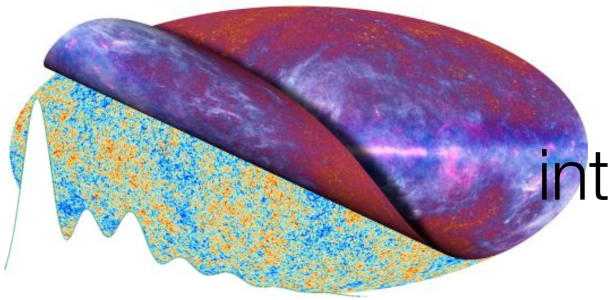

introduction to the structured universe

why is the night sky dark ? 1.
why galaxy formation is a problem ? 2.
how to adress these problems ? 3.
overview of observation facts 4.
overview of structure and galaxy formation 5.
introduction to statistical tools: towards the power spectrum 6.

Hervé Dole

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http://www.ias.u-psud.fr/dole/m2.php

1. why is the night sky dark ?

exercice 1

2. why galaxy formation is a(n interesting) problem ?

exercices 3 and 4

3. how to adress these problems ?

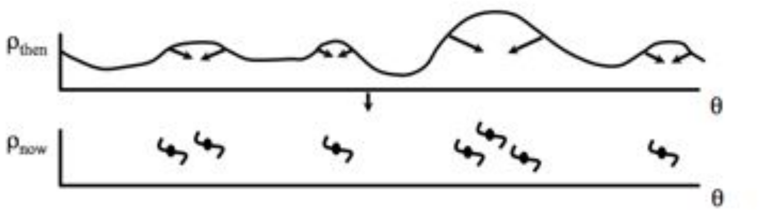
- 3.1 theory (lectures 5, 6, 7)
  - how the sctructures can grow in an expanding Universe ?
  - example
- 3.2 comparisons data vs models
  - example: CMB
  - example: statistical tools
- observations

3.1 need for theory

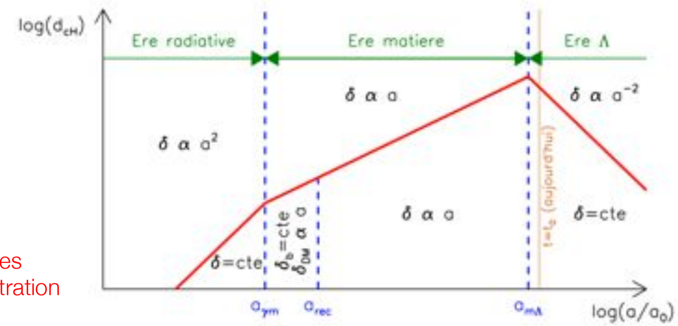
Today, matter is assembled into structures: filaments, clusters, galaxies, stars, etc.

Galaxy formation is not completely understood.

Main mechanism is gravitational instability:



growth of perturbations

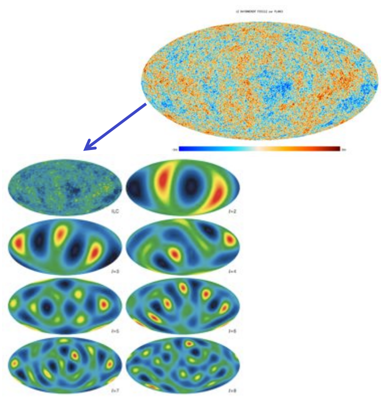


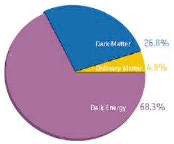
-> see Michael's lectures for the demonstration

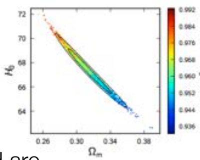
Figure I.2 – *Résumé des lois d'évolution de la surdensité δ pour les modes sous-horizons (en dessous de la courbe rouge) et les modes super-horizons (au-dessus de la courbe rouge). On distingue également trois phases dans l'évolution de l'Univers (voir section 1.1.4) : une première dominée par le rayonnement, une seconde par la matière et la phase actuelle dominée par une constante cosmologique. La courbe rouge représente l'évolution de la taille comobile de l'horizon.*

From N. Bavouzet's PhD Thesis, http://tel.archives-ouvertes.fr/tel-00363975 ; from M. Langer & H. Dole NPAC lectures, c2008

3.2 from maps to cosmological parameters



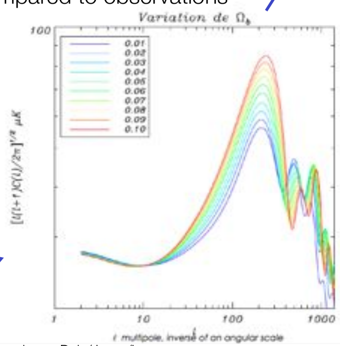




theory allow predictions and are compared to observations

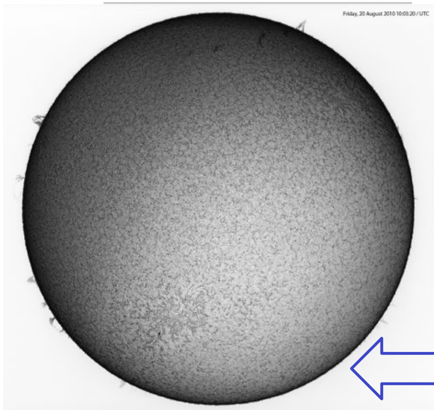
$$\frac{\Delta T(\mathbf{n})}{T_0} = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell m}^T Y_{\ell m}(\mathbf{n})$$

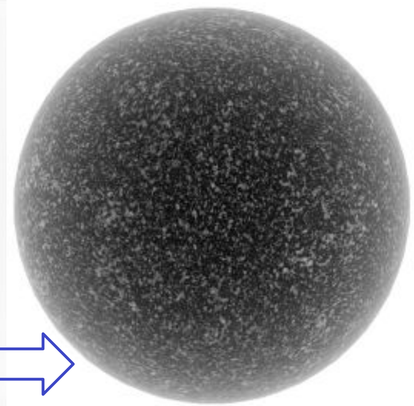
$$C_\ell^{TT} = \langle a_{\ell m}^T \cdot a_{\ell m}^{T\star} \rangle$$



3.2 between last scattering surfaces

F. Noel – AAV 2010





Planck - thecmb.org

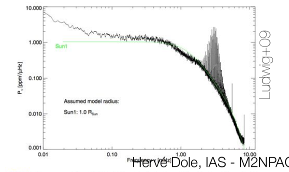
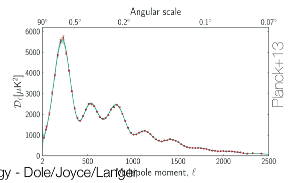


Fig. 2. Power spectra of disk-integrated photometric fluctuations for the

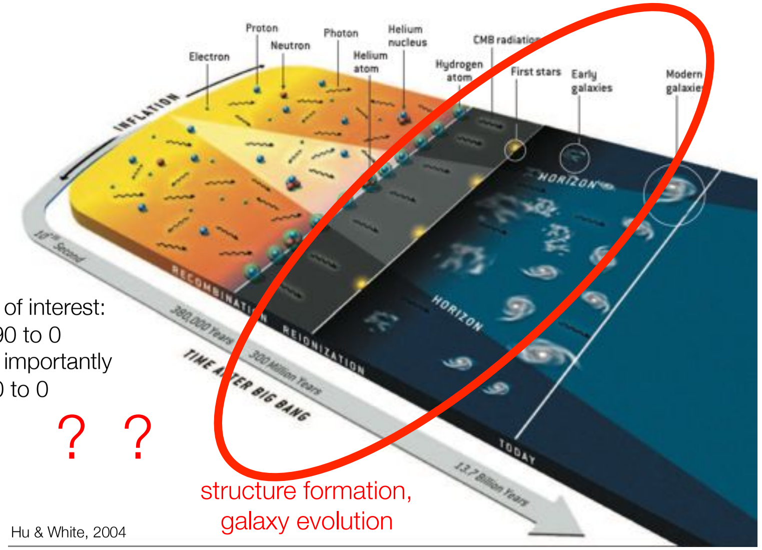
Ludwig+09

need for statistical tools



Planck+13

3.3 history of the universe



redshifts of interest:
1090 to 0
but more importantly
10 to 0

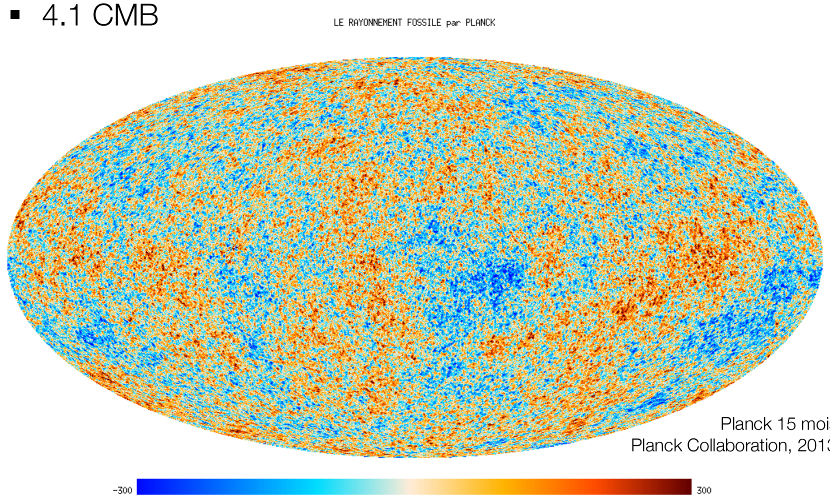
? ?

structure formation,
galaxy evolution

Hu & White, 2004

4. overview of observation facts

- 4.1 CMB



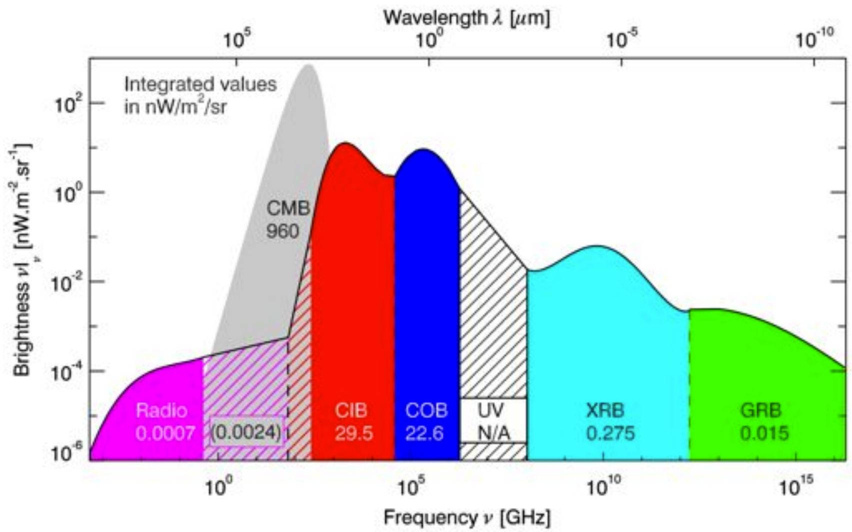
Planck 15 mois
Planck Collaboration, 2013

4.2 extragalactic background light

EBL (Extragalactic Background Light) tells us about the processes involved in galaxy formation & evolution (budget for radiation emission by nucleosynthesis & gravitation, presence of dust, …). All fundamental forces are at play.

CIB (Cosmic Infrared Background) level and structure depend on history of energy production in the post-recombination Universe [Kashlinsky, 2005]

cosmological backgrounds



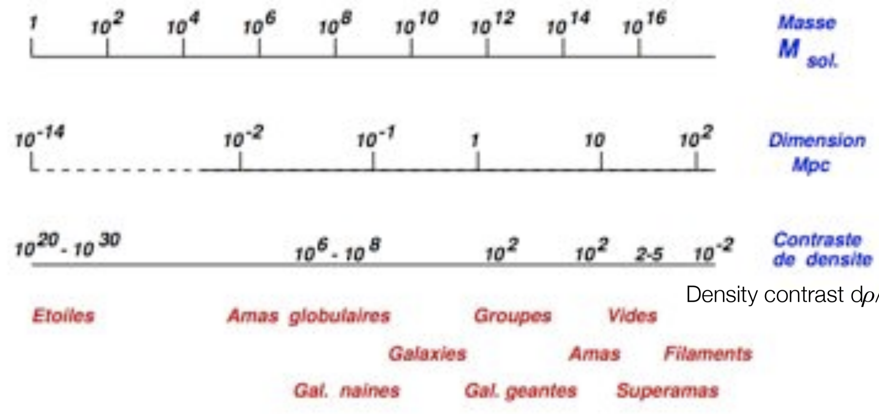
Dole et al., 2006 ; Dole 2010 HDR
Dole & Béthermin in prep

4.3 overview of observation facts

- spectrum of the CMB
- large scale isotropy of the CMB temperature
- small anisotropies of the CMB temperature and polarization
- large-scale distribution of galaxies
  - correlations (e.g. BAO), redshifts, flux distribution etc..
- galaxy clusters
- SN
- lensing on various tracors (CMB, clusters, galaxies)
- quasars and absorption lines
- ...

scales of mass, dimension, d contrast

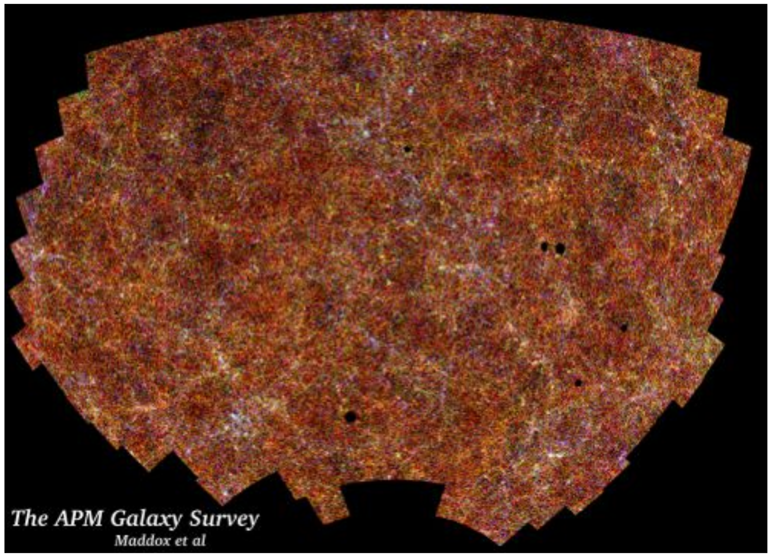
Mass in Solar masses



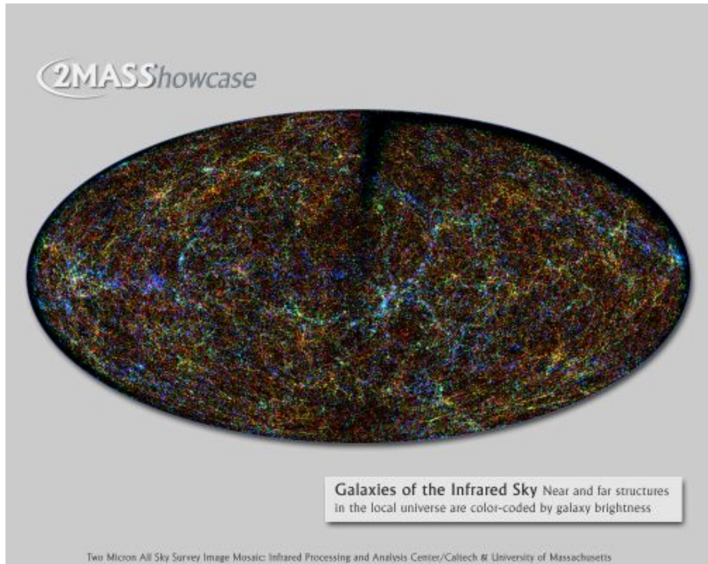
Density contrast $d\rho/\rho$

Yannick Mellier, IAP, 2002

photometric survey APM, 1990

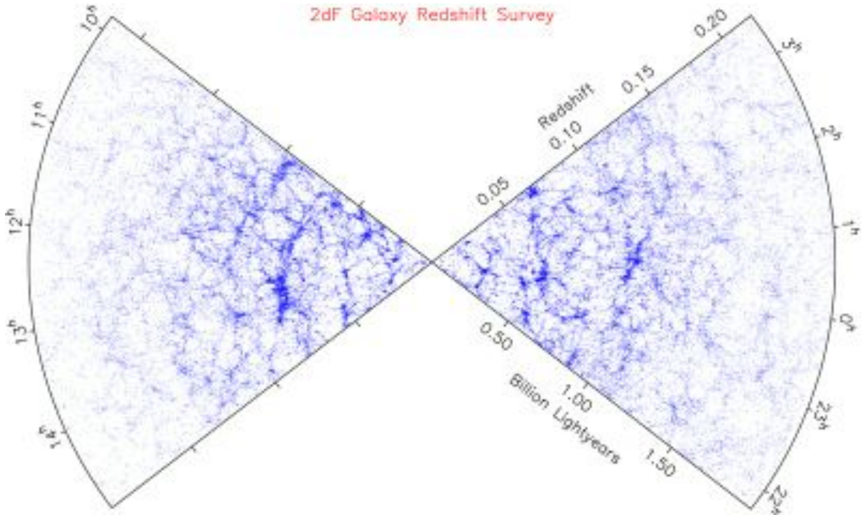


photometric near-infrared survey: 2MASS



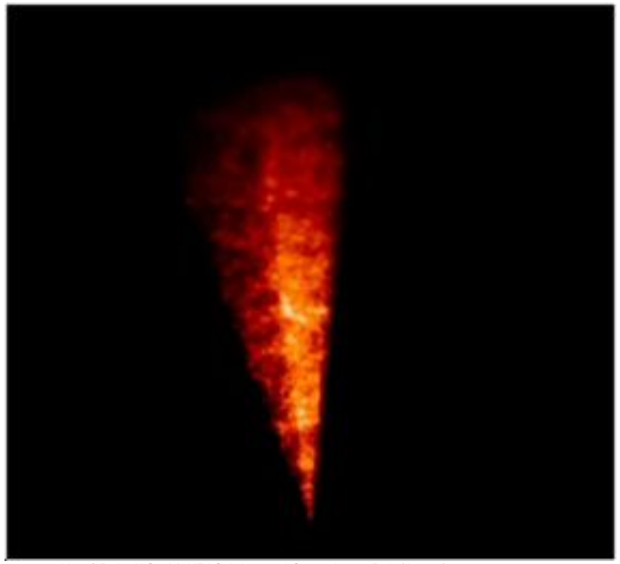
2MASS + redshifts: structures

spectroscopic surveys



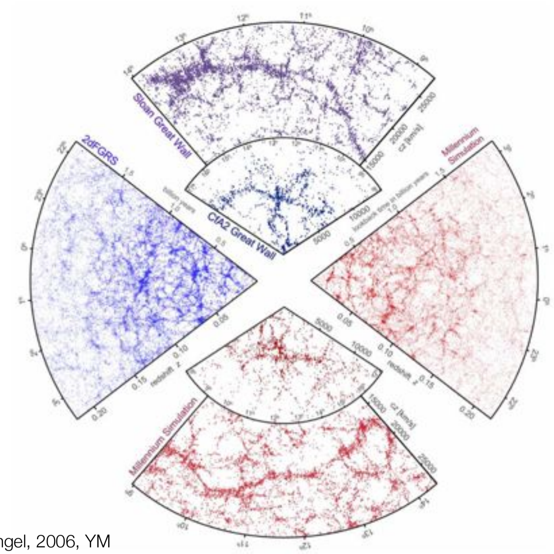
Peacock, 2002

spectroscopic surveys



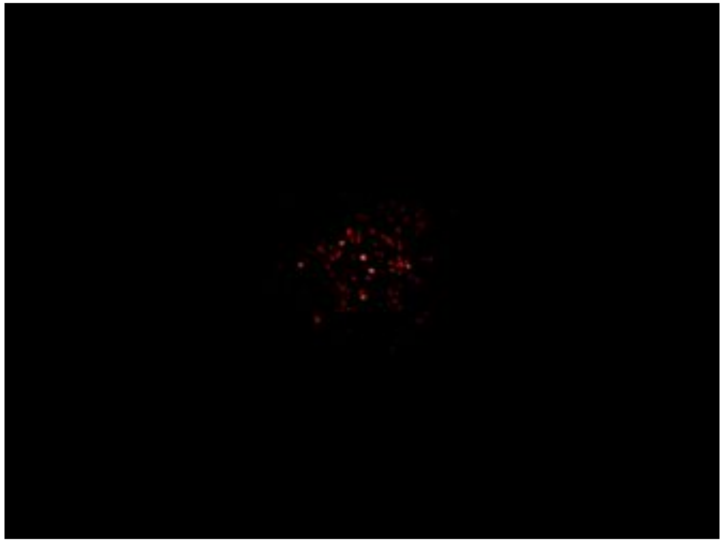
Peacock, 2002

spectroscopic surveys



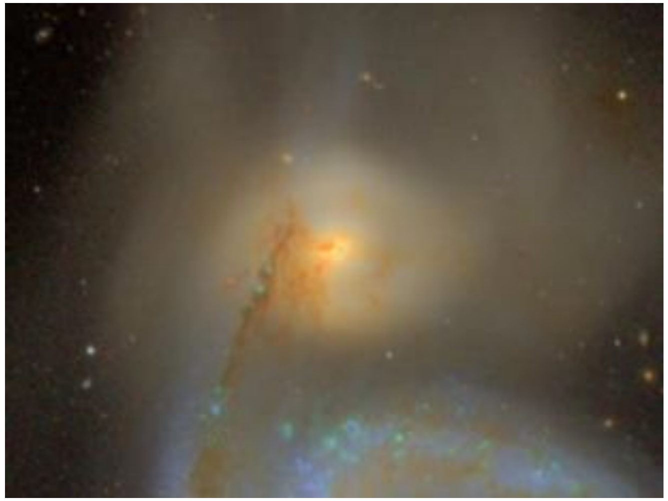
adapted from Springel, 2006, YM

spectroscopic survey VVDS



scales probed by SDSS

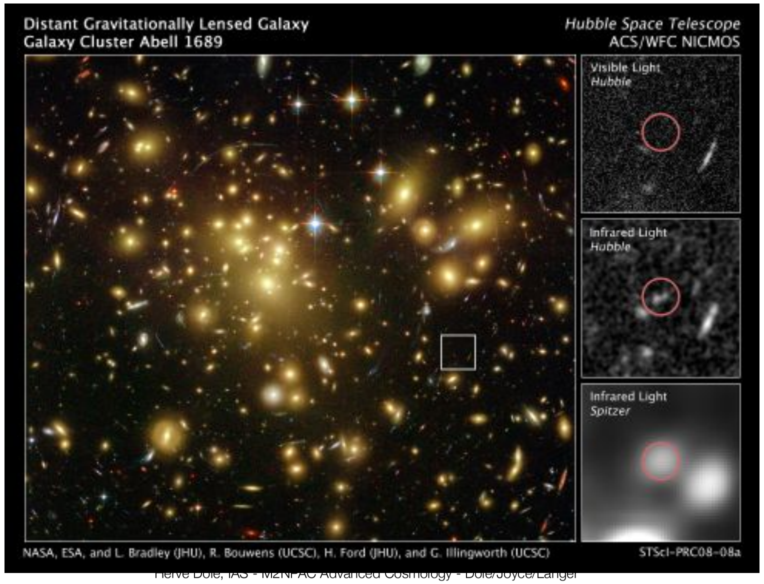
SDSS:
-8000 Sq. Deg.
-215e6 objets
-1e6 spectres
-15Tb de données en ligne



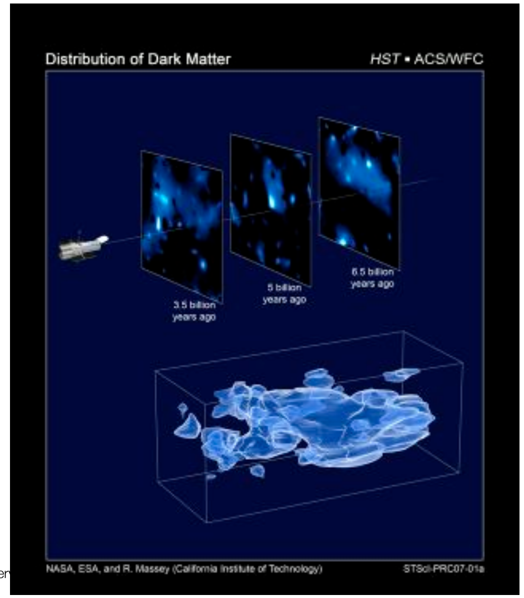
http://www.sdss.org/dr8

SDSS, D. Hogg

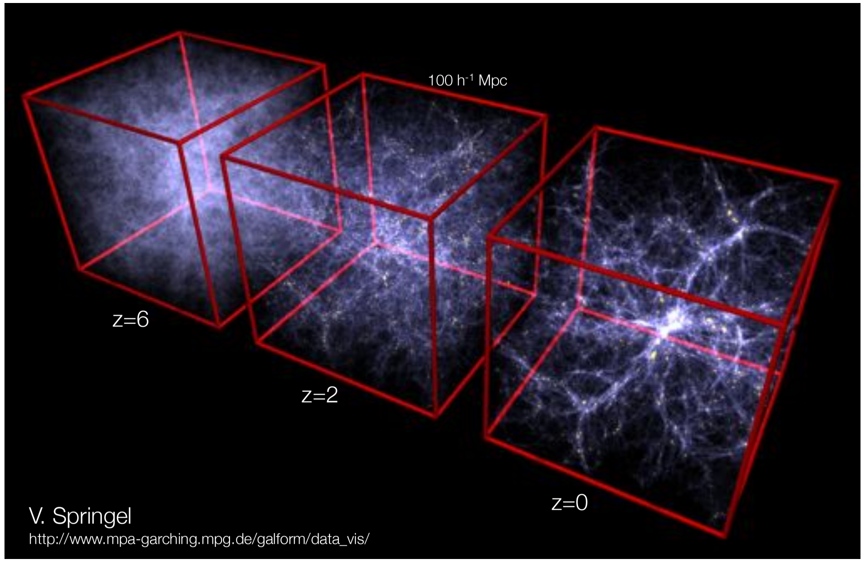
strong & weak lensing



weak lensing -> DM distribution



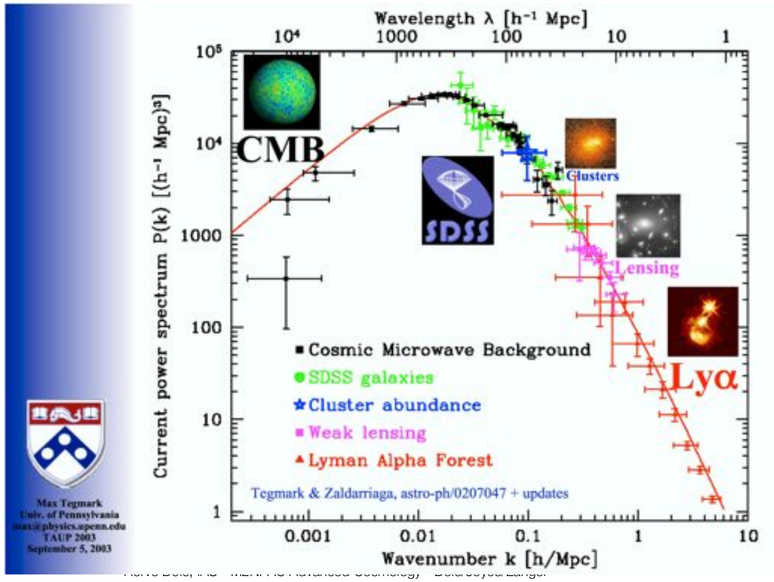
simulations



simulations

V. Springel - Code: Hydra
http://www.mpa-garching.mpg.de/galform/data_vis/

matter power spectrum P(k)



other facts and tracors

- ellipticals vs disk galaxies: physics of cooling
- Galaxy clusters
- high-z galaxies
  - infrared & submillimeter
  - Lyman-a related sources
    - forest
    - emitters
    - break
    - ERO, LRGs
- gamma ray bursts
- supernovae
- background emissions
- Baryonic Acoustic Oscillations
- other statistical properties of galaxies
  - luminosity function, number counts, colors, n(z)

5. overview of structure and galaxy formation

structure and galaxy formation

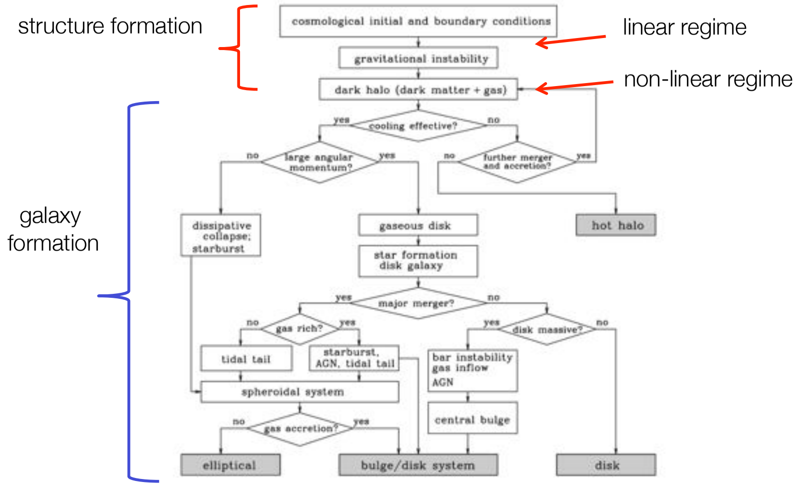


Fig. 1.1. A logic flow chart for galaxy formation. In the standard scenario, the initial and boundary conditions for galaxy formation are set by the cosmological framework. The paths leading to the formation of various galaxies are shown along with the relevant physical processes. Note, however, that processes do not separate as neatly as this figure suggests. For example, cold gas may not have the time to settle into a gaseous disk before a major merger takes place.

Mo, van den Bosch, White fig 1.1

some timescales

- **Hubble time:** This is an estimate of the time scale on which the Universe as a whole evolves. It is defined as the inverse of the Hubble constant (see §3.2), which specifies the current cosmic expansion rate. It would be equal to the time since the Big Bang if the Universe had always expanded at its current rate. Roughly speaking, this is the time scale on which substantial evolution of the galaxy population is expected.
- **Dynamical time:** This is the time required to orbit across an equilibrium dynamical system. For a system with mass M and radius R, we define it as $t_{\rm dyn} = \sqrt{3\pi/16G\bar{\rho}}$, where $\bar{\rho} = 3M/4\pi R^3$. This is related to the free-fall time, defined as the time required for a uniform, pressure-free sphere to collapse to a point, as $t_{\rm ff} = t_{\rm dyn}/\sqrt{2}$.
- **Cooling time:** This time scale is the ratio between the thermal energy content and the energy loss rate (through radiative or conductive cooling) for a gas component.
- **Star-formation time:** This time scale is the ratio of the cold gas content of a galaxy to its star-formation rate. It is thus an indication of how long it would take for the galaxy to run out of gas if the fuel for star formation is not replenished.
- **Chemical enrichment time:** This is a measure for the time scale on which the gas is enriched in heavy elements. This enrichment time is generally different for different elements, depending on the lifetimes of the stars responsible for the bulk of the production of each element (see §10.1).
- **Merging time:** This is the typical time that a halo or galaxy must wait before experiencing a merger with an object of similar mass, and is directly related to the major merger frequency.

Mo, van den Bosch, White sect 1.3

some timescales

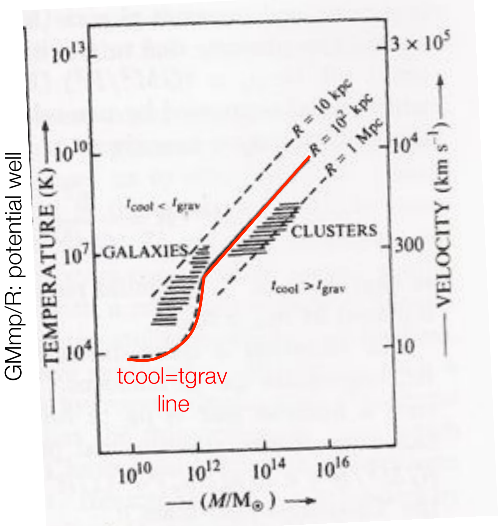
- Processes whose time scale is longer than the Hubble time can usually be ignored. For example, satellite galaxies with mass less than a few percent of their parent halo normally have dynamical friction times exceeding the Hubble time (see §12.3). Consequently, their orbits do not decay significantly. This explains why clusters of galaxies have so many 'satellite' galaxies – the main halos are so much more massive than a typical galaxy that dynamical friction is ineffective.
- If the cooling time is longer than the dynamical time, hot gas will typically be in hydrostatic equilibrium. In the opposite case, however, the gas cools rapidly, losing pressure support, and collapsing to the halo center on a free-fall time without establishing any hydrostatic equilibrium.
- If the star formation time is comparable to the dynamical time, gas will turn into stars during its initial collapse, a situation which may lead to the formation of something resembling an elliptical galaxy. On the other hand, if the star formation time is much longer than the cooling and dynamical times, the gas will settle into a centrifugally supported disk before forming stars, thus producing a disk galaxy (see §1.4.5).
- If the relevant chemical evolution time is longer than the star-formation time, little metal enrichment will occur during star formation and all stars will end up with the same, initial metallicity. In the opposite case, the star-forming gas is continuously enriched, so that stars formed at different times will have different metallicities and abundance patterns (see §10.4).

Mo, van den Bosch, White sect 1.3

mass-radius relationship

mass-radius relationship

GMmp/R: potential well



tcool = cooling time

tgrav = timescale for gravitational collapse

Padmanabhan, 1993, fig1.1

hierarchical formation

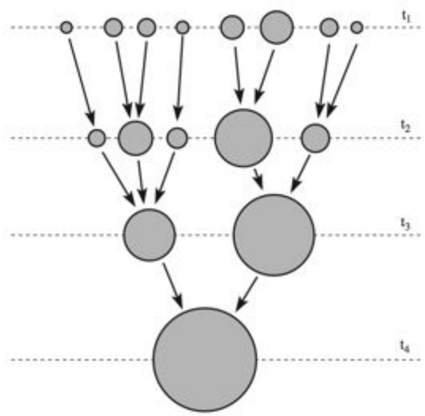


Fig. 1.3. A schematic merger tree, illustrating the merger history of a dark matter halo. It shows, at three different epochs, the progenitor halos that at time t_4 have merged to form a single halo. The size of each circle represents the mass of the halo. Merger histories of dark matter halos play an important role in hierarchical theories of galaxy formation.

Mo, van den Bosch, White fig 1.3

6. introduction to statistical tools: towards the power spectrum

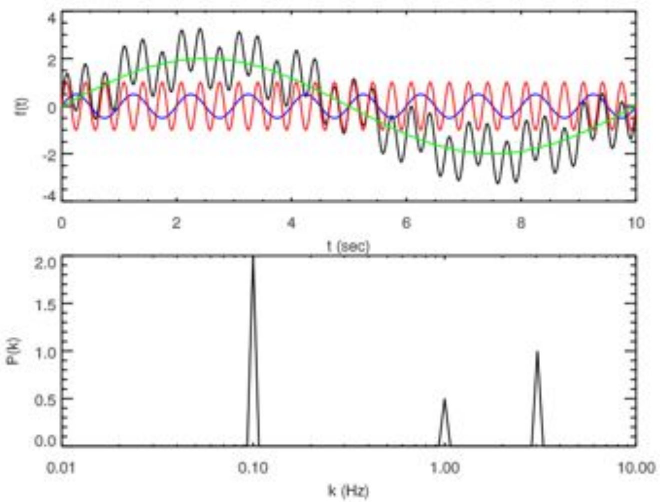
what is a power spectrum ?

Fourier analysis

$$\tilde{f}(\nu) = \int_{-\infty}^{+\infty} f(t) e^{-i2\pi\nu t}\, dt$$

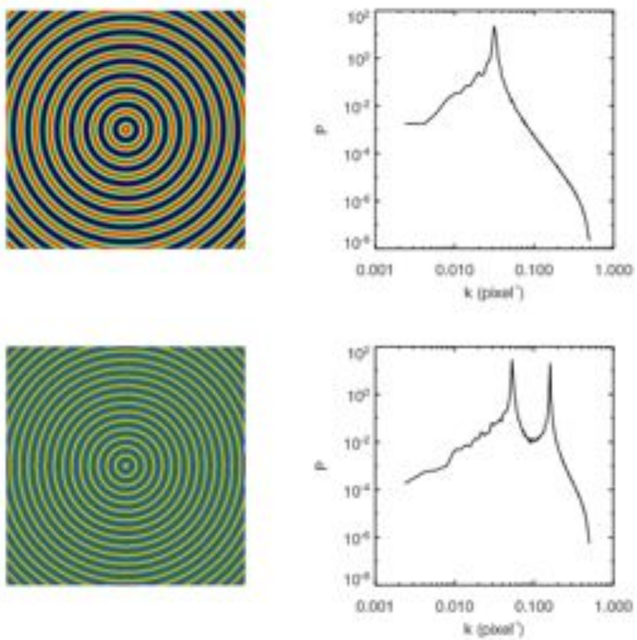
$$f(t) = \int_{-\infty}^{+\infty} \tilde{f}(\nu) e^{i2\pi\nu t}\, d\nu$$

Courtesy Marc-Antoine Miville-Deschênes



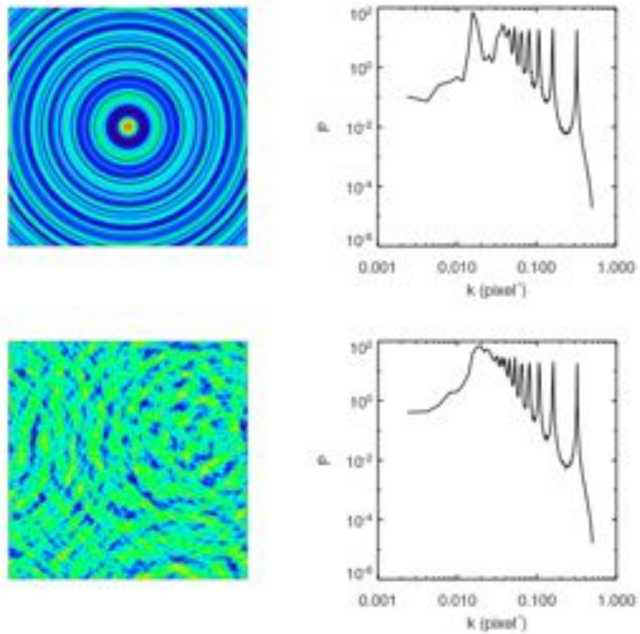
Espace direct: time

Espace conjugué: fréquence temporelle



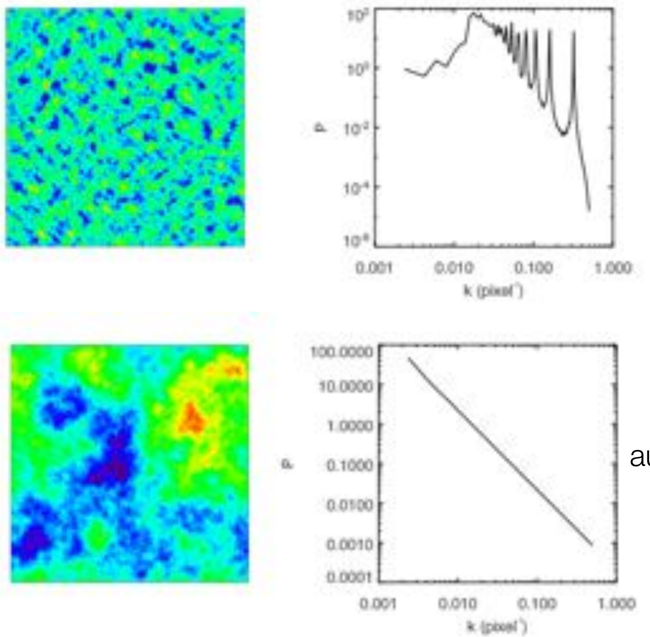
1 sine
centered

2 sine
centered



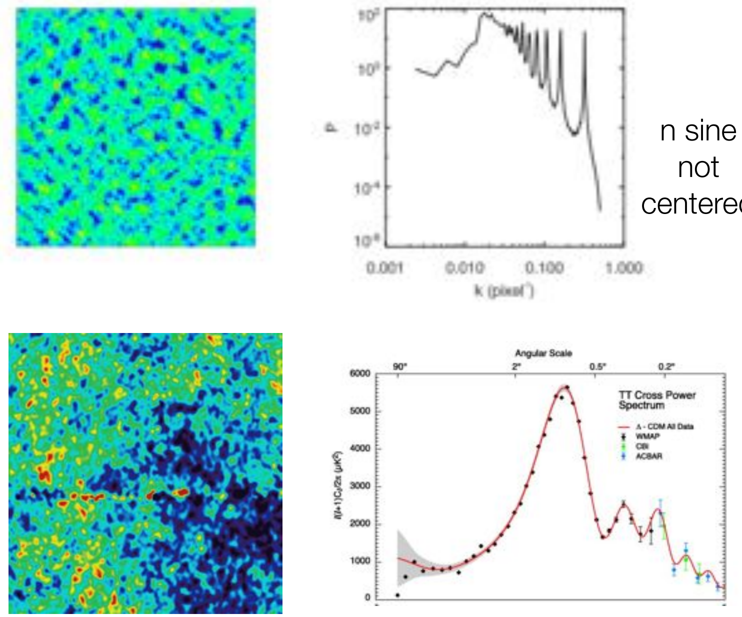
n sinus
centrés

n sinus
décentrés



n sine
not
centred

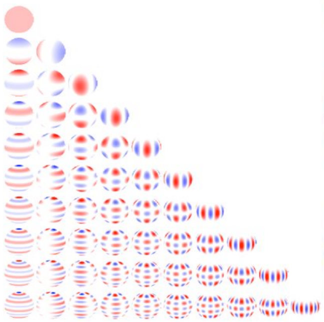
autosimilar
form
(fractal)



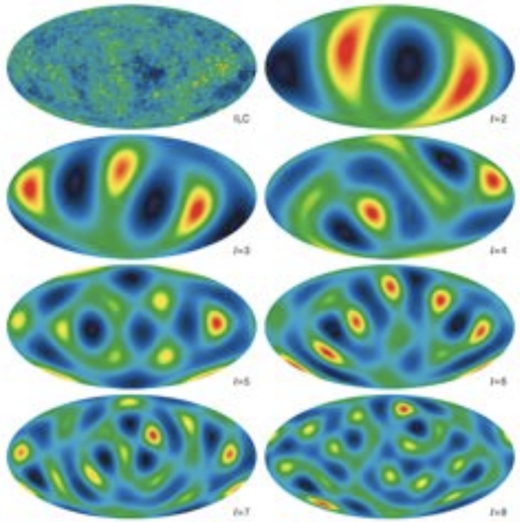
n sine
not
centered

WMAP 1 yr

multipoles applied to the CMB



Ylm courtesy Benoit Mosser, LESIA



Hinshaw et al., 2007, WMAP3