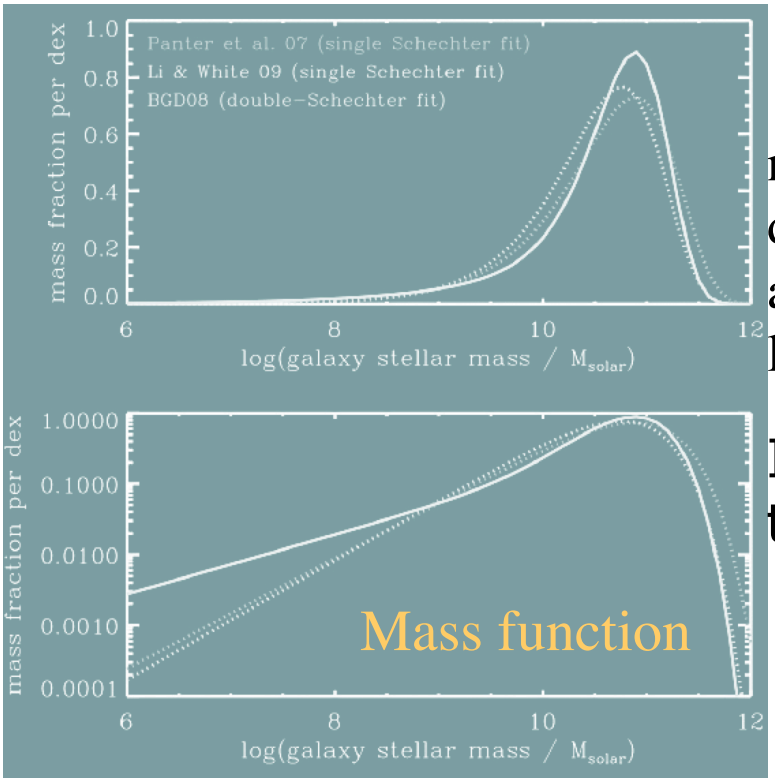
Galaxies Have a Wide Range in Mass

- There is a range of **~10^8** in galaxy masses- but most stars reside in galaxies in a narrow mass range ~6+/-3x$10^{10}M_\odot$ (in stars)- certain types of galaxies tend to live in certain mass ranges.
- The baryons are distributed in gas, stars and dust; wide range in gas/stars, relatively narrow range in dust/gas.



Bell et al. 2003

Where is the mass-



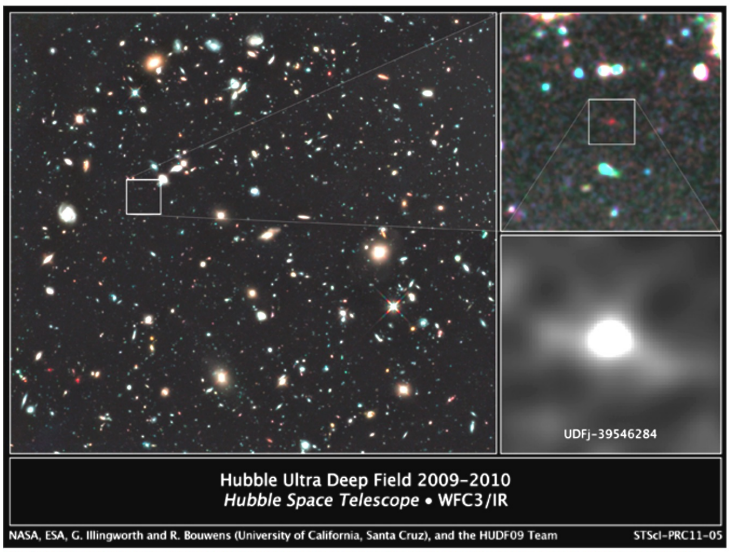
narrow distribution around $\log M_{star} \sim 10.5 M_\odot$

In mass MW is typical

How Old are Galaxies? http://www.astronomy.com/news/2018/01/nasa-images-the-most-distant-galaxy-ever-resolved

- HST imaging of galaxies at z~9 (13.17 Gyrs age, for an age of the universe of 13.72 Gyrs)
- Stellar ages: in MW oldest stars are ~13.2 Gyrs old (error of +/-2 Gyrs) (Physics Today, vol. 65, issue 4, p. 49)
- ***However galaxies have changed enormously over cosmic time***
- The present day pattern of galaxies emerged at z~1

(z is the redshift and for a given cosmology there is a straightforward relation between distance, age and z see http://www.astro.ucla.edu/~wright/sne_cosmology.html)



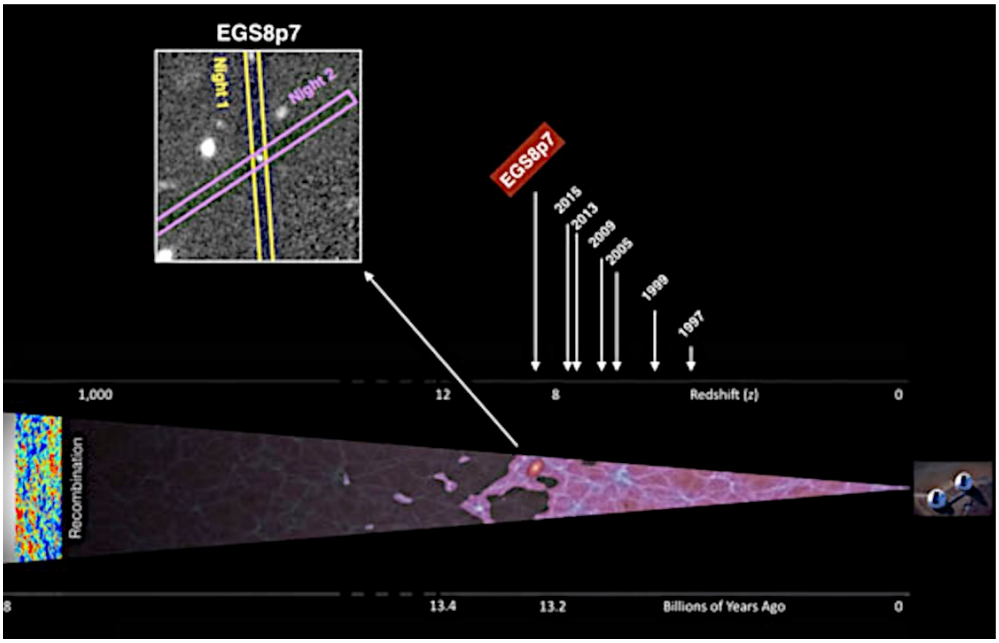
The farthest and one of the very earliest galaxies ever seen in the universe appears as a faint red blob in this ultra-deep-field exposure taken with NASA's Hubble Space Telescope. This is the deepest infrared image taken of the universe. Based on the object's color, astronomers believe it is 13.2 billion light-years away. (Credit: NASA, ESA, G. Illingworth (University of California, Santa Cruz), R. Bouwens (University of California, Santa Cruz, and Leiden University), and the HUDF09 Team)

http://www.astro.ucla.edu/~wright/CosmoCalc.html

In the Beginning

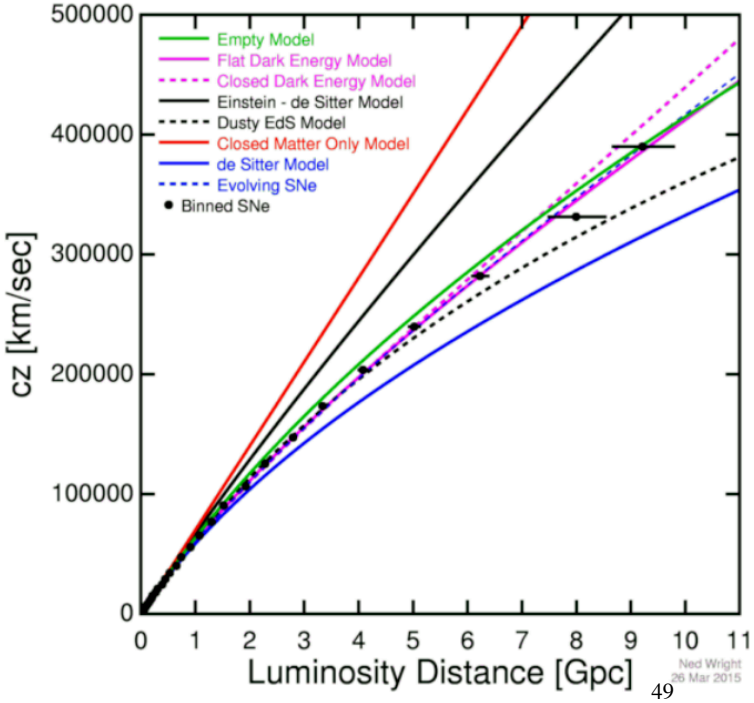
- Galaxy detected at a *redshift* of 8.68 http://scitechdaily.com/caltech-astronomers-detect-the-farthest-galaxy-to-date/

How do we know how old the galaxy is ??



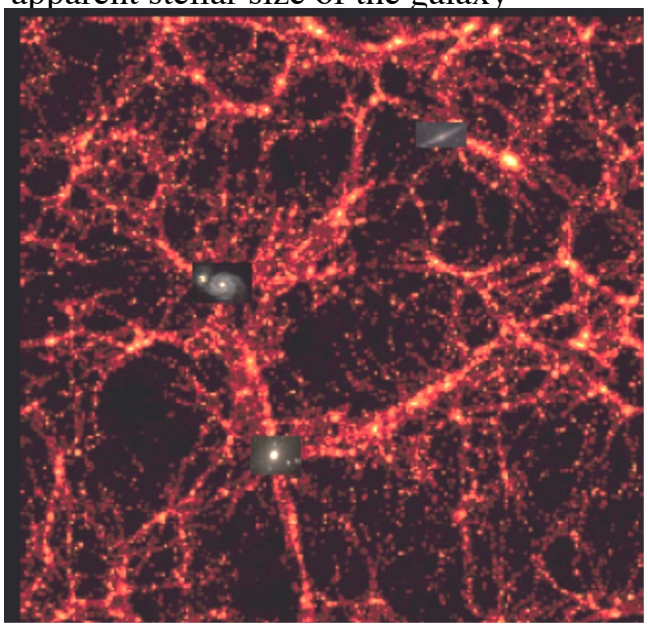
Distance Redshift Relation- Different cosmological parameters (N. Wright)

- Data points- Nobel prize....



Galaxies Do Not Live Alone

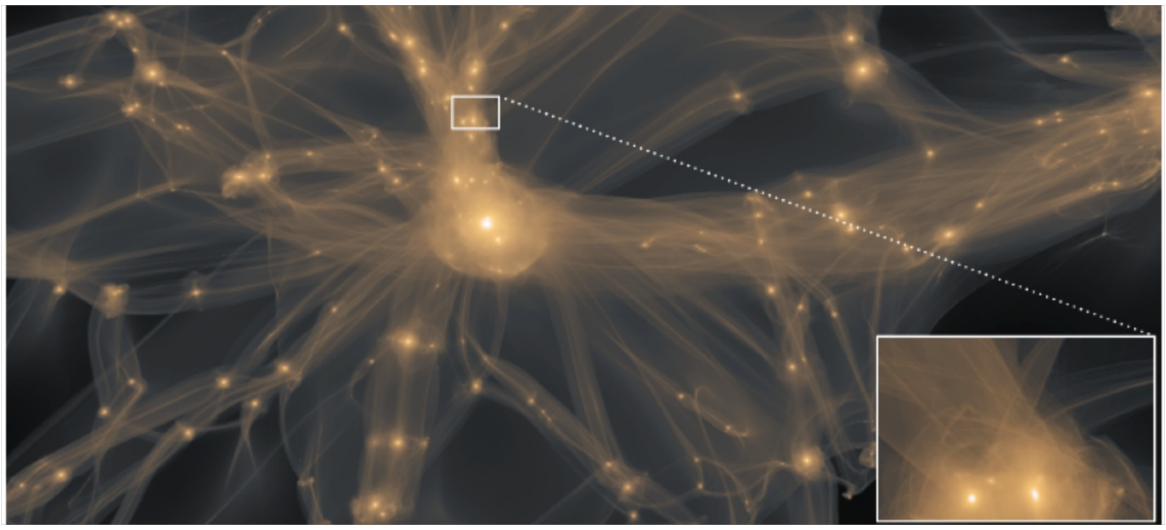
- Galaxies are part of the 'cosmic web'- representing over dense regions of baryons **and** dark matter
- The effective size of the **dark matter halo** is much larger than the apparent stellar size of the galaxy



The cosmic web has structure at all scales but eventually becomes homogenous at scales >70Mpc

Eric Bell

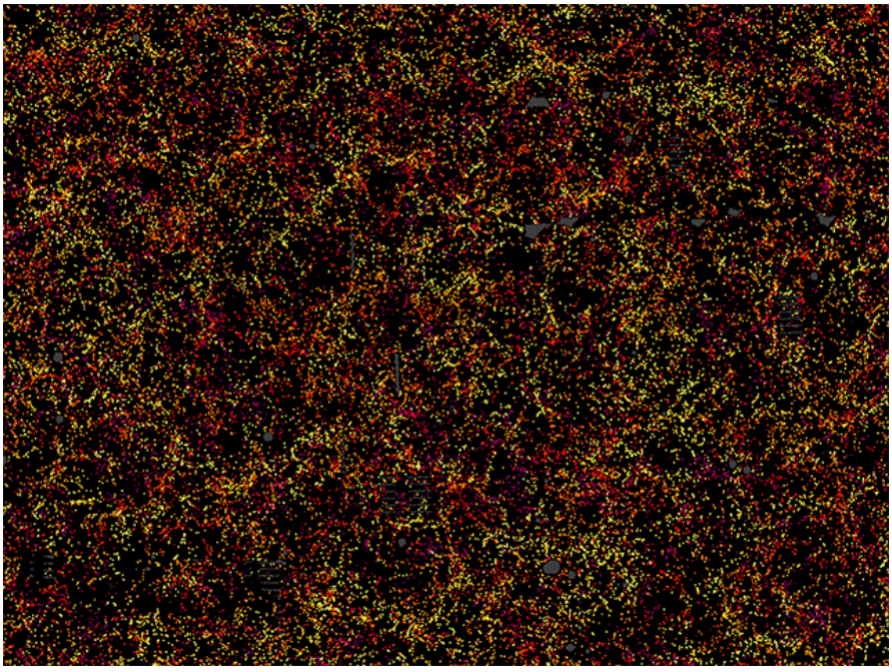
Cosmic Web- Numerical Simulation

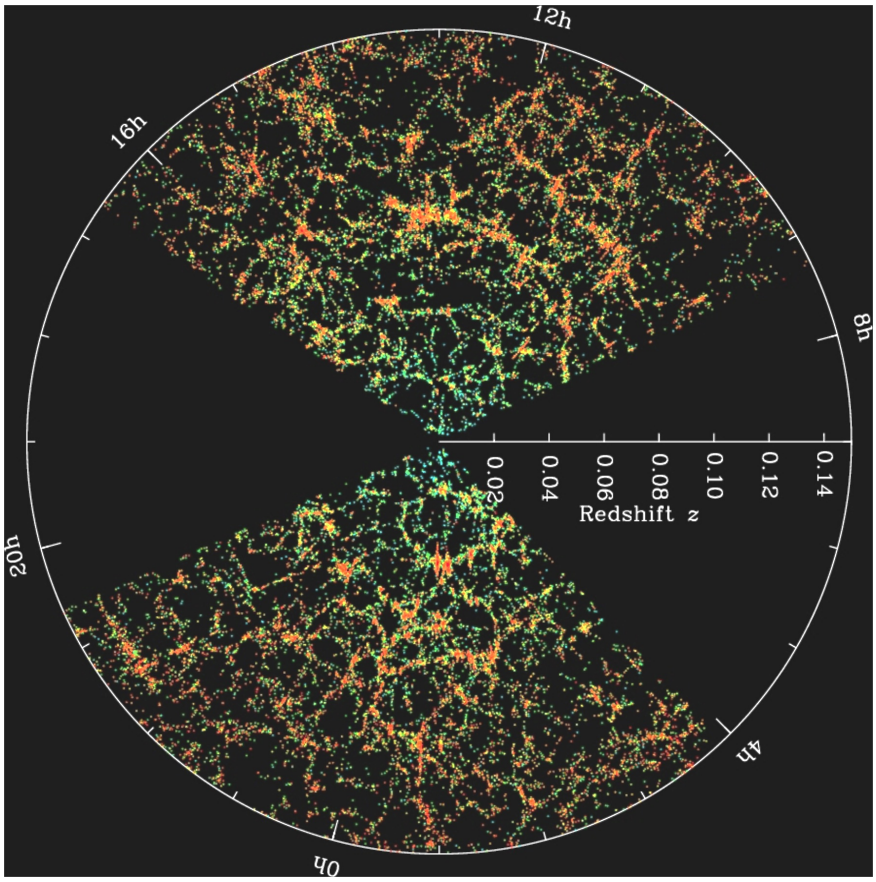


In this rendering the large scale sheets and filaments are more easily seen- galaxies tend to reside in these sheets and filaments and are rare in voids.

Latest SDSS ~2,000 sq degrees

color coded by distance yellow to purple



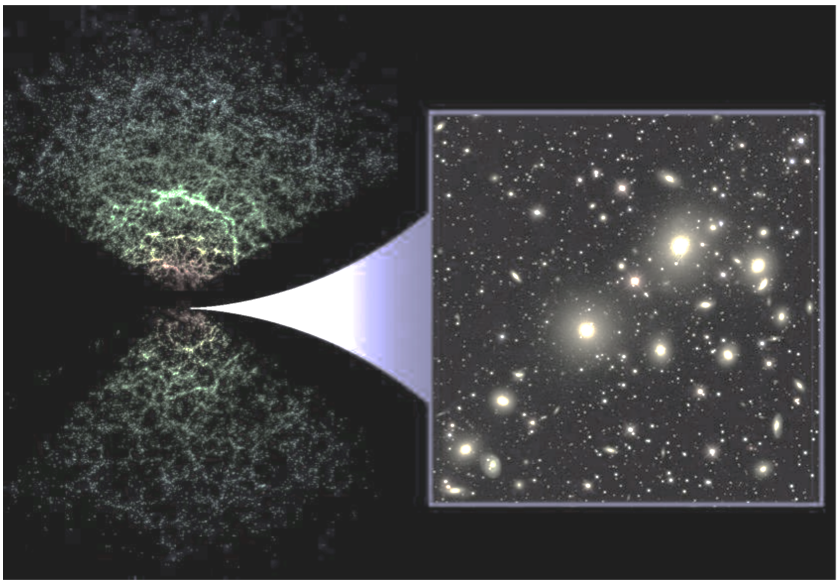


Sloan Digital Sky Survey

Galaxies color coded by the age of their stars
red= old
blue=young
http://www.sdss.org

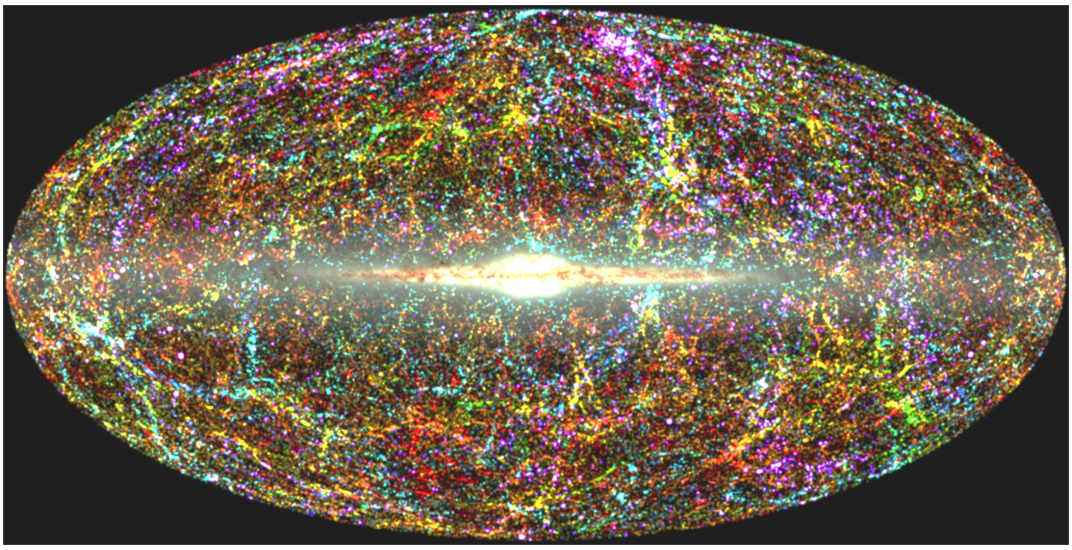
Large Scale distribution of galaxies

- On scales $<10^8$pc the universe is 'lumpy'- e.g. non-homogenous
- On larger scales it is more homogenous- and isotropic

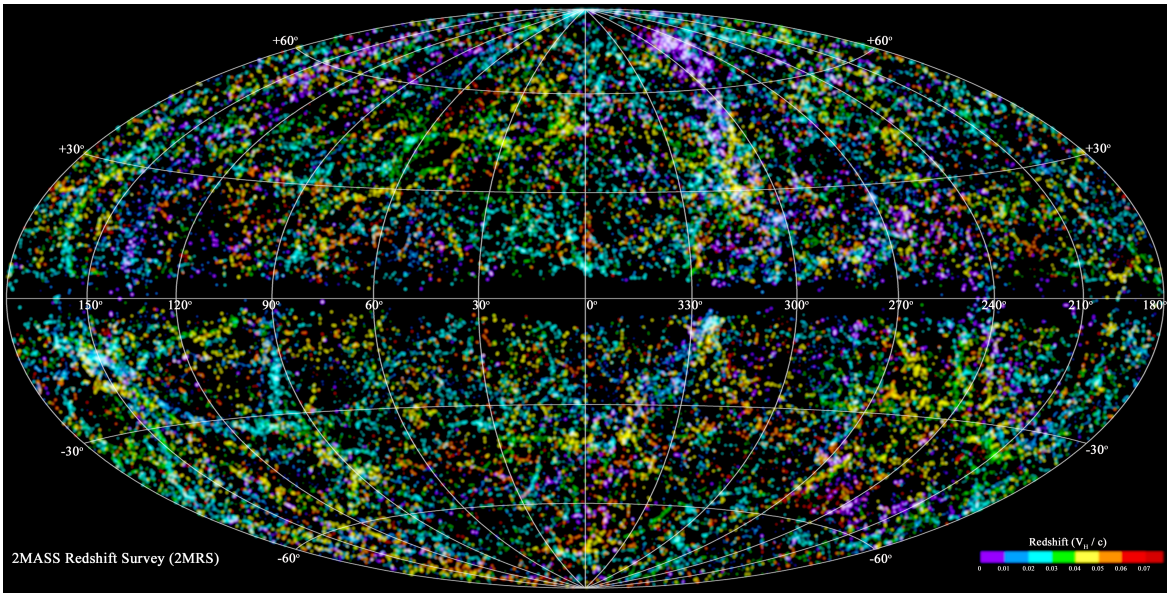


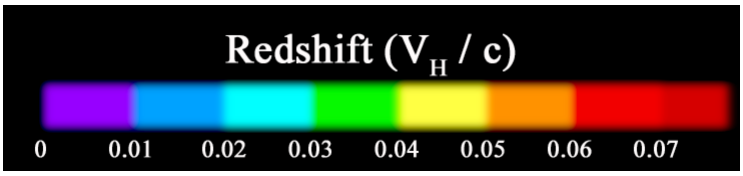
Sloan Digital Sky Survey- http://skyserver.sdss3.org/dr8/en/

2MASS view of galaxies selected by infrared flux notice filamentary structure



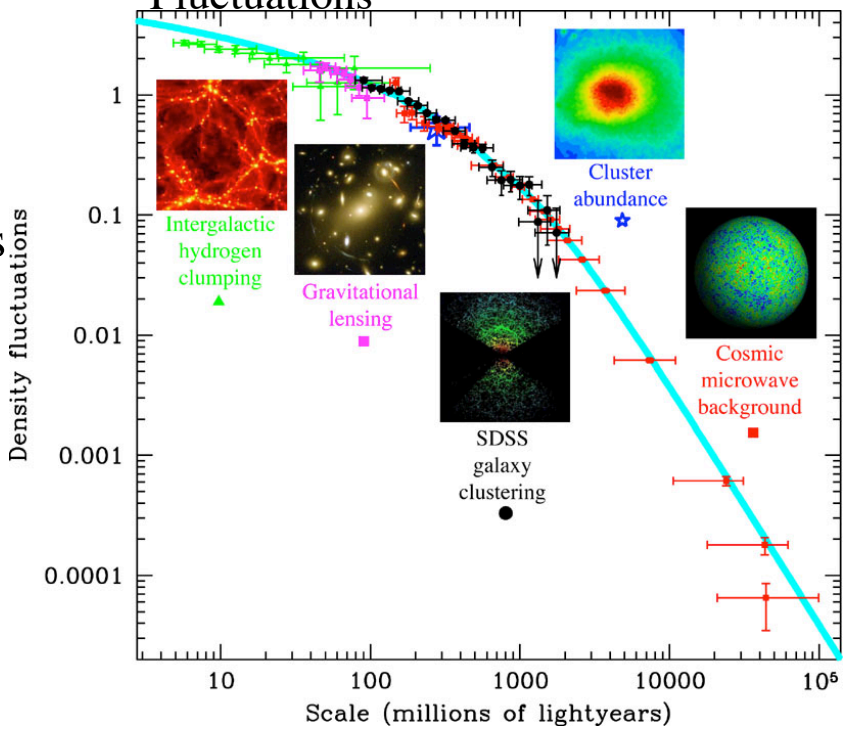
Blue: near; red: far
Credit: T. Jarrett, IPAC





How 'Lumpy' is the Universe-Power Spectrum of Fluctuations

- As one goes to larger scales the universe gets less lumpy (on average)



Tegmark 2004

size of box

Dark Matter Dominates Gravity

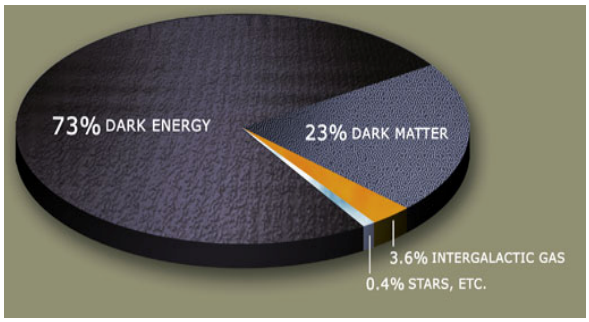
The cosmic ratio of dark matter to baryons is 6:1

$\Omega_{baryons}/\Omega_{dark\ matter}$ =0.167

$\Omega_{baryons}$ = 0.042 ± 0.003

$\Omega_{dark\ matter}$ = 0.28

$\Omega_{baryons/stars}$ = 0.0011

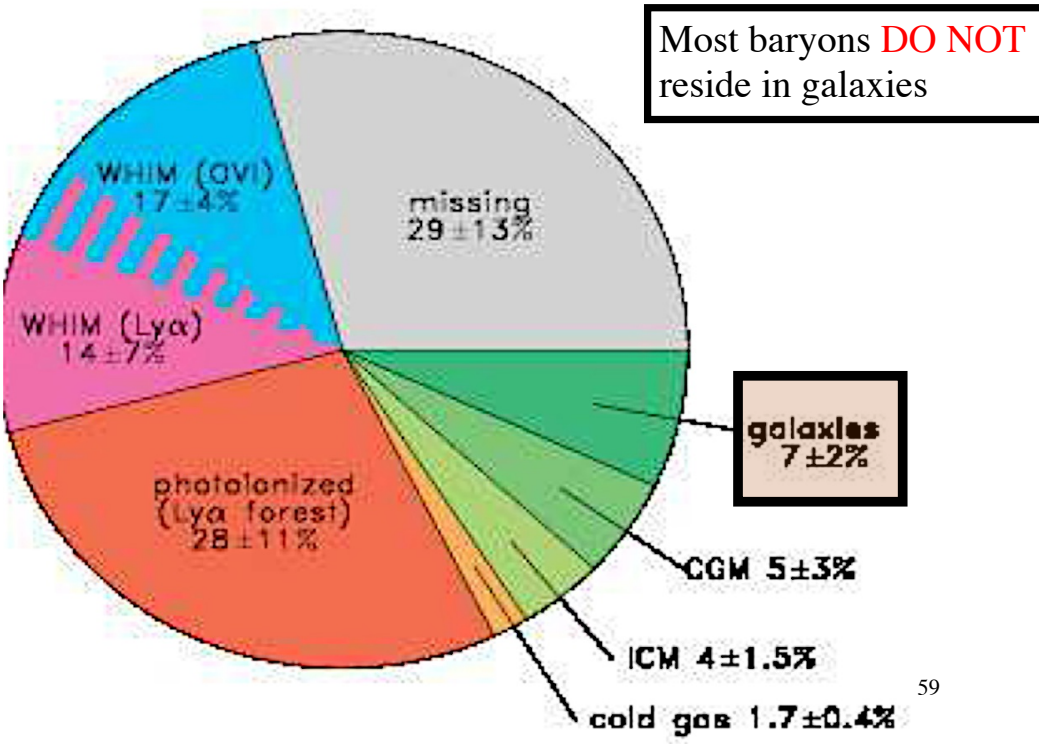


Ω_{stuff} is the ratio of the mass of the component to the closure density

Notice how little of the universe's baryonic matter is in stars !

Where are the Baryons

Shull Danforth 2012



Next Time

- You are reading ch 1 of Sparke and Gallagher sec's 1.1,1.2 and 1.3; not necessary to read 1.4 and 1.5
  - 1.1 The stars
  - 1.2 Our Milky Way
  - 1.3 Other galaxies

    1.4 Galaxies in the expanding Universe

    1.5 The pregalactic era: a brief history of matter
- Lecture will be a continuation of general galaxy properties

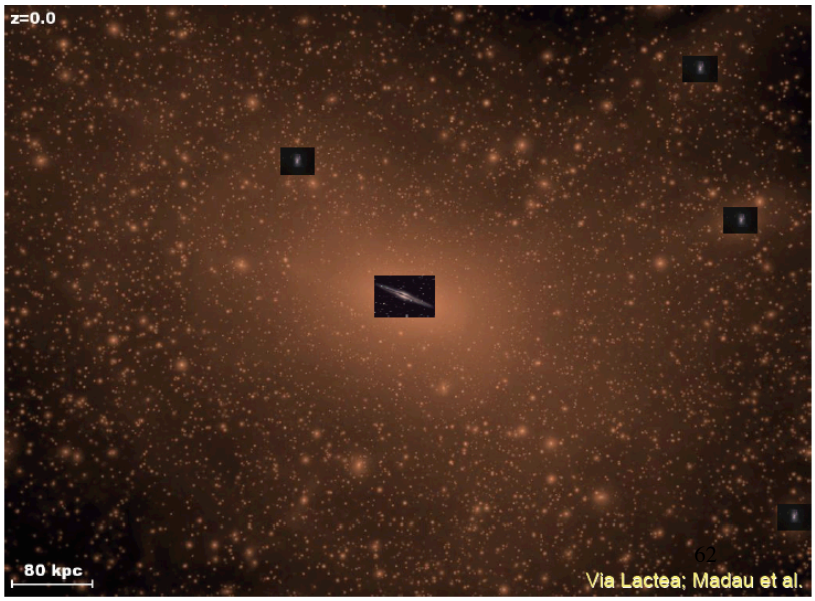
Dark Matter

- Dark matter provides a "skeleton" on which galaxies reside and grow
- There is a very complex relation between how the dark matter and baryons (gas and stars) are related and distributed on a wide variety of scales
  - baryons are more concentrated than dark matter
  - **light** does not trace mass well
- Dark matter can only interact via gravity while baryons can interact with photons, shocks, cosmic rays, be heated and cooled.
- http://astro.berkeley.edu/~mwhite/darkmatter/essay.html for a nice essay on dark matter

Dark Matter Distribution and Galaxies

- A numerical simulation of the formation of structure (Madau et al 2008) shows the scale of dark matter and the baryons

Dark matter is the 'beige' material

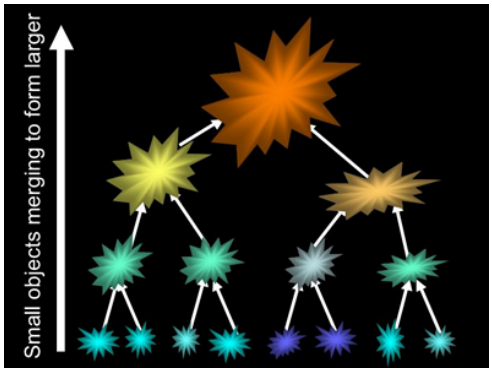


Deep Breath... What Did we cover?

- Big picture of galaxy research
  - brief history
- What are galaxies
  - 2 generic classes
- How Many Galaxies are There
- How "Old" are Galaxies
- Galaxies do not live alone- large scale structure
- Baryons, dark matter and how they are sampled by galaxies -complex relation between how the dark matter and baryons (gas and stars) are related and distributed on a wide variety of scales

How Things Form

- Gravity acts on over densities in the early universe making them collapse.
- As time goes on these collapsed regions grow and merge with others to make bigger things



•Hierarchical clustering (or hierarchical merging) is the process by which larger structures are formed through the continuous merging of smaller structures.

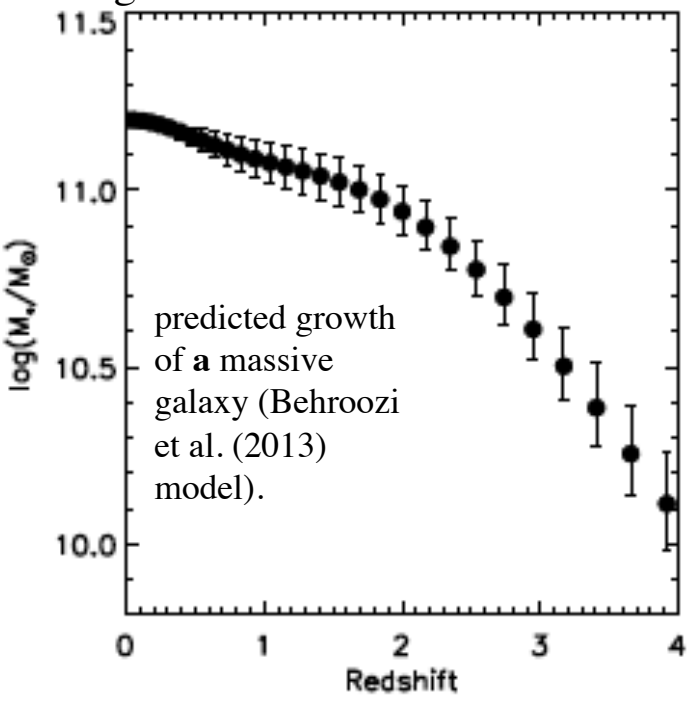
•The structures we see in the Universe today (galaxies, clusters, filaments, sheets and voids) are predicted to have formed by the combination **of collapse and mergers** according to Cold Dark Matter cosmology (the current concordance model).

Galaxy growth and changes over cosmic time

However the *nature* of a given galaxy can change strongly over cosmic time

mass may increase, morphology can change

Galaxies are NOT stationary objects

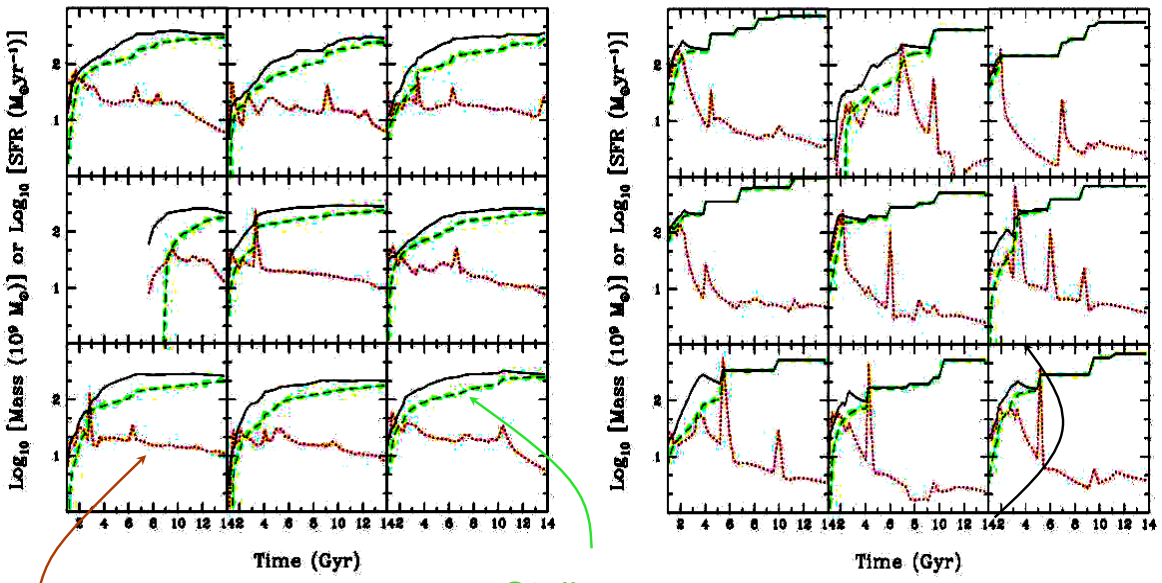


Growth in mass of a elliptical galaxy over cosmic time

A set of results from numerical simulations

spirals

ellipticals



SFR

Stellar mass

Gas+stars

notice SFR not constant

mass growth has 'jumps' - mergers J. Blaizot-