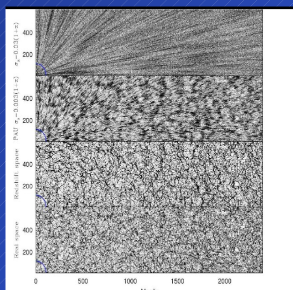
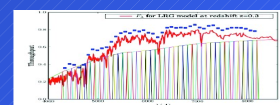
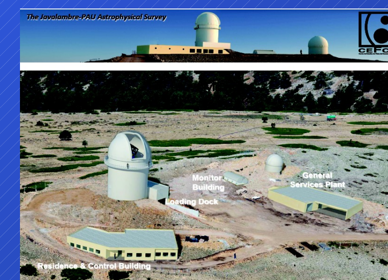
Cosmology with Large Galaxy Redshift Surveys: *introducing JPAS*







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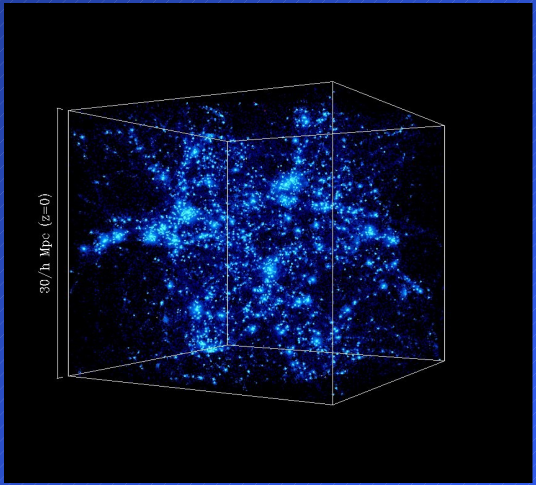
I COSMOSUL

Observatório Nacional, RJ

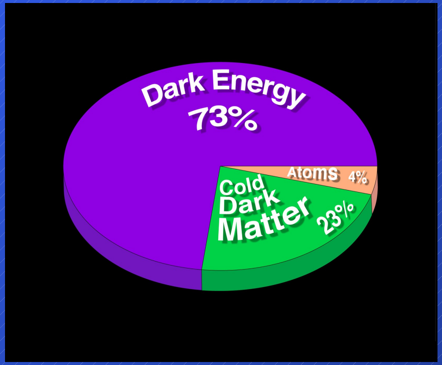
1-5/08/2011

What is a galaxy redshift survey?

- Aim: 3-D maps of galaxy distribution



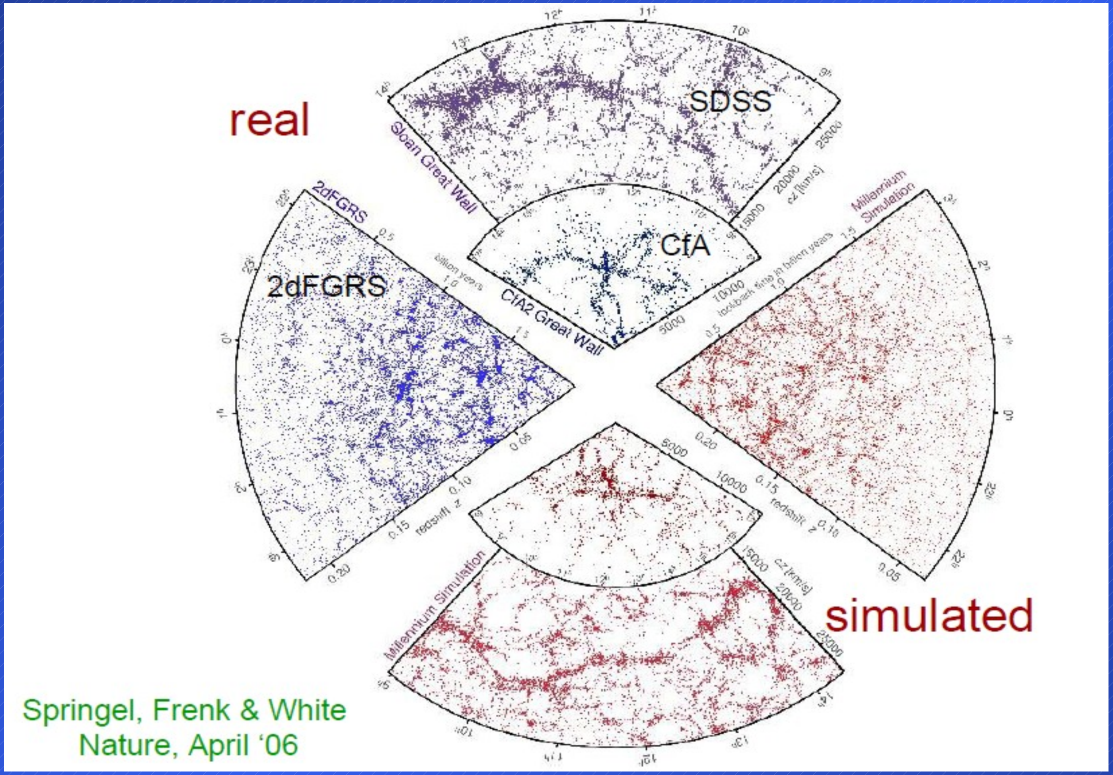
- Why? The values of the cosmological parameters are “printed” in the galaxy distribution; use 3-D maps to study cosmology!

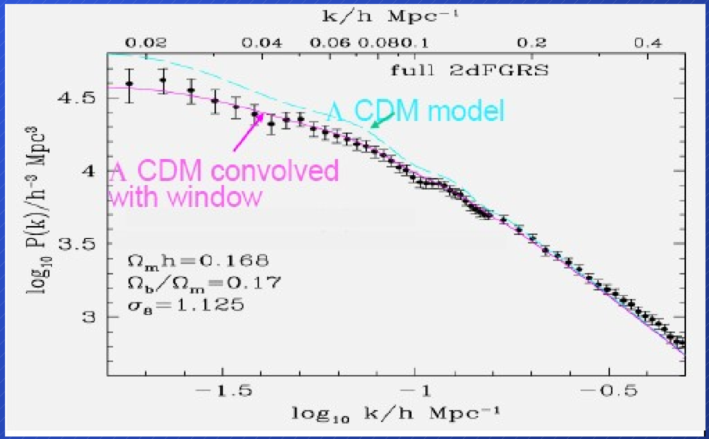


- Added Value: The “spectra” required to estimate distances are also informative on galaxy properties

What is a galaxy redshift survey?

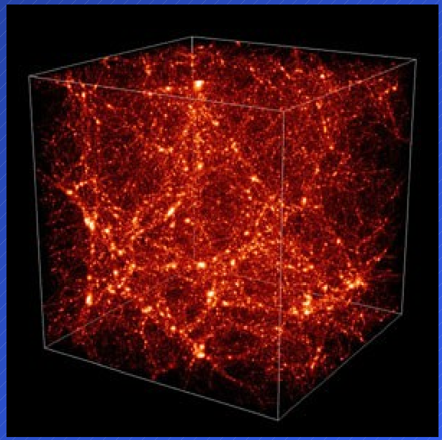
- Galaxy redshift surveys allow to test and advance the cosmological paradigm with observations of the universe in its largest scales





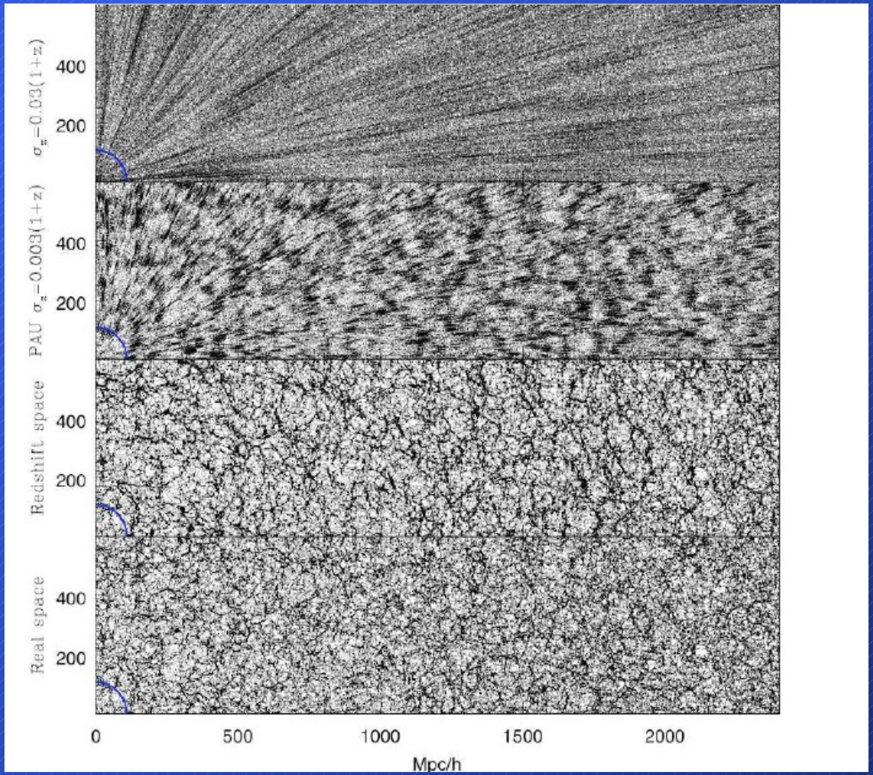
What is a galaxy redshift survey?

- Aim: 3-D maps of galaxy distribution



- *Data analysis is challenging!*

- But what we get is very different:



Outline:

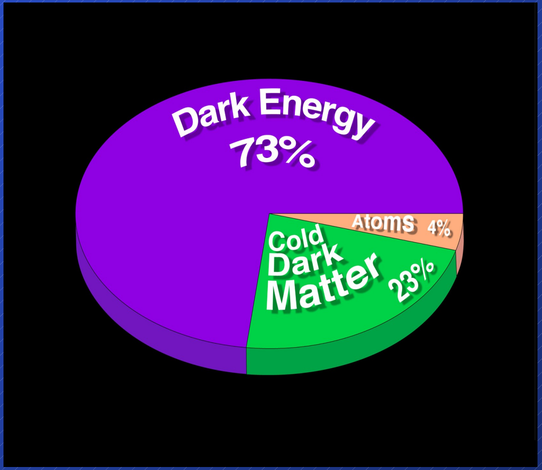
- **Where do we live?**
- **Structure formation**
- **Cosmological observables in surveys**
- **Cosmology with galaxy redshift surveys**
- **The data challenge**
- **Cosmology with photometric redshifts**
- **JPAS**

Where do we live?

- **Here! In a ΛCDM universe!**

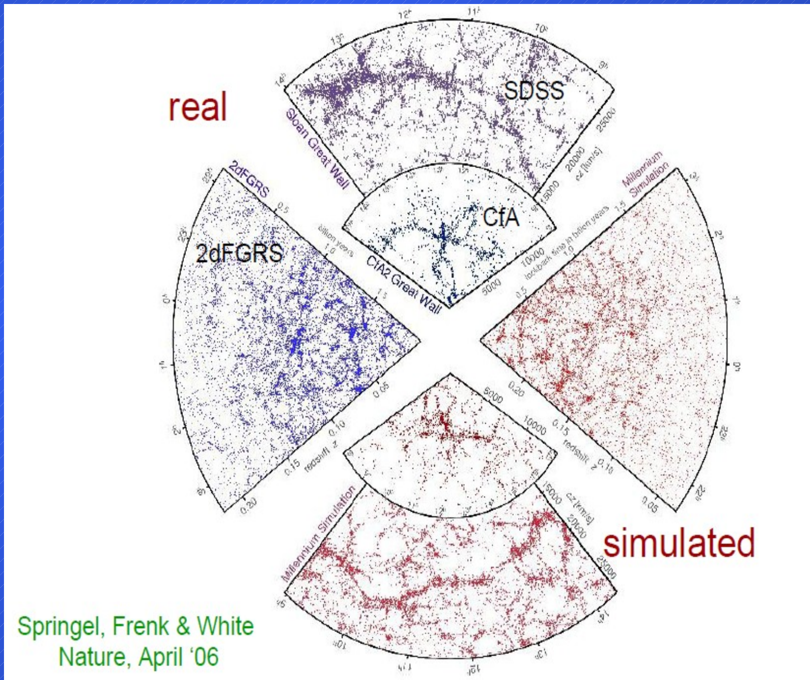
- Cosmological paradigm @2011:
- universe (within a multiverse?) with:
- ***zero curvature***
- dominated by ***dark energy (73%)***
- containing ***dark matter (23%)***
- and a bit of ***barions (~4%)***

  (in units of the critical density)

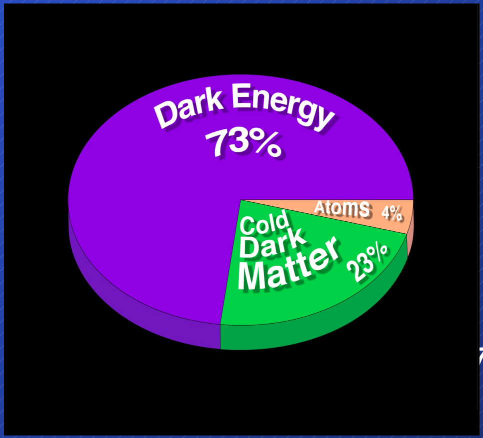


Where do we live?

- the ΛCDM model explains very well the universe in its largest scales
- the Λ component is responsible for accelerating the universe
- dark matter is necessary to explain galaxy dynamics and formation

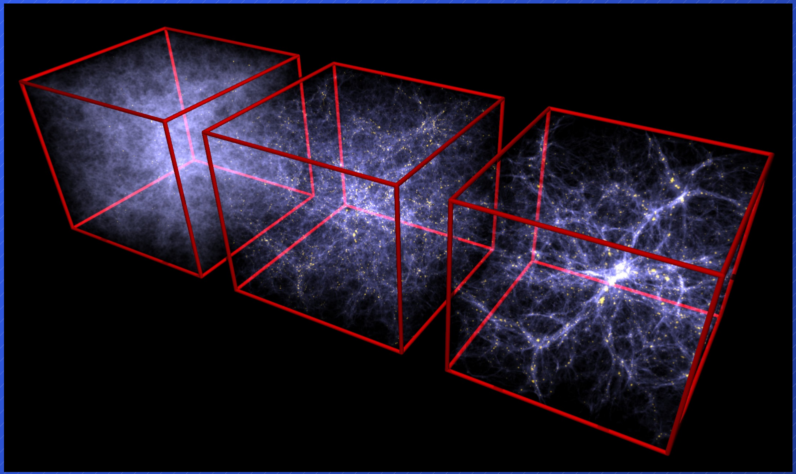


Springel, Frenk & White
Nature, April '06



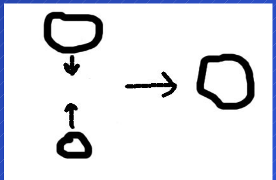
Structure Formation: the recipe

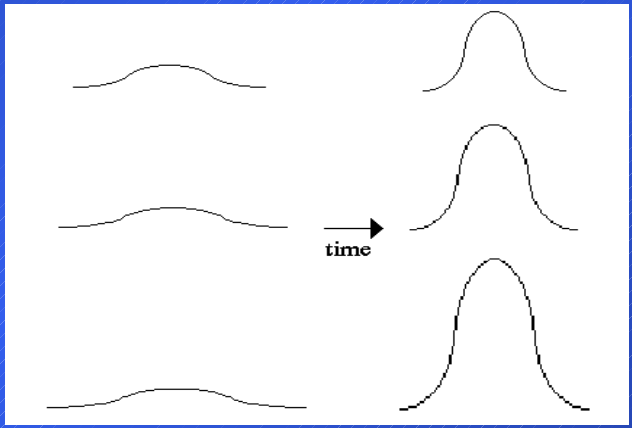
- **In the ΛCDM model the large scale of the universe can be determined from:**
  - the values of the cosmological parameters; mainly the content of Dark Matter
  - the mechanism by which structures grow: gravity
  - the initial conditions (statistical distribution of density fluctuations)



Structure Formation: initial conditions

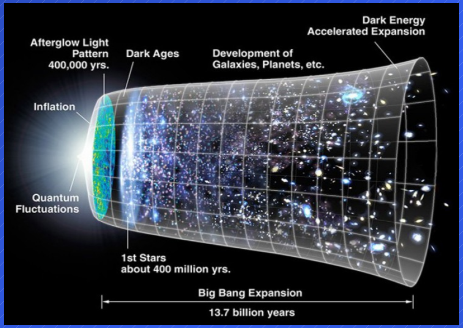
- **Hypothesis: structures grow from density fluctuations by gravity**

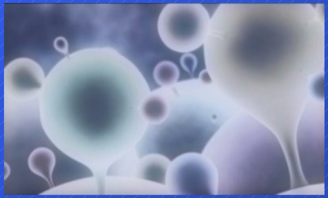


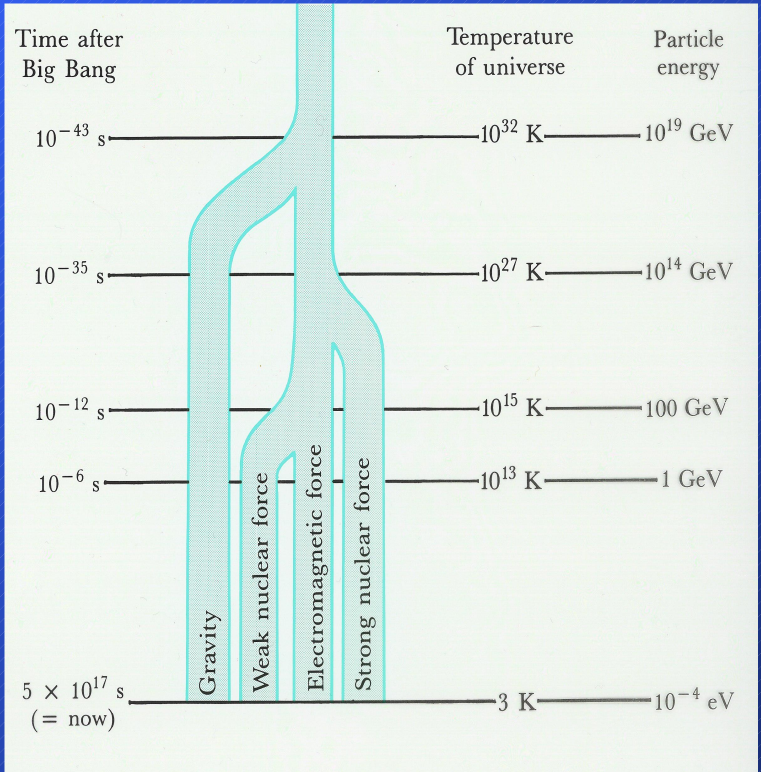


- **Seeds: primordial density fluctuations:**

  quantum fluctuations produced during *inflation*

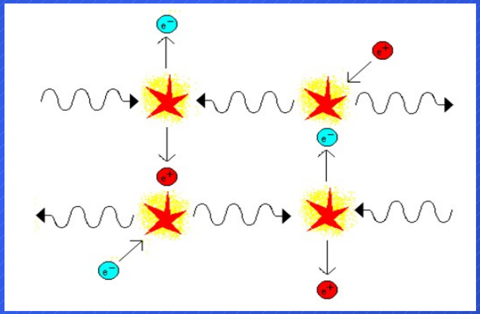




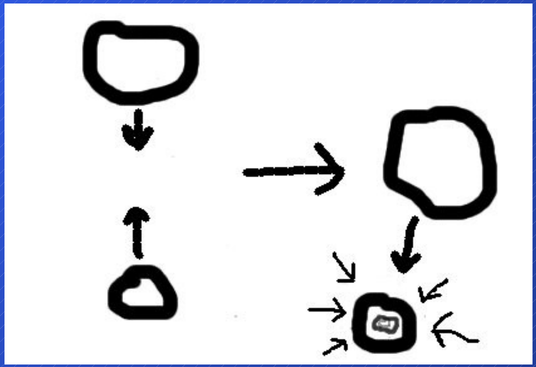


Structure Formation: the radiative era

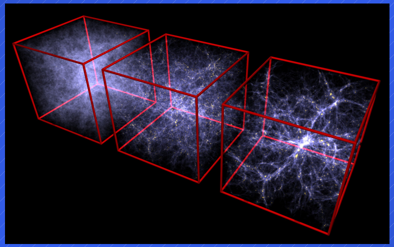
- **in the beginning the universe is a hot plasma, with photons coupled with baryons (protons) and electrons**

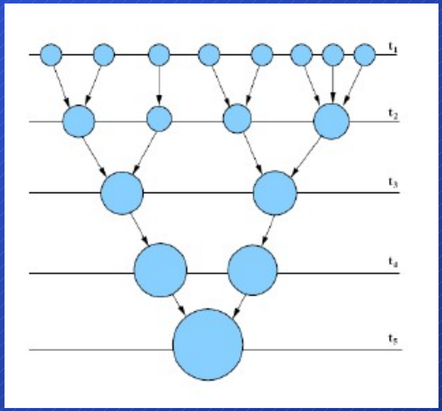


- **dark matter *halos* can form by gravitational collapse of density fluctuations**



- ***hierarchical scenario*: DM halos grow through mergers with other halos**

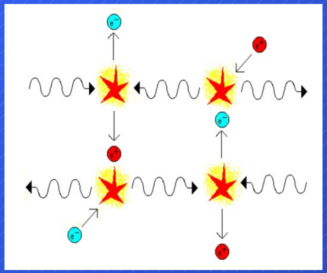




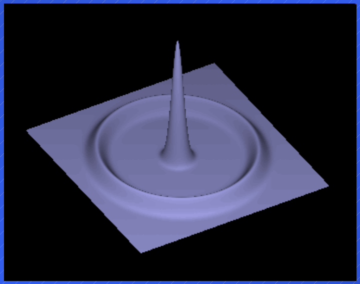
a merger tree

Structure Formation: BAOs

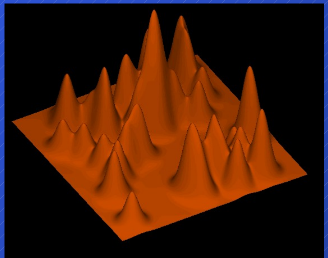
- density fluctuations in the baryon-photon plasma are attracted by the DM halos but the radiation pressure of the compressed plasma avoids their capture



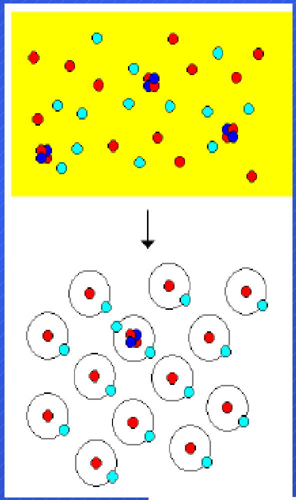
- as a consequence, the photon/baryon density fluctuations expand as sound waves, with velocity $v \sim c/3^{1/2}$

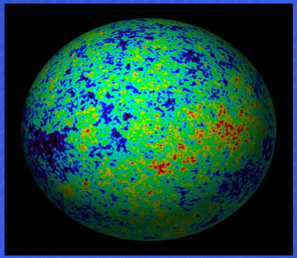


- these oscillations are known as ***Baryon Acoustic Oscillations*** **(BAOs)**



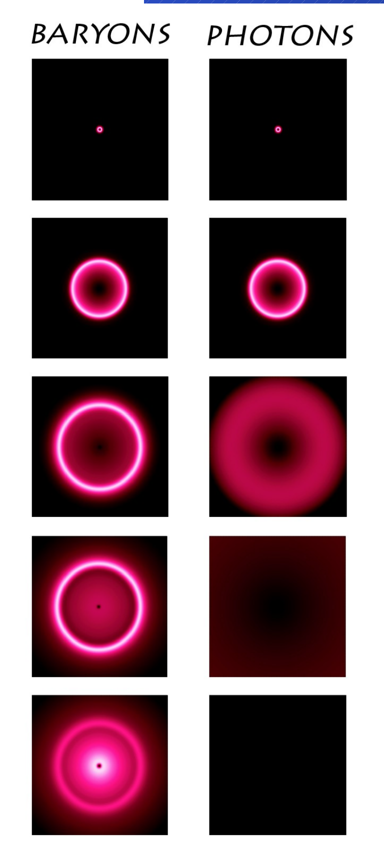
Structure Formation: BAOs



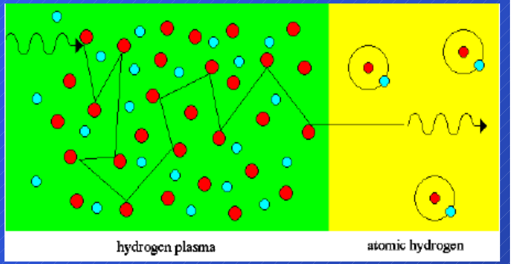


- The photon-baryon plasma cools as the universe expands and by

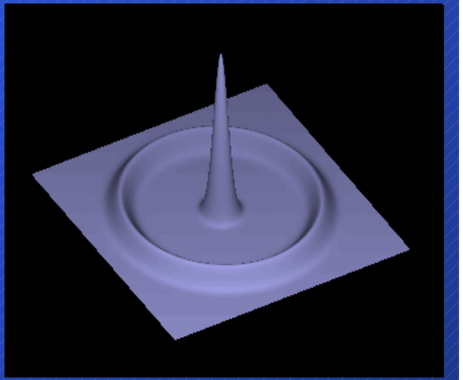
  z ~1000 (t ~ 400 Myr) it is cold enough to allow the formation of atoms: the *epoch of recombination*



- the universe becomes electrically neutral: photons and baryons decouple and the photons are free to travel

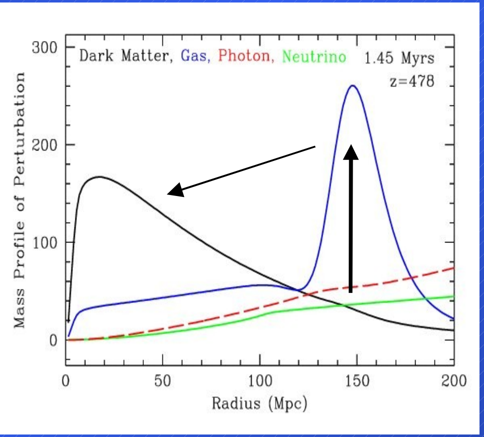


- *this expansion of the sound waves is halted at the recombination,when they have a radius l ~ c/3$^{1/2}$ t ~ 150 Mpc (in comoving units)*

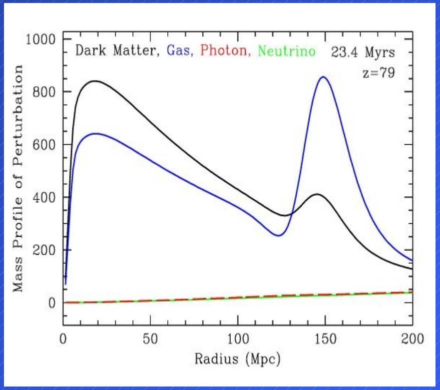


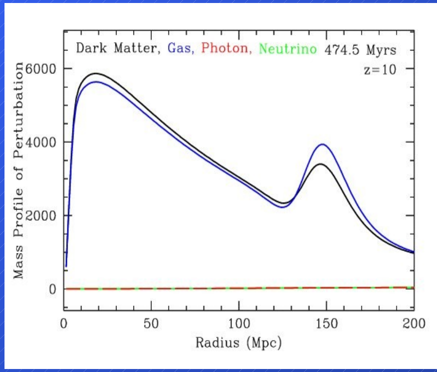
Structure Formation: BAOs evolution of the density profile $\rho(r)r^2$

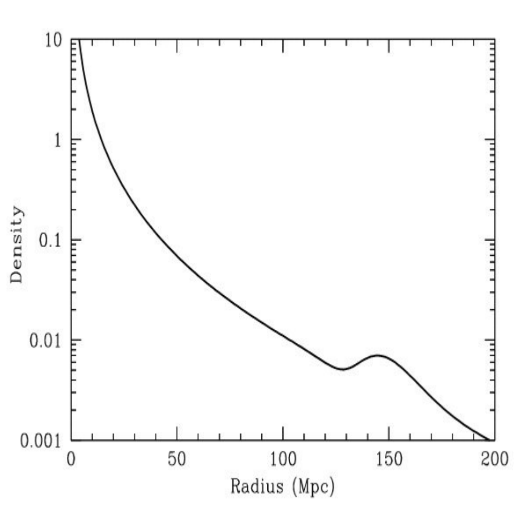
- after recombination the universe becomes neutral and the baryons can fall onto dark matter halos



recombination



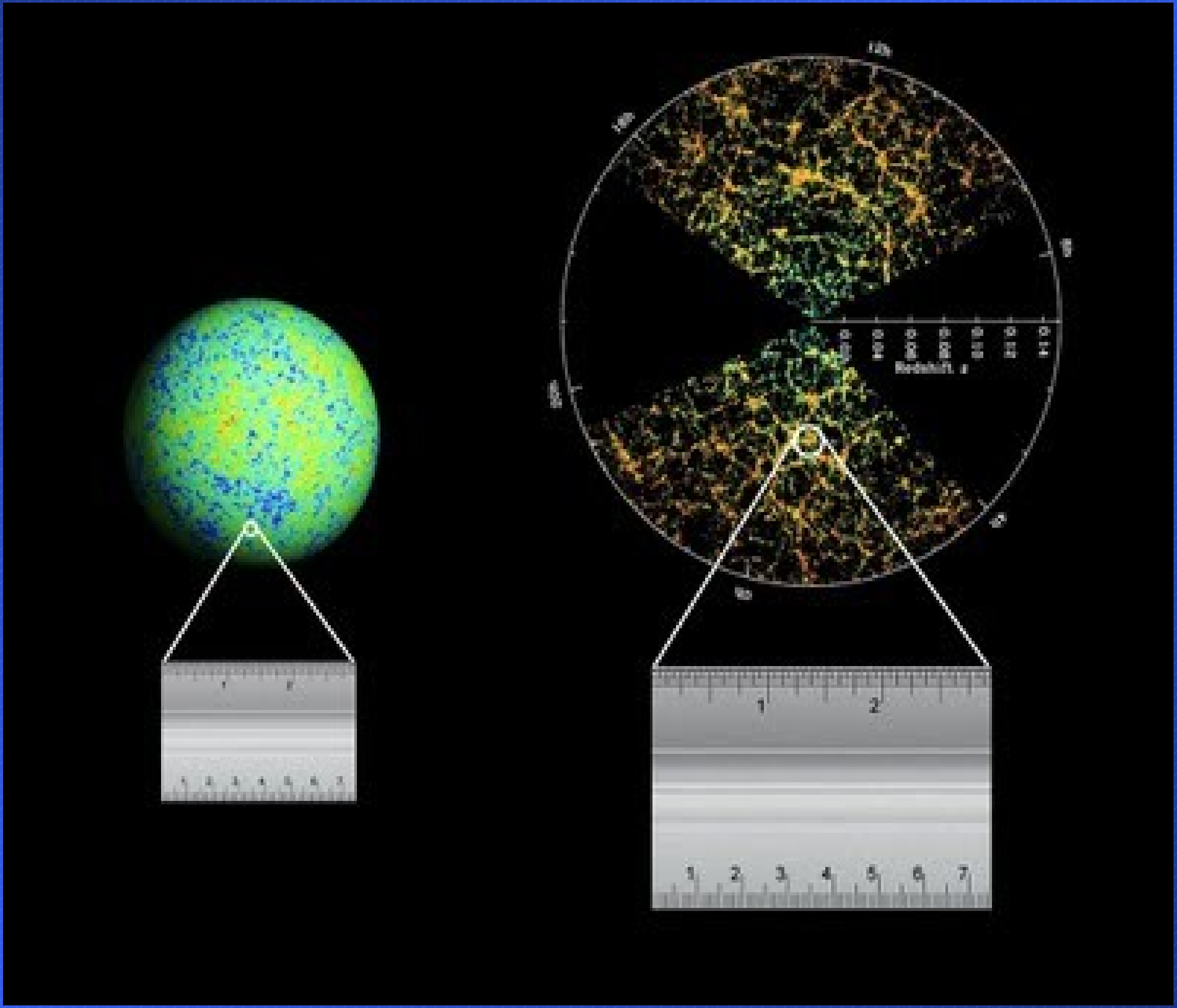




$\rho(r)$

- *There is an excess of probability that a galaxy will be found at ~150 Mpc from another!*

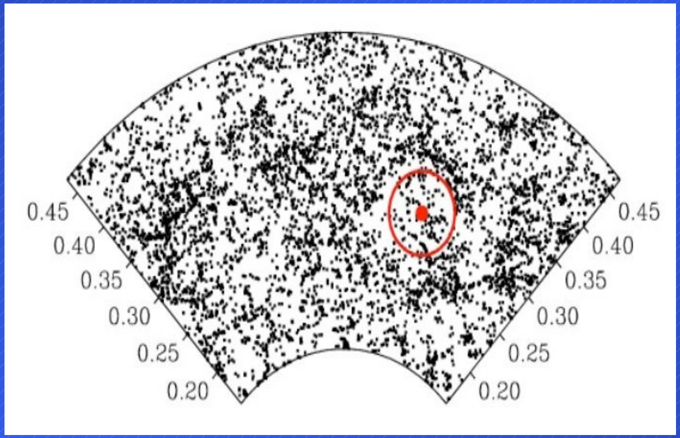
The BAO scale is a *standard rule:* useful to test cosmological models

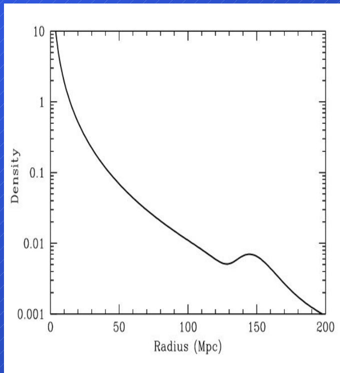


BAOs as cosmological observables

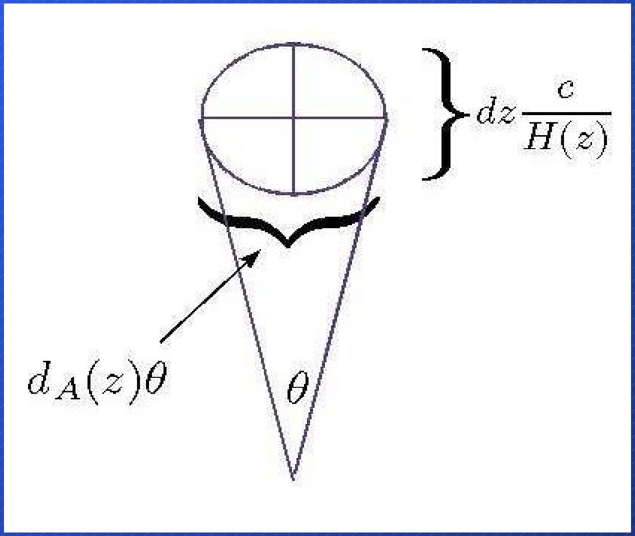
- The BAO scale is *printed* in the galaxy distribution:

  there is a probability above the mean in finding a galaxy at ~150 Mpc of a bright galaxy





- The BAO scale- *a standard rule*- can be measured either in the *transversal* or *radial* directions
- The measurement of radial BAO requires well determined radial distances



$$r_{\rm BAO} = D_A(z)\Delta\theta_{\rm obs} \qquad r_{\rm BAO} = \frac{\Delta z_{\rm obs}}{H(z_{\rm survey})}$$

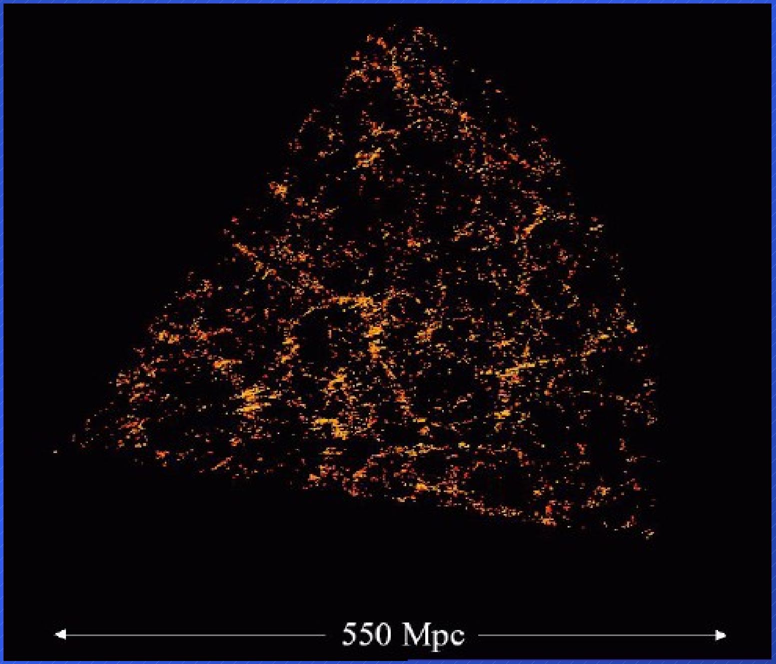
BAOs as cosmological observables

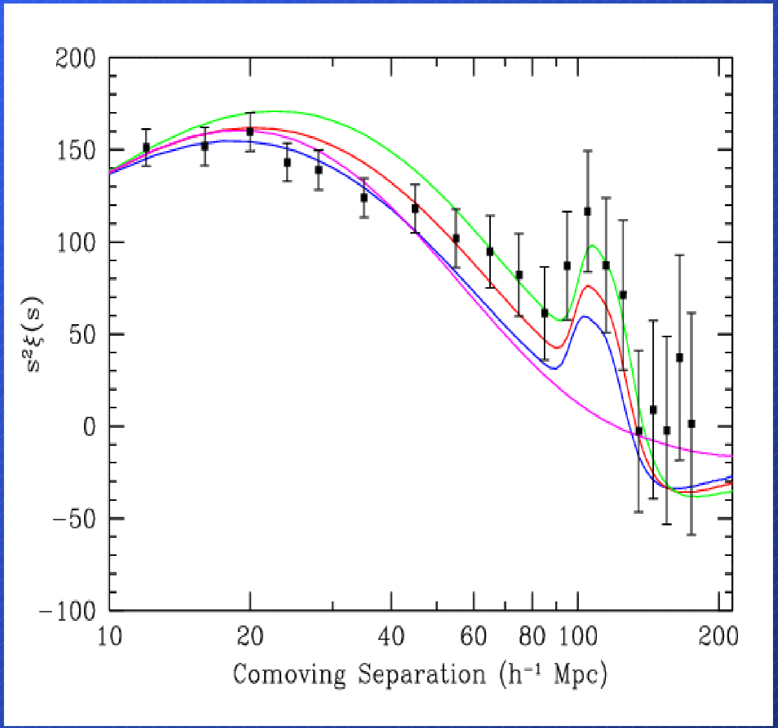
- detection of transversal BAOs in the SDSS survey

- *Two-point correlation function of galaxy pairs*:

  the expected number of galaxies within a volume *dV* at a distance *r* of another galaxy is $dN = n[1 + \xi(r)]\, dV$

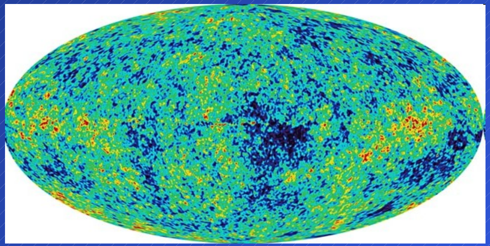
  where *n* is the mean density



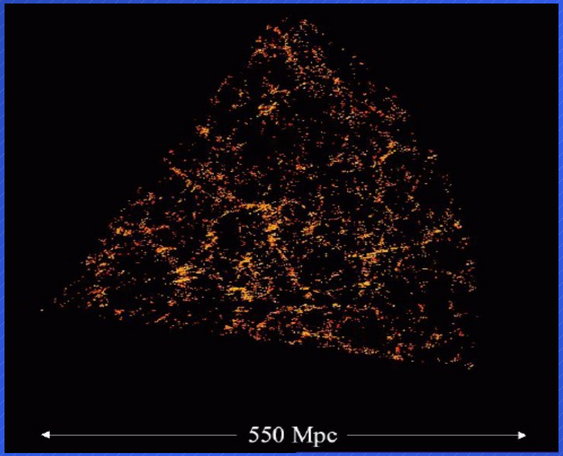


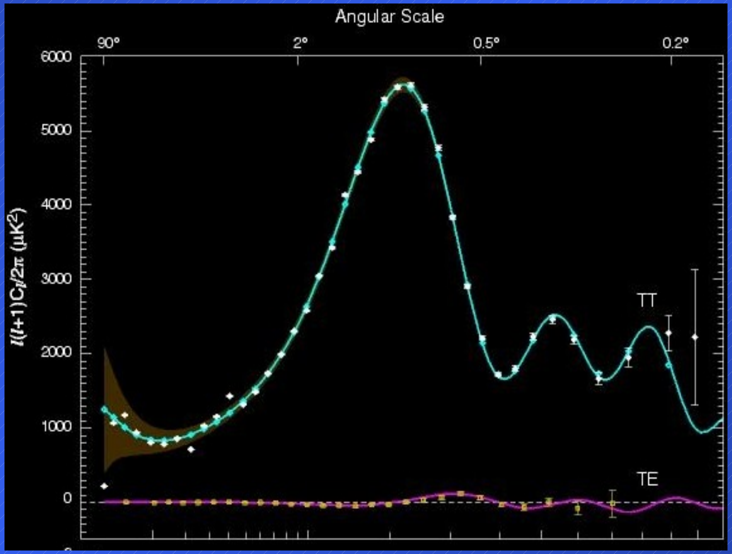
BAOs are *printed* in the large scale structures

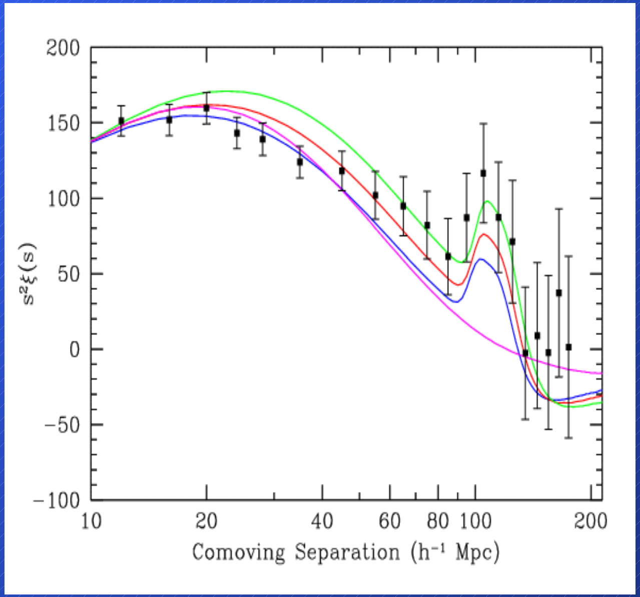
- in the cosmic microwave background



- in the nearby galaxy distribution

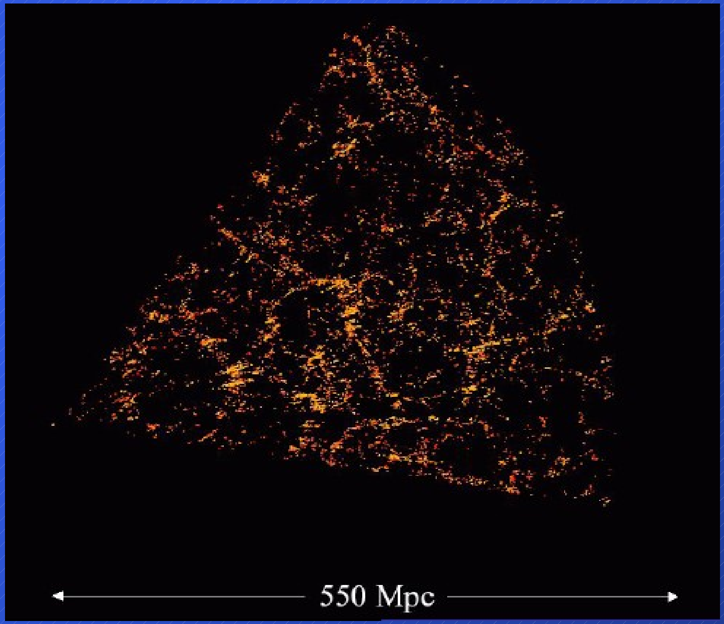


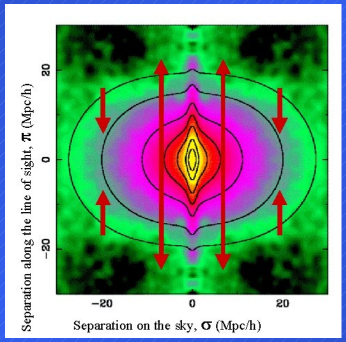


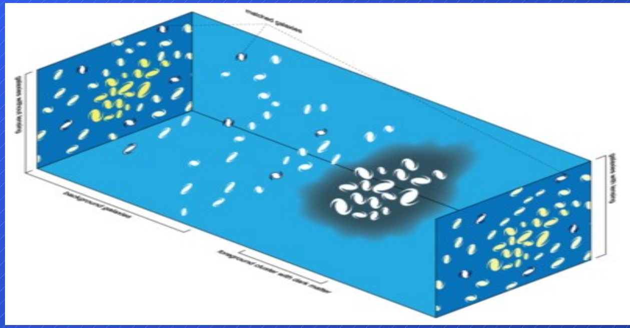


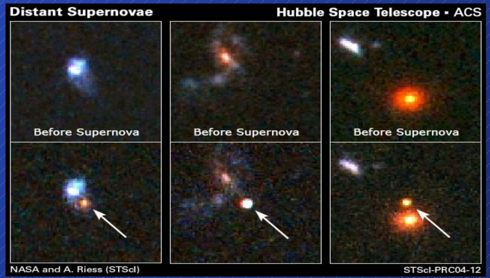
Cosmological observables in surveys

- Power spectrum of the galaxy distribution
- Galaxy clusters
- Weak lensing tomography
- SN Ia
- Peculiar velocity fields
- ...









Cosmological observables in surveys

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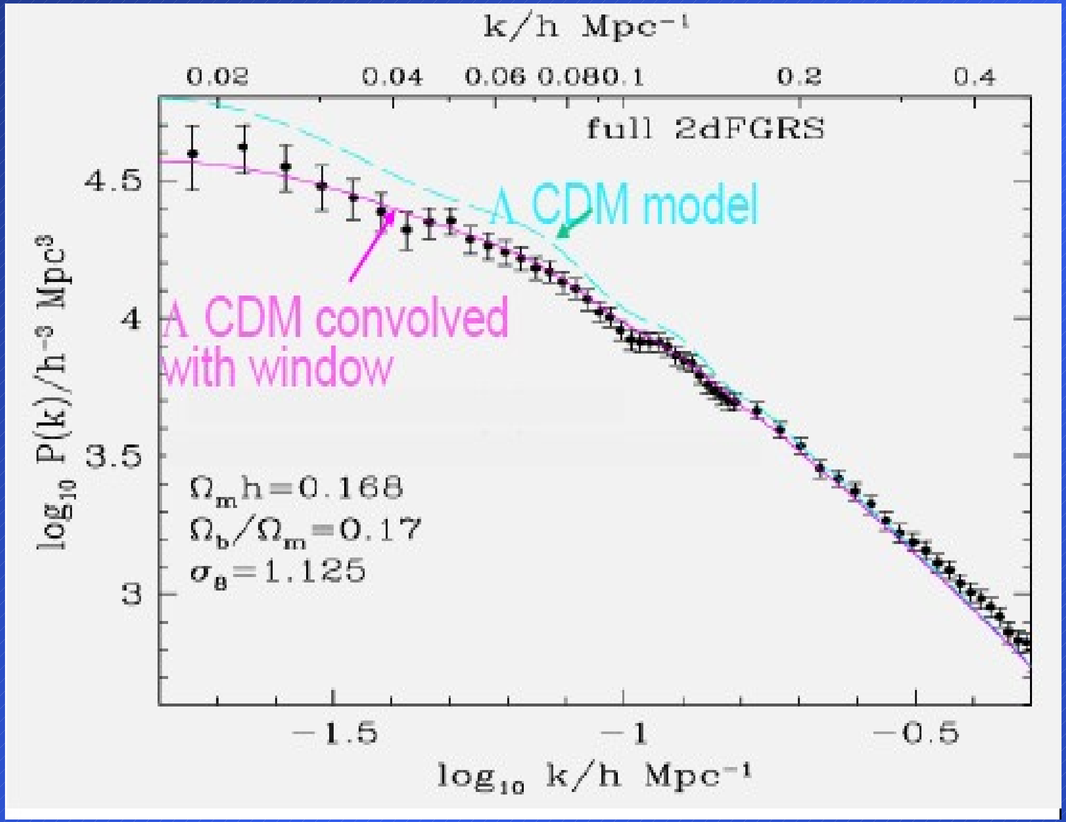

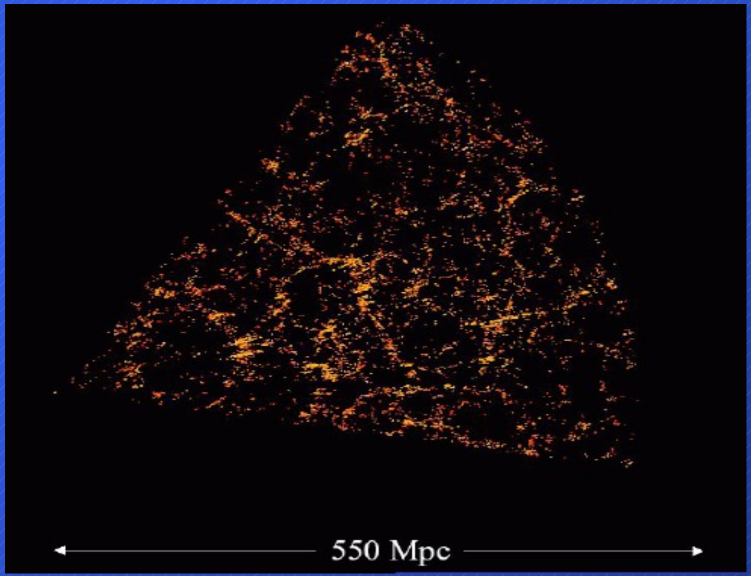

Cosmological observables in surveys

- Galaxy clusters

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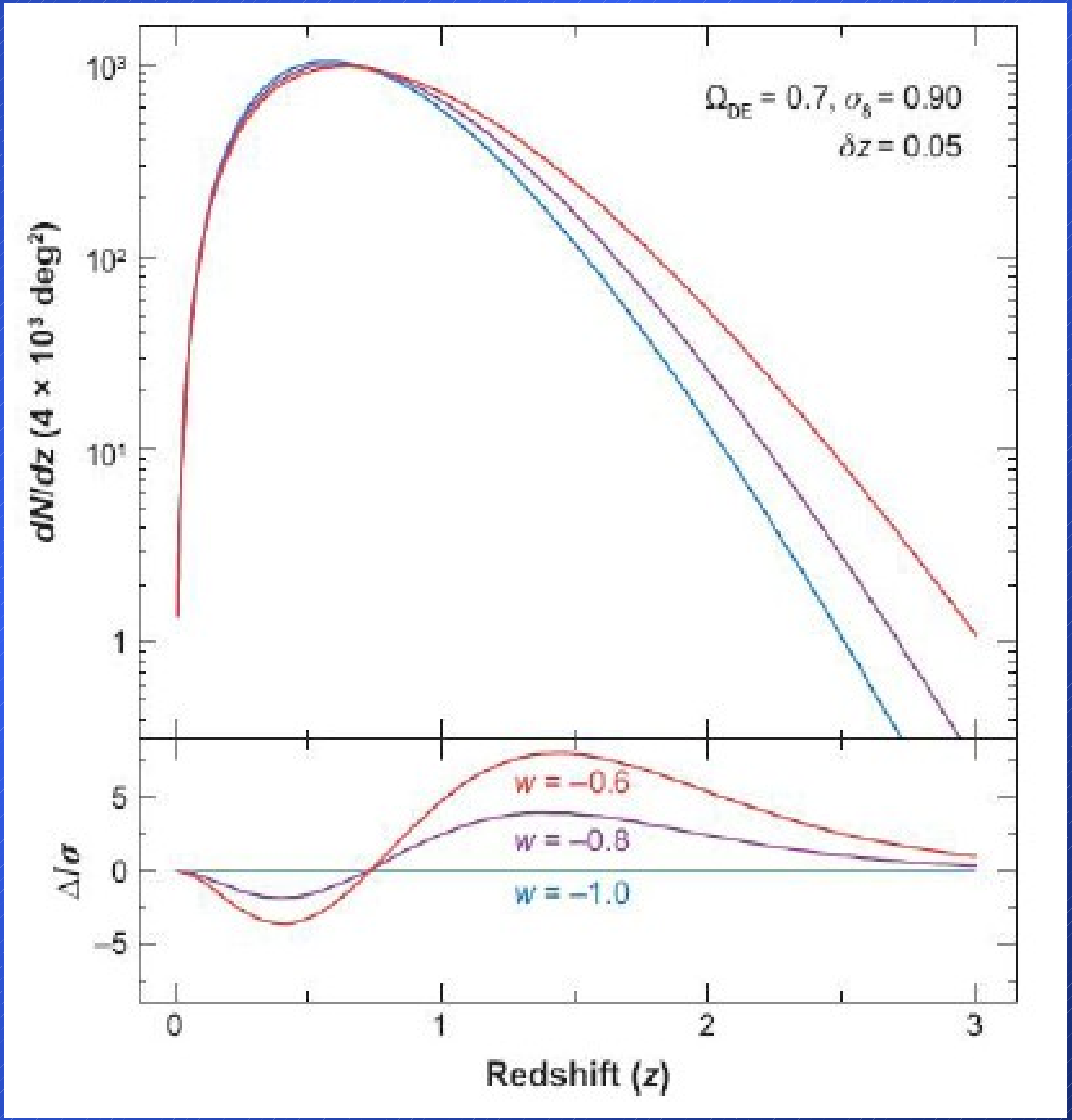
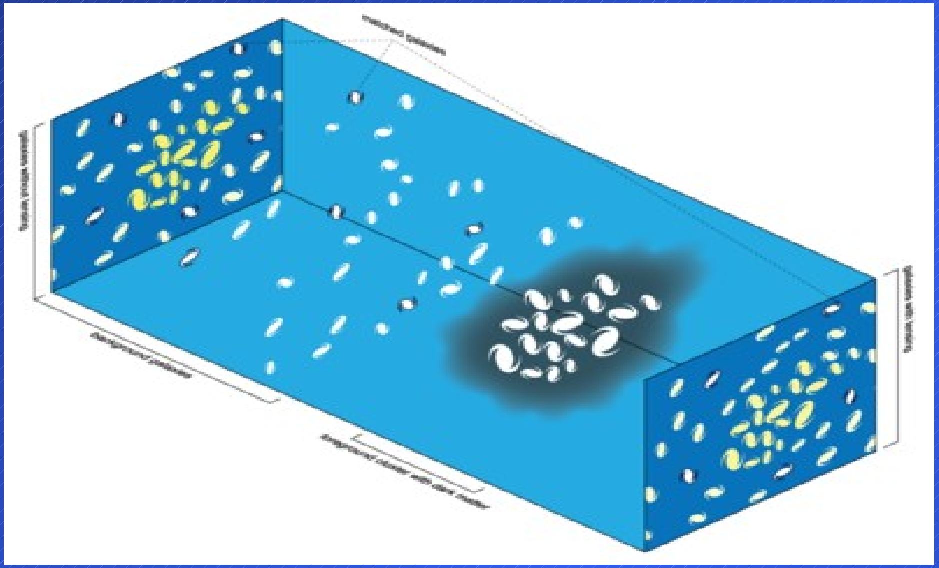
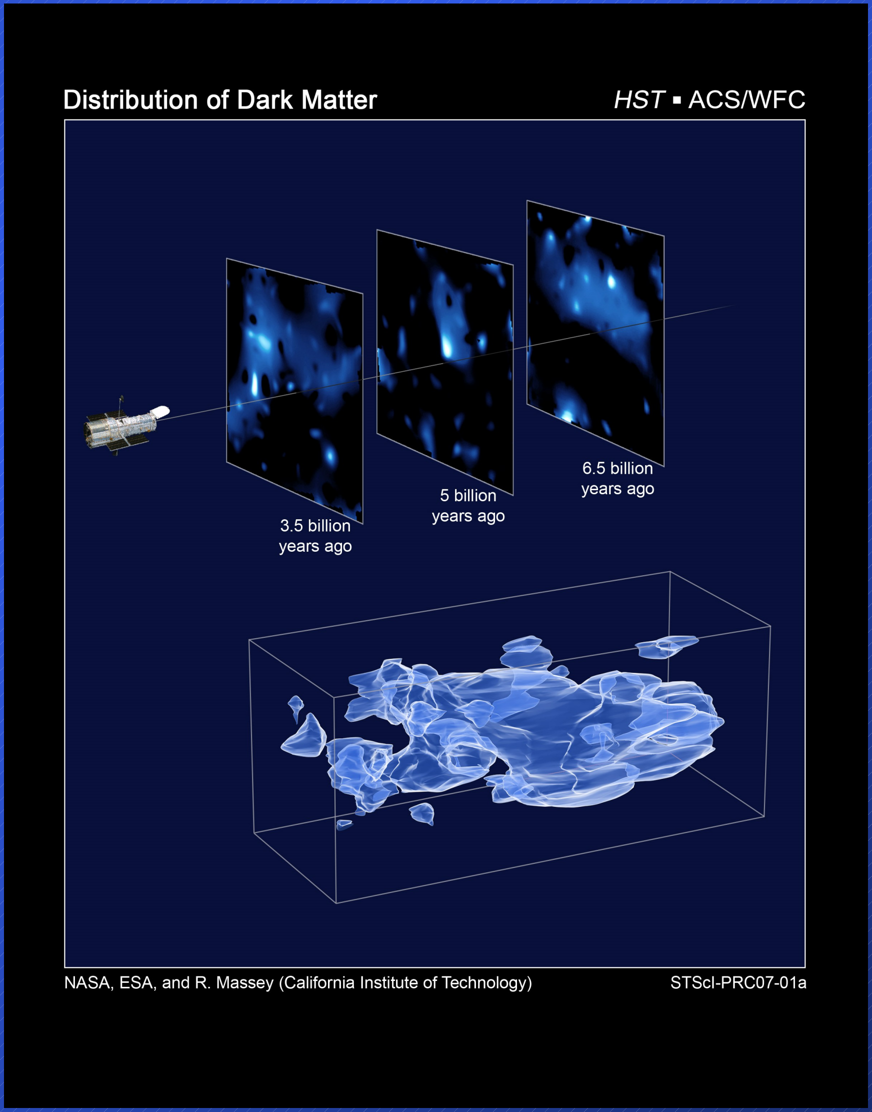


Cosmological observables in surveys

- Weak lensing tomography of the cosmic shear

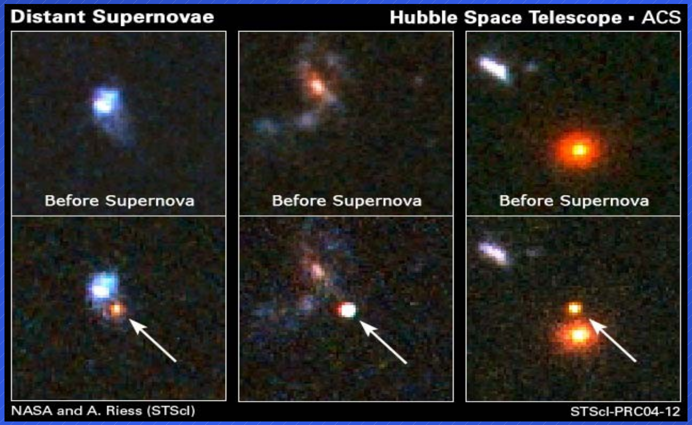


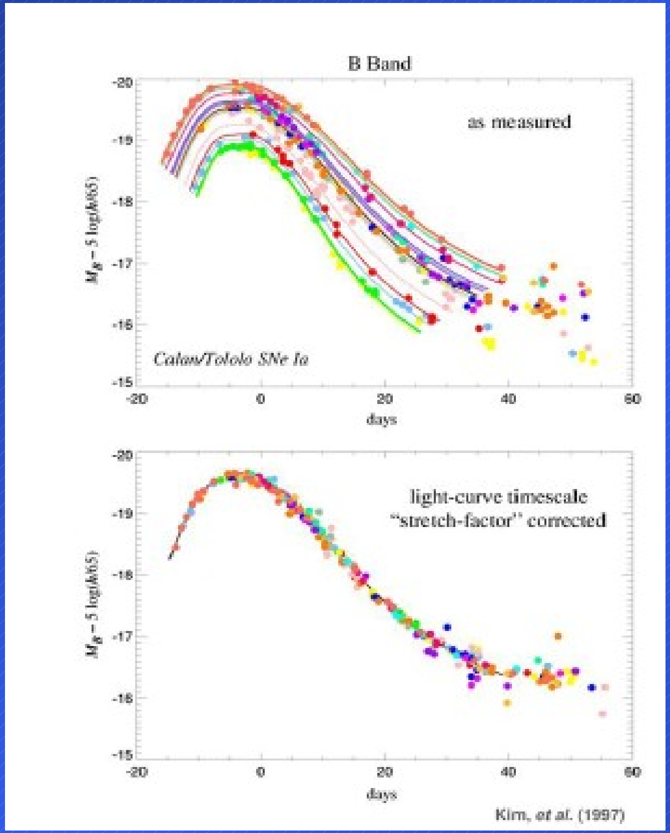


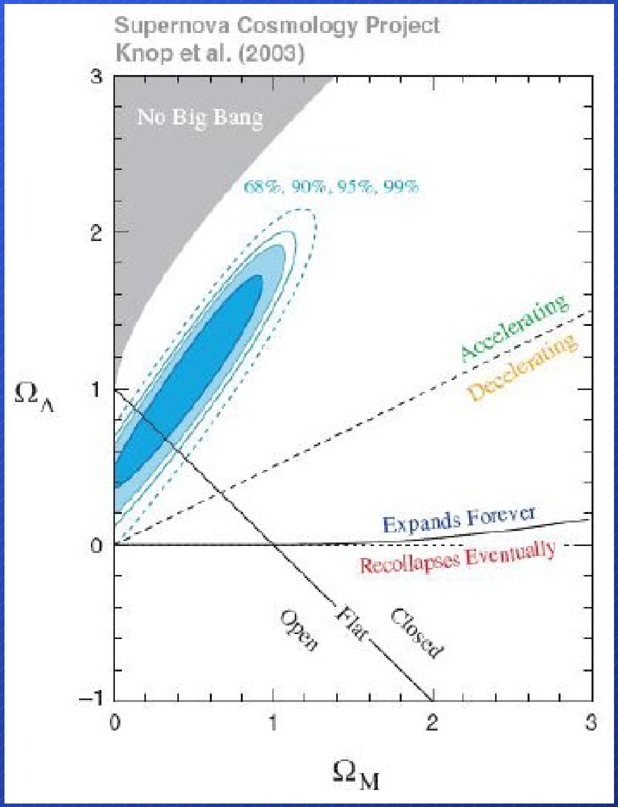
Cosmological observables in surveys

- SN Ia: standard candles

  detection depends on the cadence of the survey

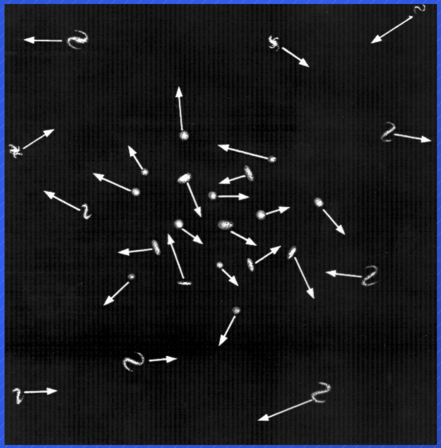


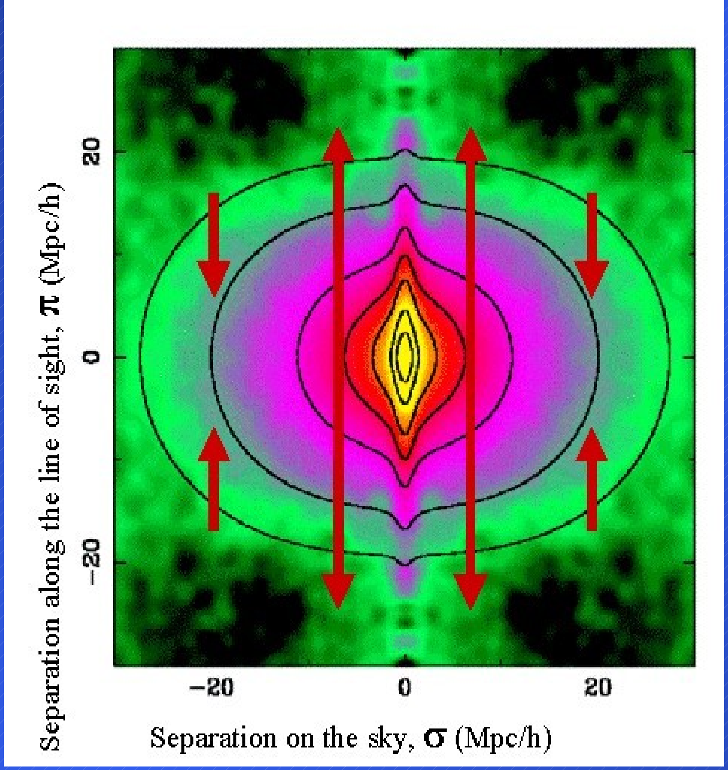


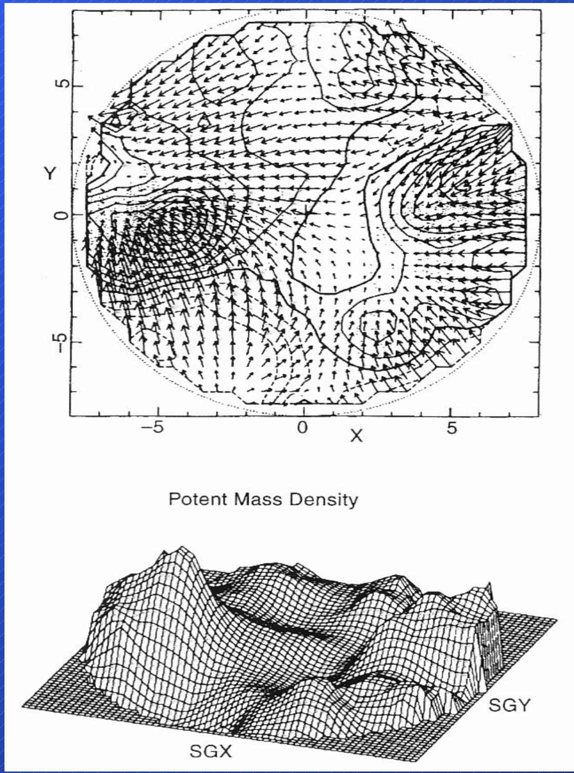


Cosmological observables in surveys

- Peculiar velocity field
- $V = H_0 D + V_{pec}$
- V_{pec} depends on the matter distribution



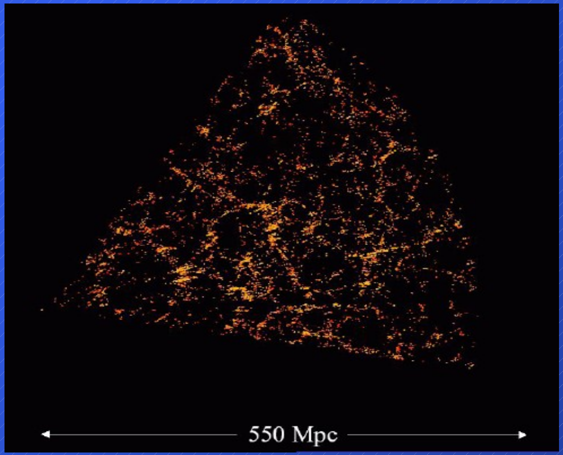




Cosmology with redshift surveys

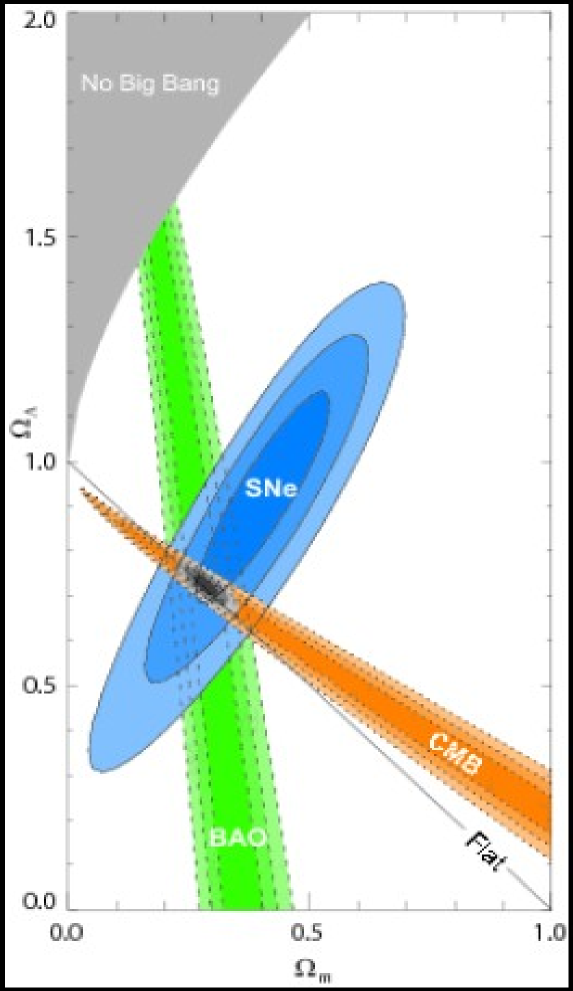
Large scale redshift surveys are useful for many things:

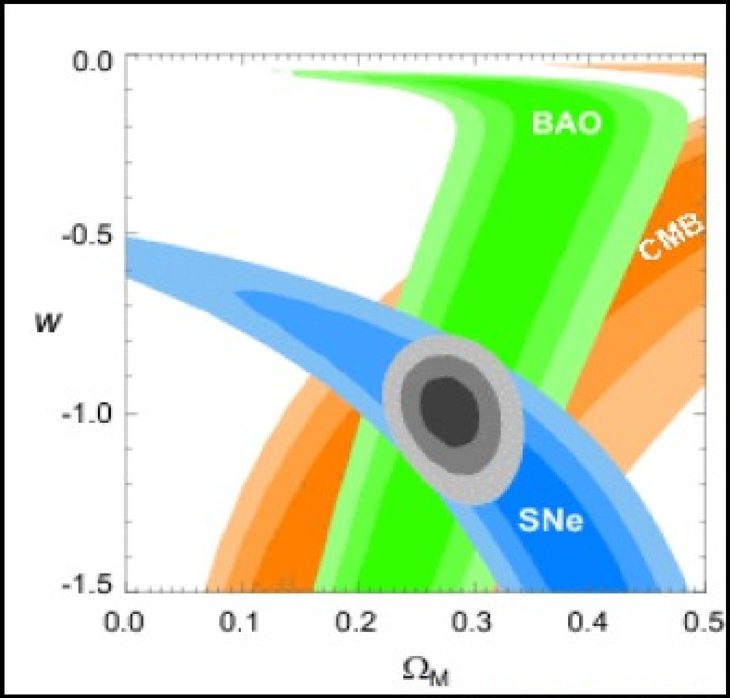
- estimation of cosmological parameters
- estimation of the sum of neutrinos' mass
- test of the theory of gravitation
- Investigation of galaxy formation and evolution
- ...



Cosmology with redshift surveys

Cosmological Parameters

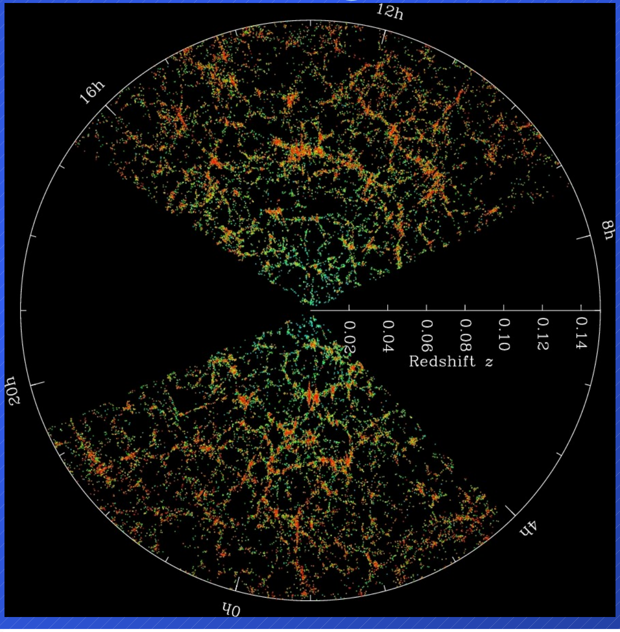




Kowalski *et al.* (2008)

$w = -0.94 \pm 0.1$

Cosmology with redshift surveys

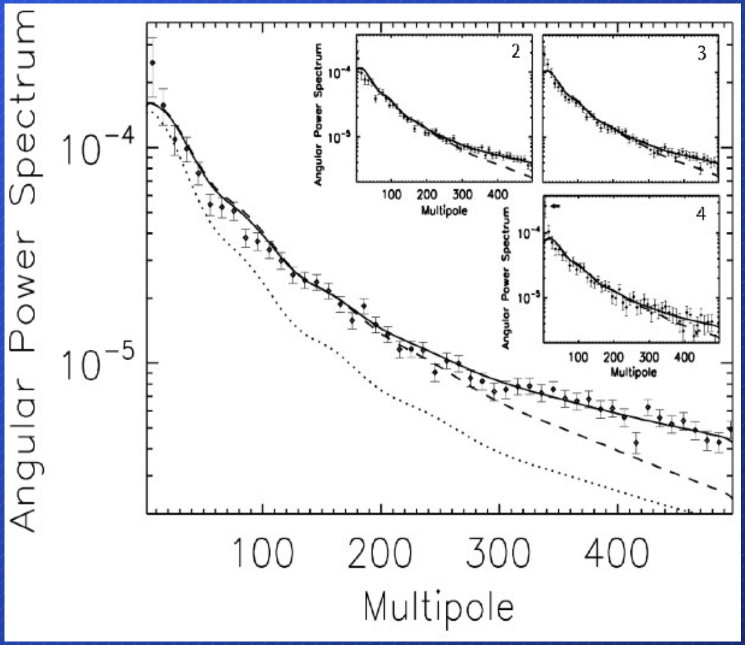


- **neutrino masses**: estimation from the power spectrum of galaxy distribution
- neutrino free-streaming *suppress* the growth of structures
- Thomas et al. (2010):

  Sum of neutrino mass eigenstates:

  < 0.28 eV

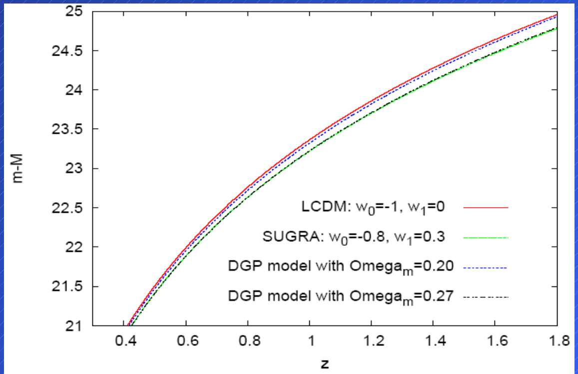
$\sum m_\nu$ (95% CL)	Analysis
< 1.271 eV	WMAP5
< 0.695 eV	WMAP5 + SNe + BAO
< 0.651 eV	WMAP5 + MegaZ
< 0.393 eV	WMAP5 + SNe + BAO + MegaZ$_{(\ell_{200})}$
< 0.344 eV	WMAP5 + SNe + BAO + MegaZ$_{(\ell_{200})}$ + HST
< 0.325 eV	WMAP5 + SNe + BAO + MegaZ
< 0.281 eV	WMAP5 + SNe + BAO + MegaZ + HST
< 0.491 eV	WMAP5 + SNe + BAO + MegaZ$_{(\ell_{200})}$ + HST
< 0.471 eV	WMAP5 + SNe + BAO + MegaZ + HST

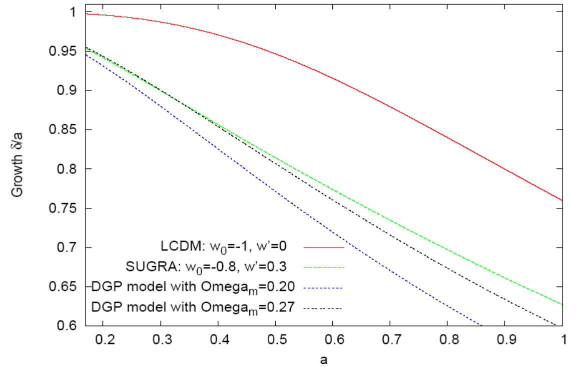


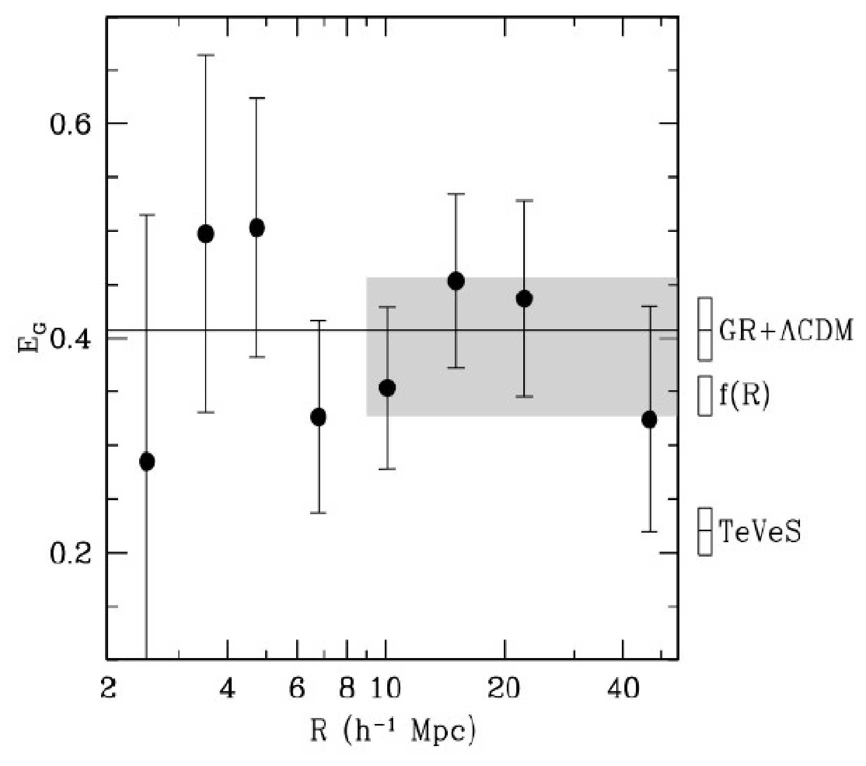
Cosmology with redshift surveys

- Tests of theory of gravitation:
  - two different phenomena depend in very different ways of the gravitation theory:

    the *expansion of the universe* and the *growth of structures*
  - this allows to test General Relativity and other theories in very large scales!



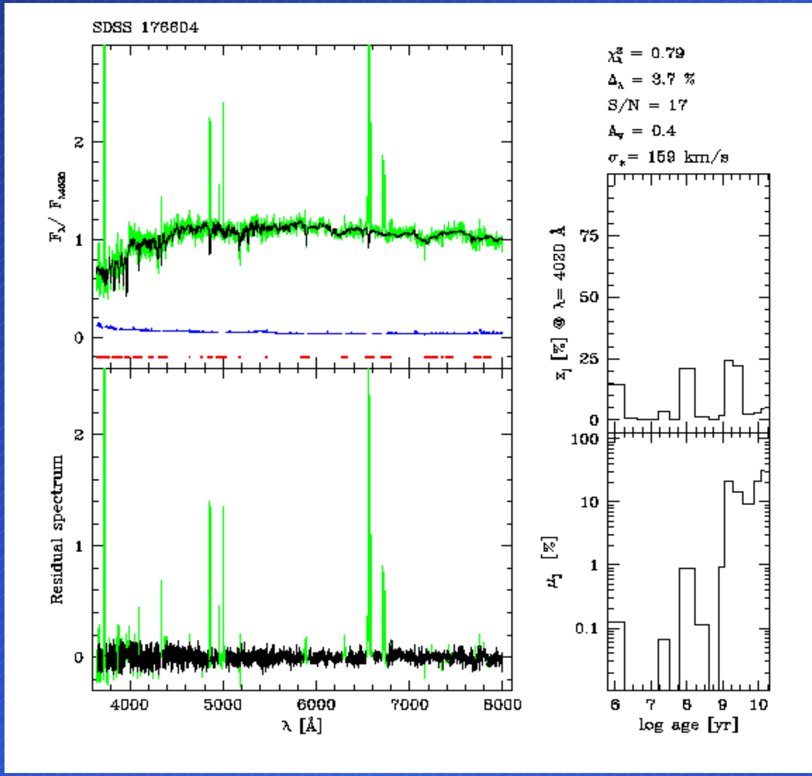


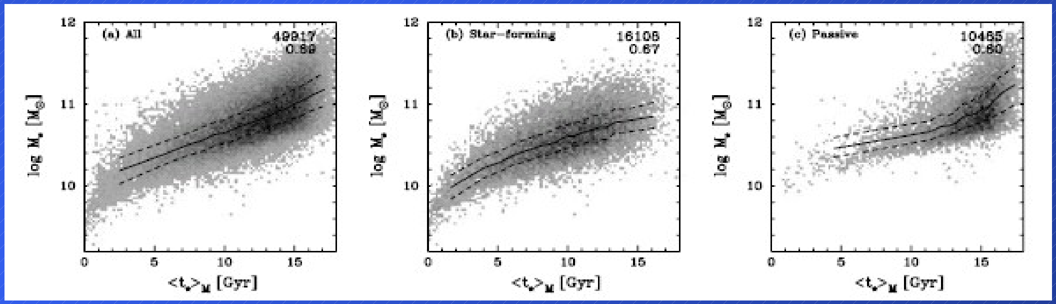


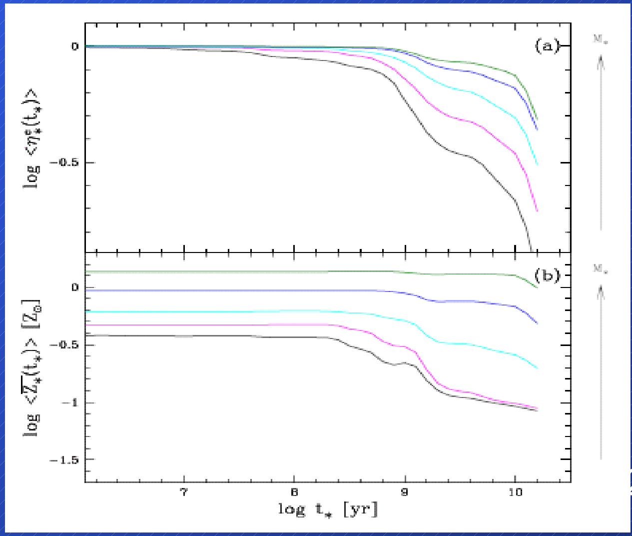
Reyes et al et al. (2010)

Cosmology with redshift surveys

- Galaxy evolution: galaxy spectra or colors contain information on their stellar populations







But what we observe?

- We measure the spectral deviation z:
- in general, redshifts (z > 0)

$$z \equiv \frac{\lambda_0 - \lambda_e}{\lambda_e}$$

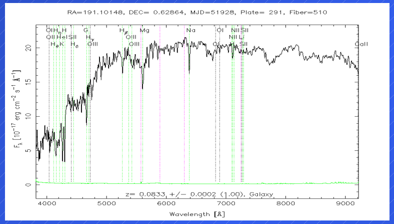
- in cosmology, z is related to the expansion of the universe:
- $1+z = R_0/R$ where R(z) is the expansion factor
- distances are a function of z: d(z)
- Hubble law: $v = cz = H_0\, d$

- But the spectral deviation is affected by peculiar velocities:
- $v = v_H + v_{pec}$

But what we observe?

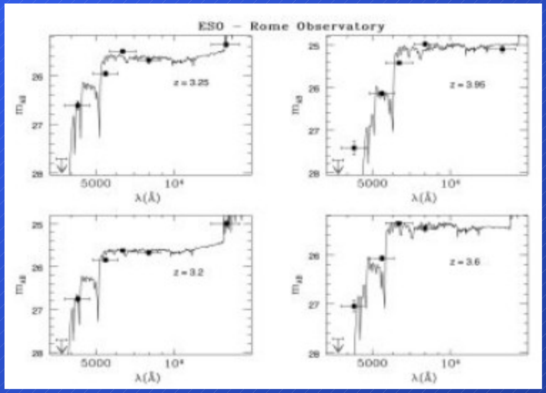
- We can measure the spectral deviation z with a spectrograph

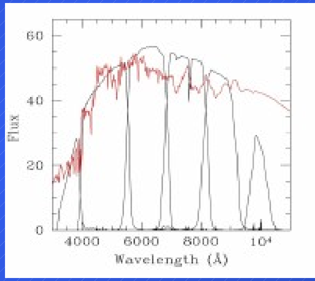
  error in v: ~100 km/s



- or from multi-band photometry: ***photometric redshifts***
- SDSS (5 optical bands):

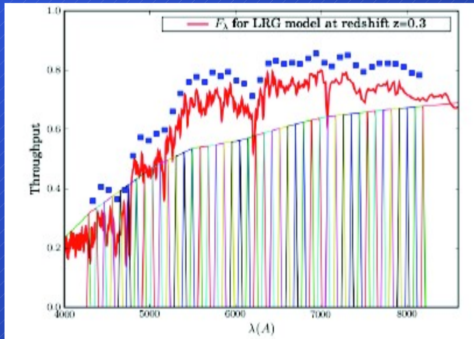
  error in v: ~10,000 km/s





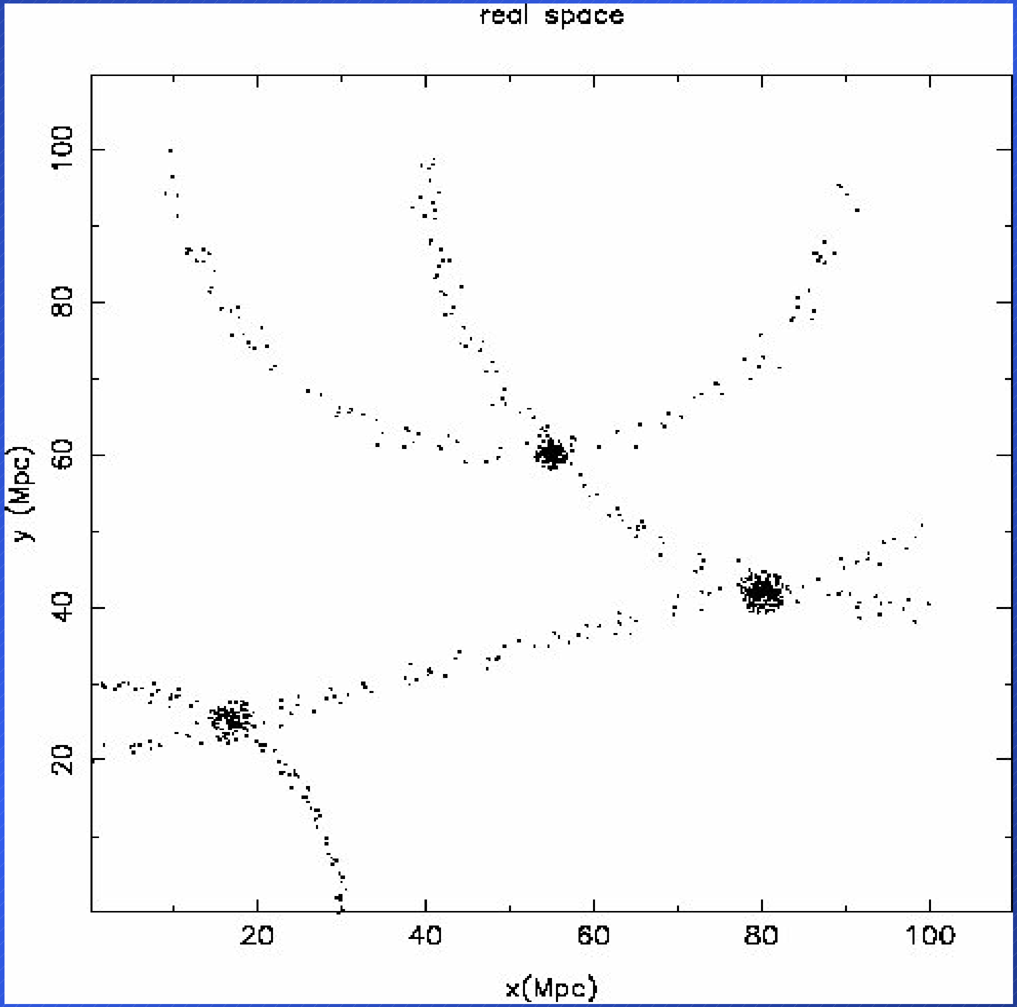
- JPAS (56 bands):

  error in v: ~1,000 km/s



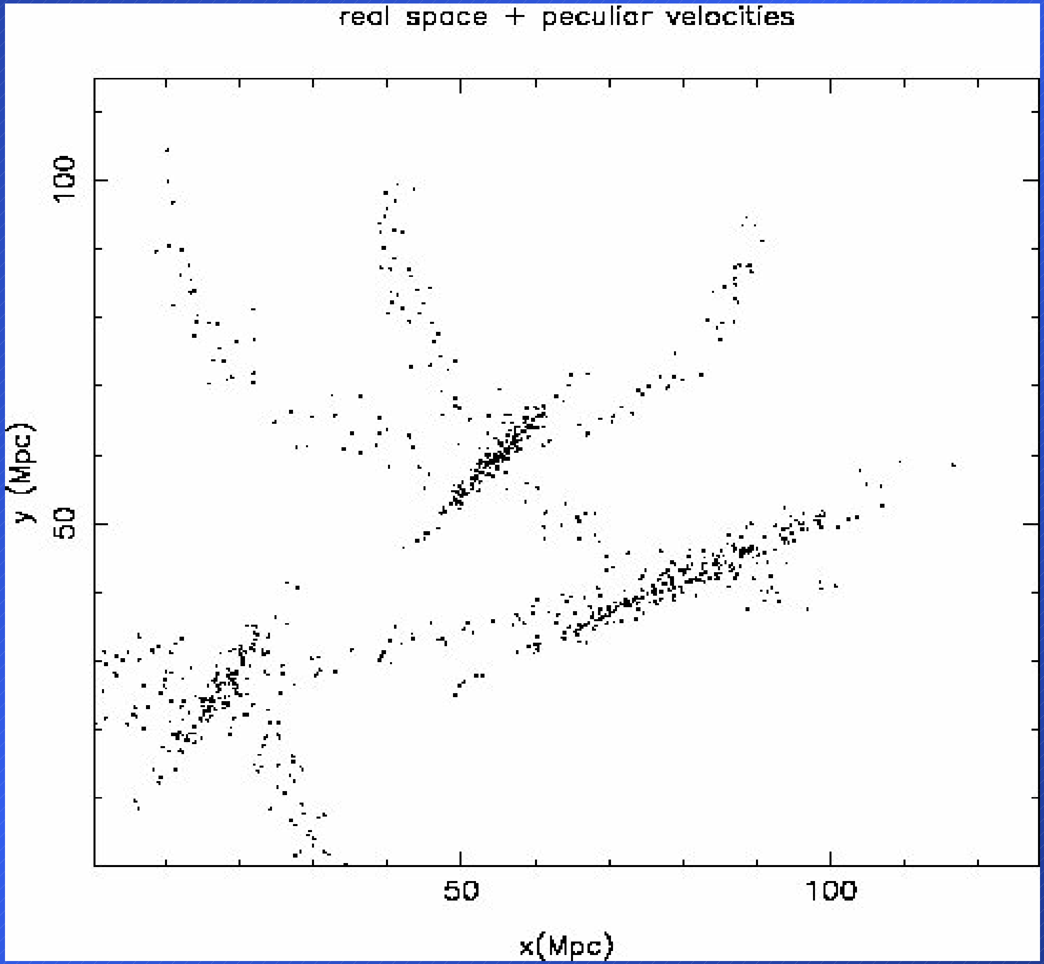
But what we observe?

- an illustration of the 3-D galaxy distribution in the local universe



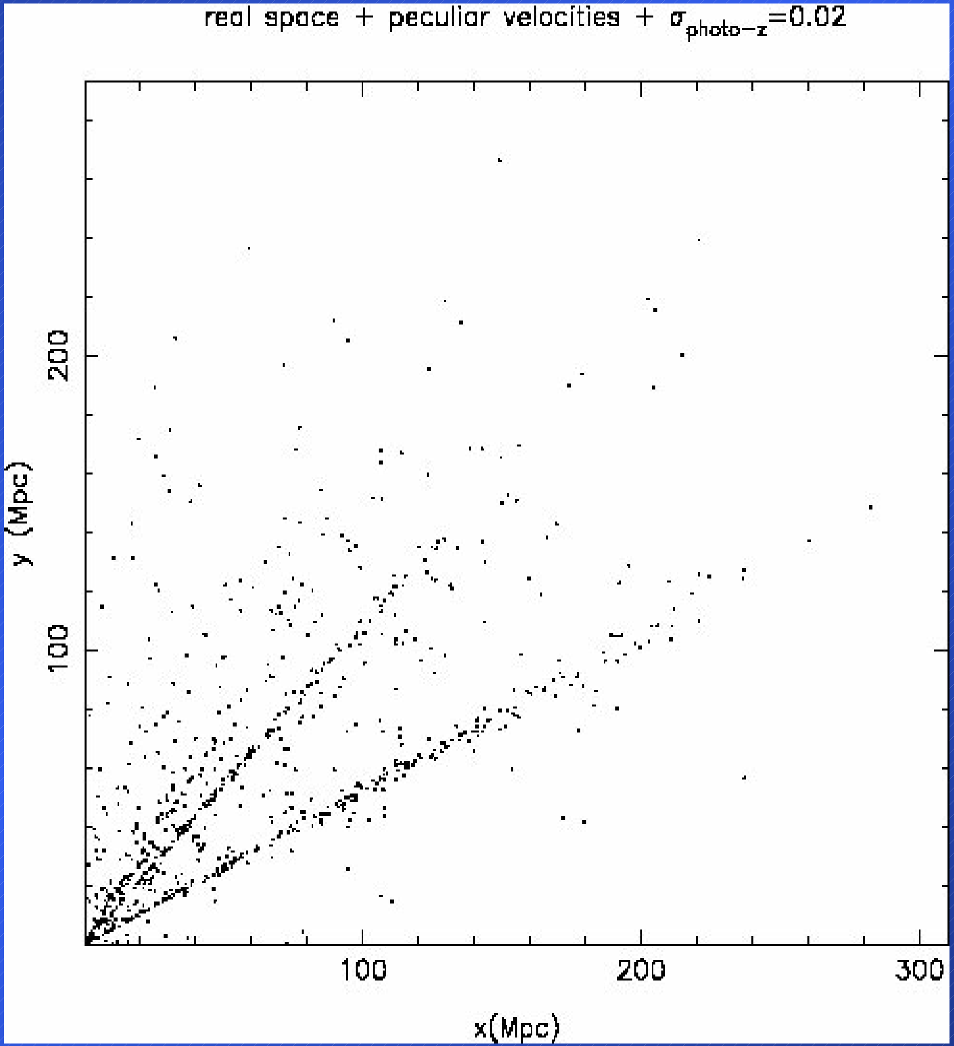
But what we observe?

- Now adding peculiar velocities



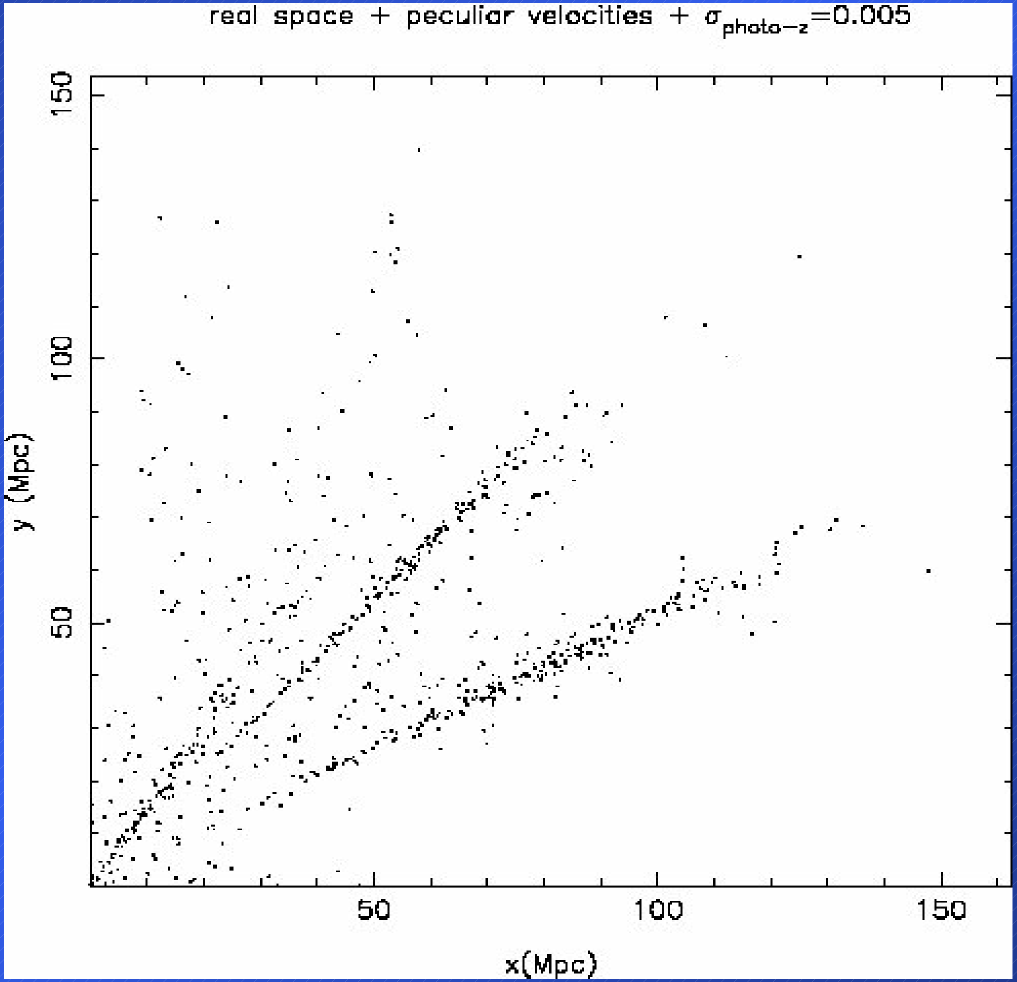
But what we observe?

- + photometric redshift errors (0.02)



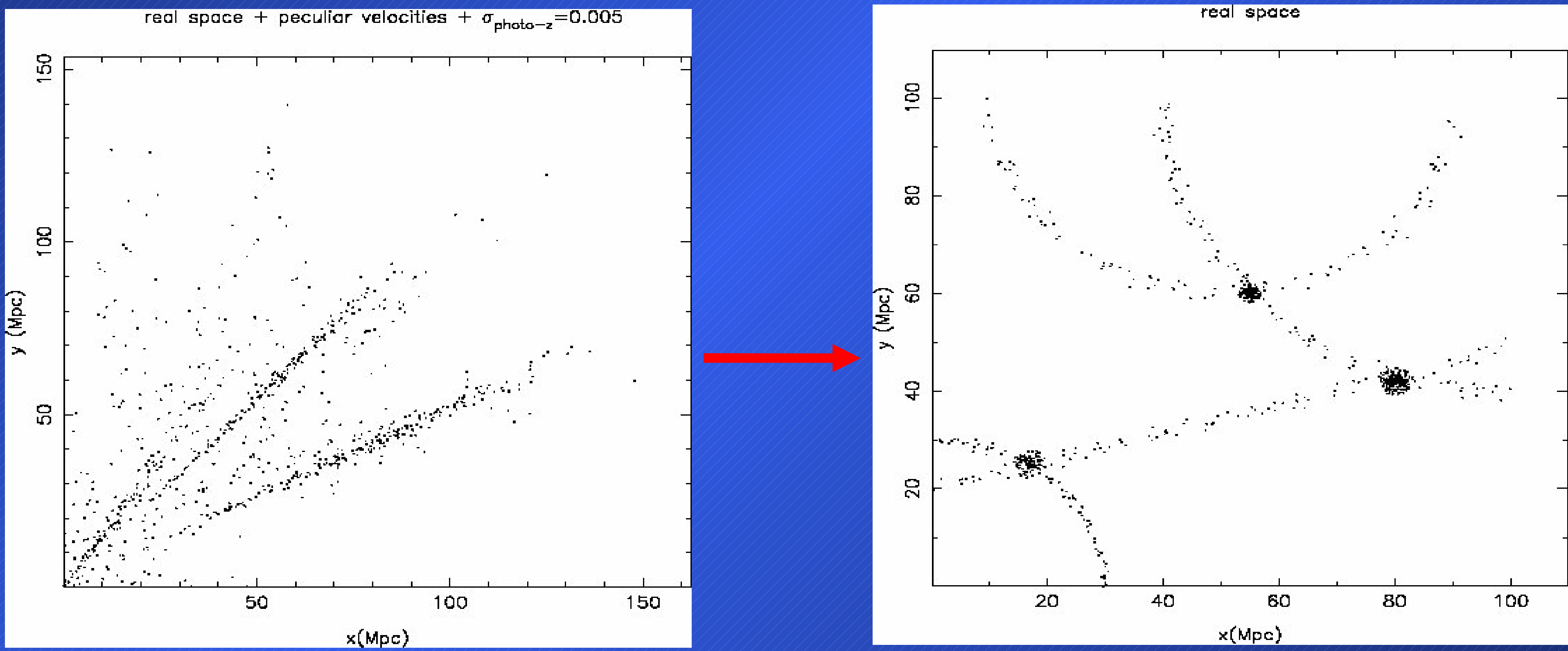
But what we observe?

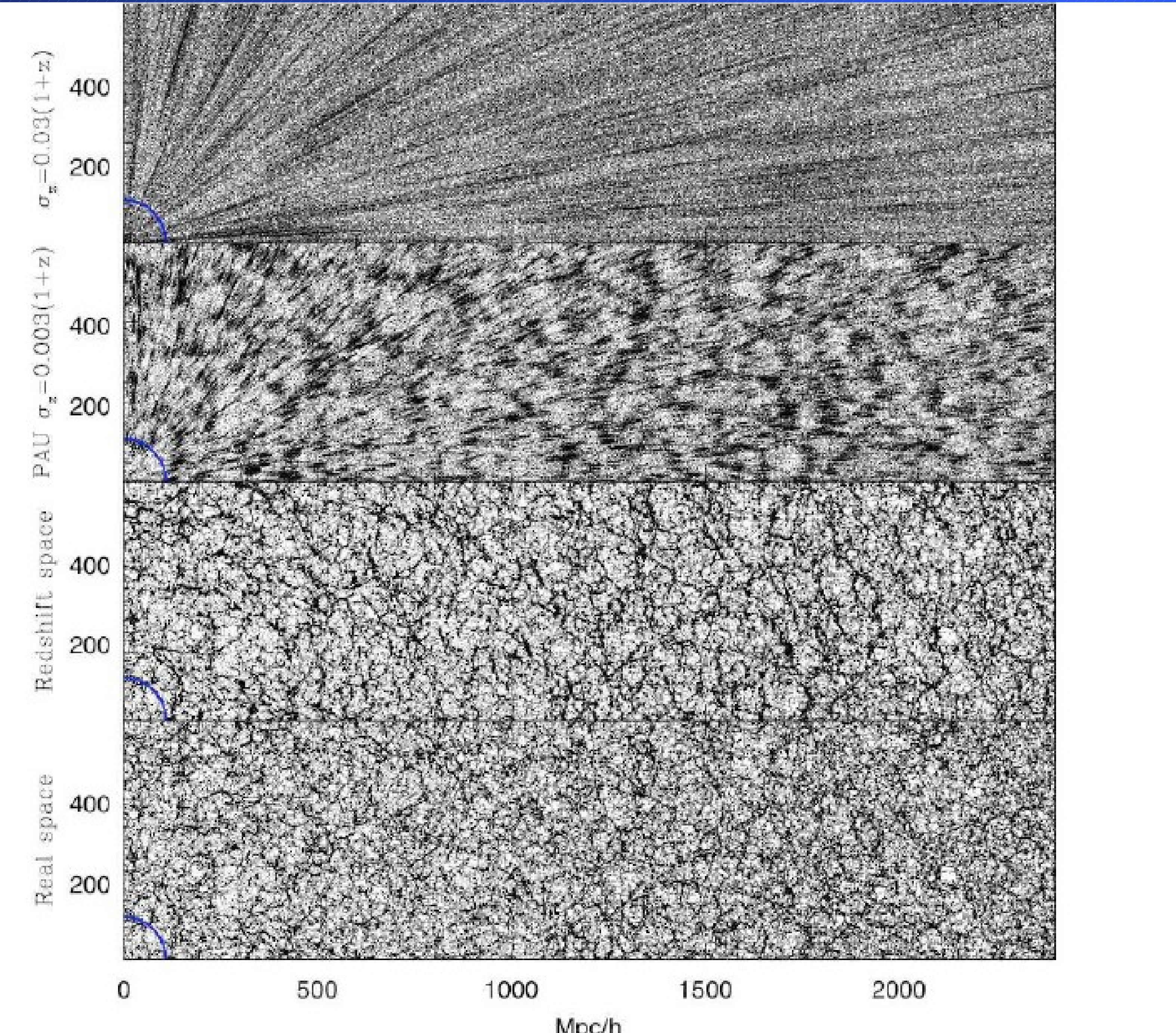
- + photometric redshift errors (0.005)



But what we observe?

- a challenging data analysis!





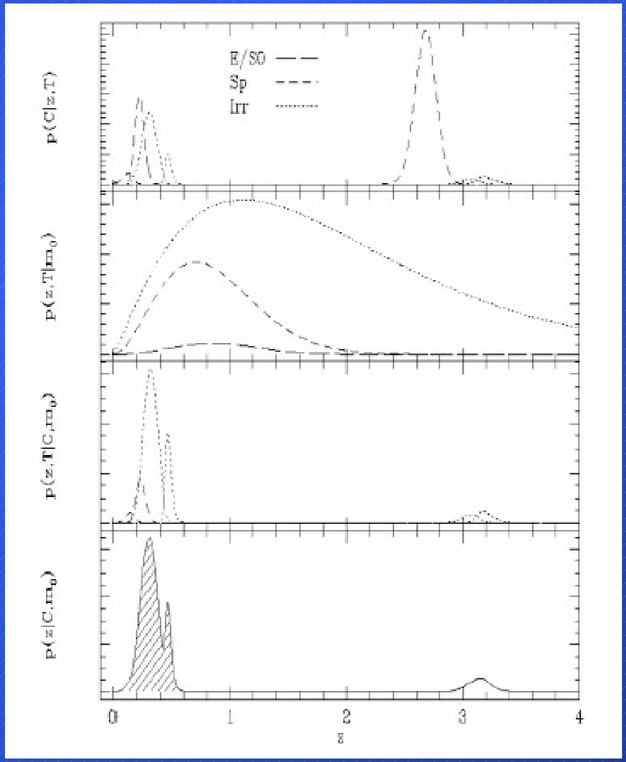
Real space
Redshift space
PAU σ_z=0.003(1+z)
σ_z=0.03(1+z)
200
400
0
500
1000
1500
2000
Mpc/h

Data Analysis: Bayes Theorem

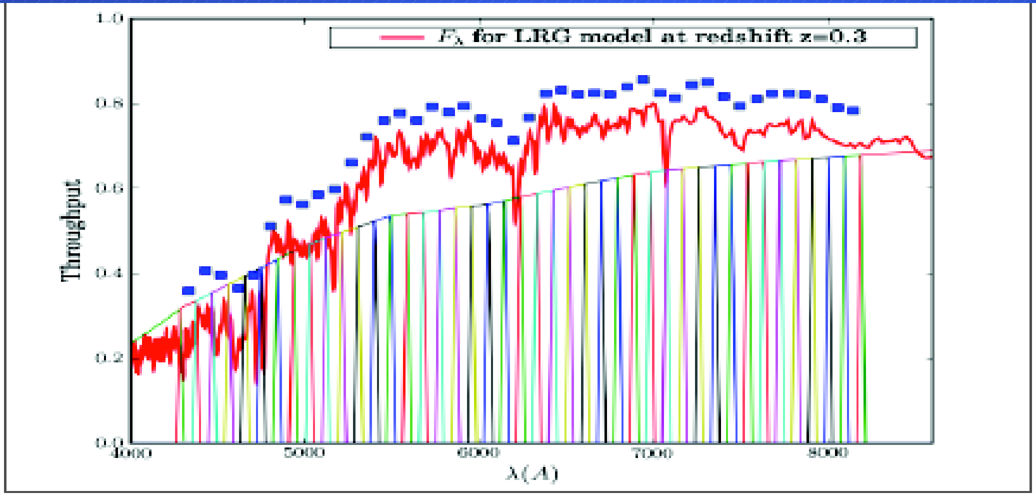
- results very sensitive to uncertainties and selection effects
- estimation of photometric redshifts from colors and magnitudes for galaxies of type T:

  $p(z|C,m)\ \alpha\ \Sigma_T\ p(C|z,T)\ p(z|m,T)\ p(T|m)$

- priors are essential!



JPAS =
ALL SKY IFU



JPAS = Javalambre-*Physics of the Accelerated Universe* Astrophysical Survey, Spanish-Brazilian collaboration

8000 sq.deg. survey with 56 filters with 100A width, I<22.5

Dark site with 0.71 arcsec seeing: Javalambre in Teruel, Spain

2.5m tel. + 5 sq.deg. cam, 1.2Gpix, etendue = 1.5 x PS1

It will measure 0.003(1+z) photo-z for ~100M galaxies

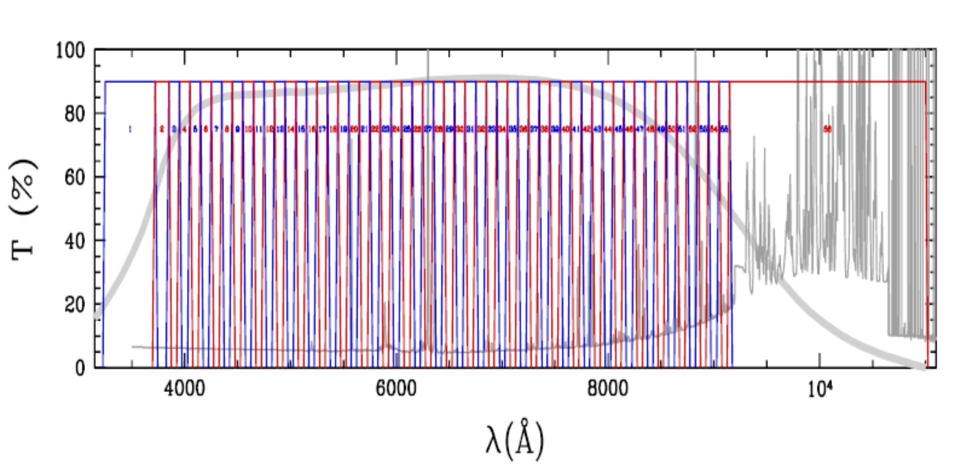
It will measure radial BAOs up to z~1.3: 11 (Gpc/h)^3

Clusters, Weak lensing, SN, QSOs, Galaxy evolution, Stars, Solar system

Start=2013-2014 End= 2017-2018

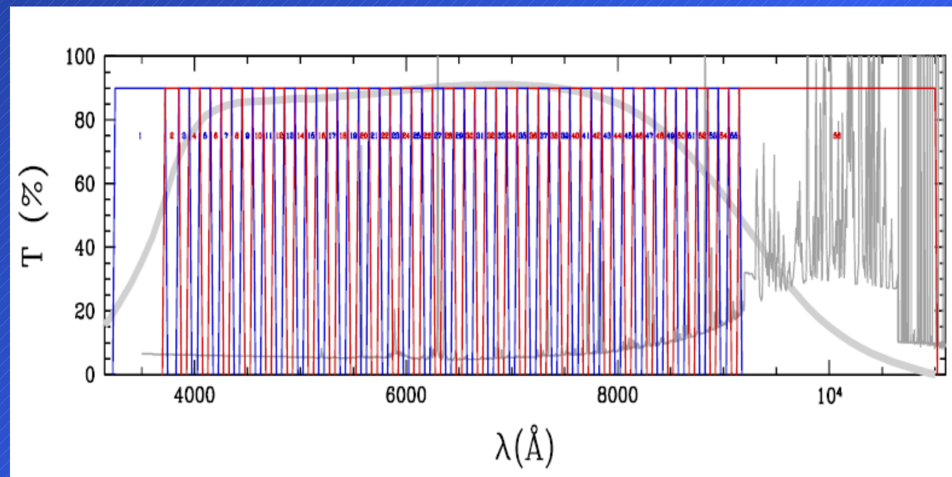
Benítez 2009, ApJ, 691, 241

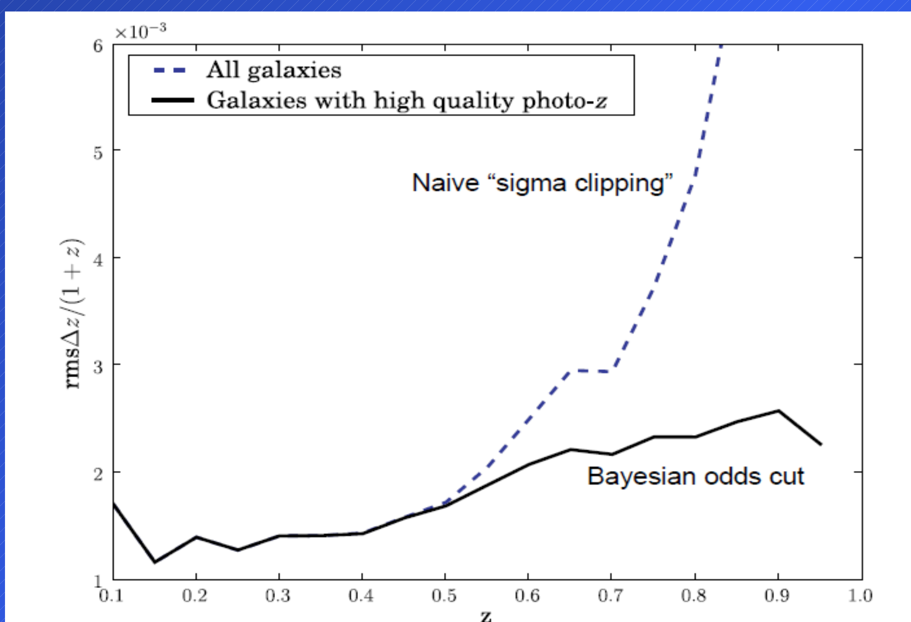
56 filters- accuracy in photo-z: ~0.003(1+z)

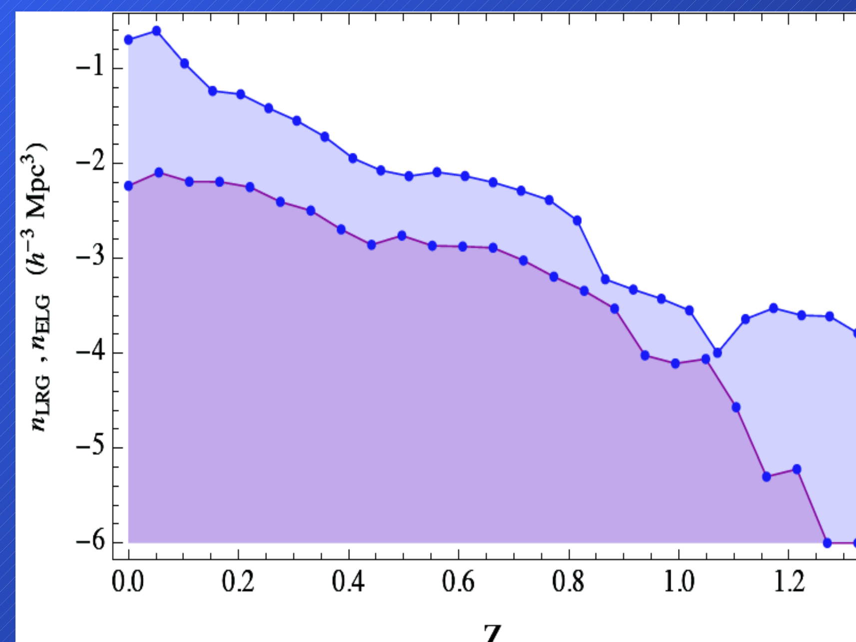


- Low resolution spectra (R~50) for all pixels of an image: *ALL SKY IFU*

56 filters- accuracy in photo-z: ~0.003(1+z)







JPAS

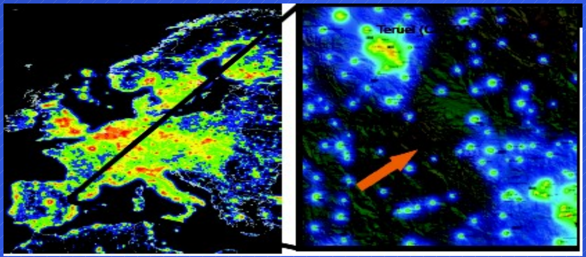
- IAA-CSIC (MICINN)
- CEFCA
- Observatorio Nacional, Río de Janeiro
- Departamento de Astronomia, Universidade de São Paulo
- Centro Brasileiro de Pesquisas Físicas

WHO?

CEFCA: Mariano Moles, Javier Cenarro, David Cristóbal, Antonio Marín-Franch, Nicolás Gruel, Carlos Hernández-Monteagudo, Gustavo Bruzual **IAA:** Txitxo Benítez, Emilio Alfaro, Teresa Aparicio, Carlos Barceló, Rosa González, Javier Gorosabel, Matilde Fernández, Yolanda Jiménez-Teja, Alberto Molino **Universitat de Valencia:** Vicent Martínez, Pablo Arnalte, Juan Fabregat, Alberto Fernández-Soto, Vicent Peris, Vicent Quilis **IAC:** Jordi Cepa, José Miguel Rodríguez-Espinosa, Angel Bongiovanni, José Alfonso López-Aguerri, Elena Ricci, Ignacio Trujillo, Alexander Vazdekis **IFCA:** Xavier Barcons, Enrique Martínez-González, José María Diego, Ignacio González- Serrano, Patricio Vielva **Universidad Complutense de Madrid:** Jesús Gallego, Javier Gorgas, Nicolás Cardiel, Patricia Sánchez-Blázquez **Universidad del País Vasco-EHU:**Tom Broadhurst, Ruth Lazkoz **CAB:** Álvaro Giménez, Eduardo Martín **Universidad de Zaragoza:** Antonio Elipe **Universidad de Barcelona:** Jordi Torra **ESAC:** Enrique Solano **Universidad Autónoma de Madrid:** Gustavo Yepes **Universidad de Florida:** Rafa Guzmán **Brazil** Renato Dupke, Raúl Abramo, Jailson Alcaniz, Bruno Castillo, Mauricio Calvão, Jorge Carvano, Roberto Cid-Fernandes, Eduardo Cypriano, Fabricio Ferrari, Claudia Mendes de Oliveira, Marcelo Rebouças, Thaisa Storchi-Bergman, Keith Taylor, Laerte Sodré, Joao Steiner, Eduardo Telles, Ioav Waga

WHERE?

Sierra de Javalambre,Teruel, Spain
Site testing since 2007 @ Moles et al. (2010), PASP, Vol. 122, 889, 363



JPAS STRUCTURE

Scientific Coordinators: Txitxo Benítez and Renato Dupke

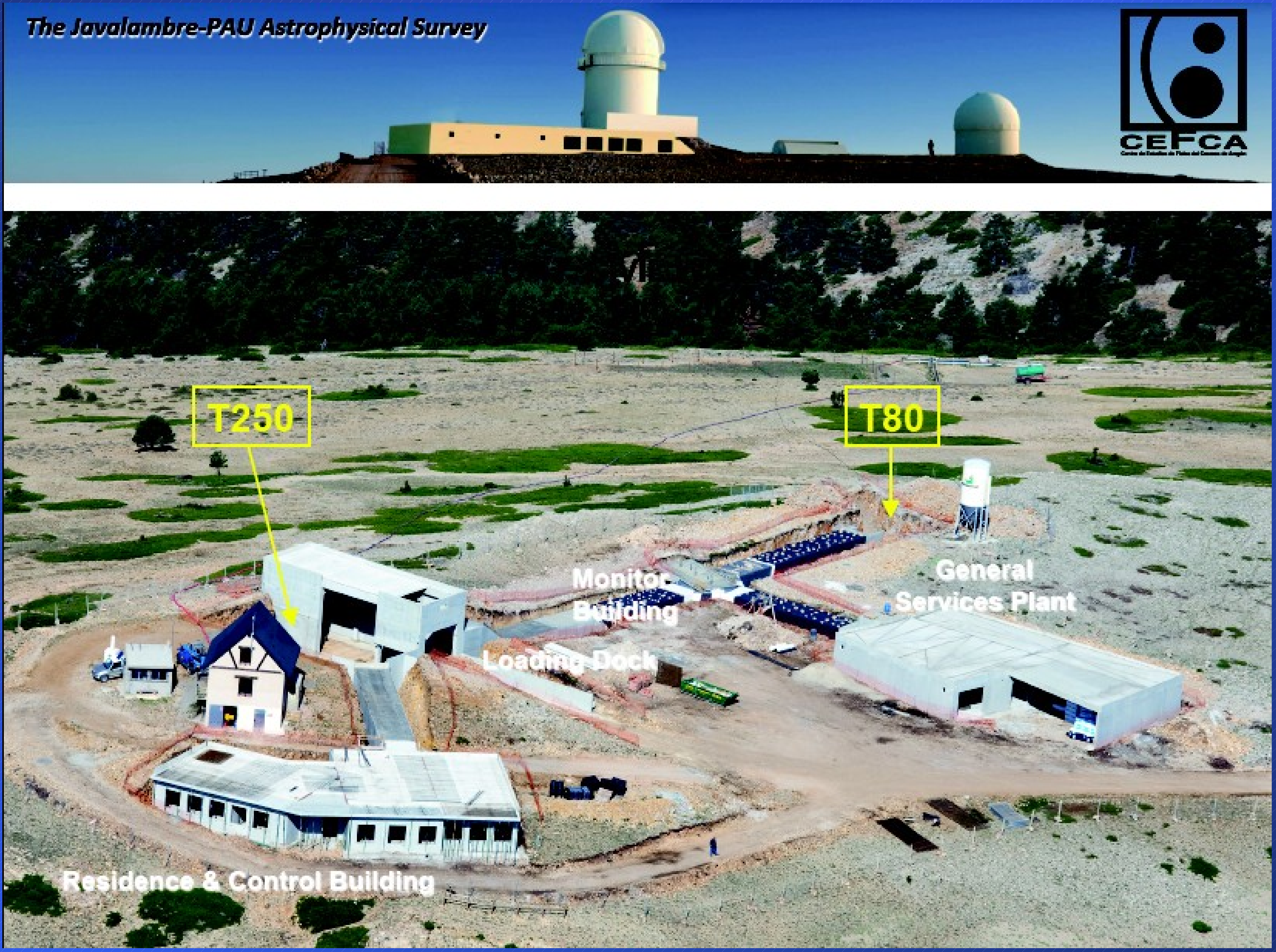
Scientific Board: + Mariano Moles, Laerte Sodré

SMC: +Keith Taylor, Jordi Cepa, J. Cenarro, A. Marín-Franch, Claudia Mendes de Oliveira, A. Fernández-Soto, D. Cristóbal

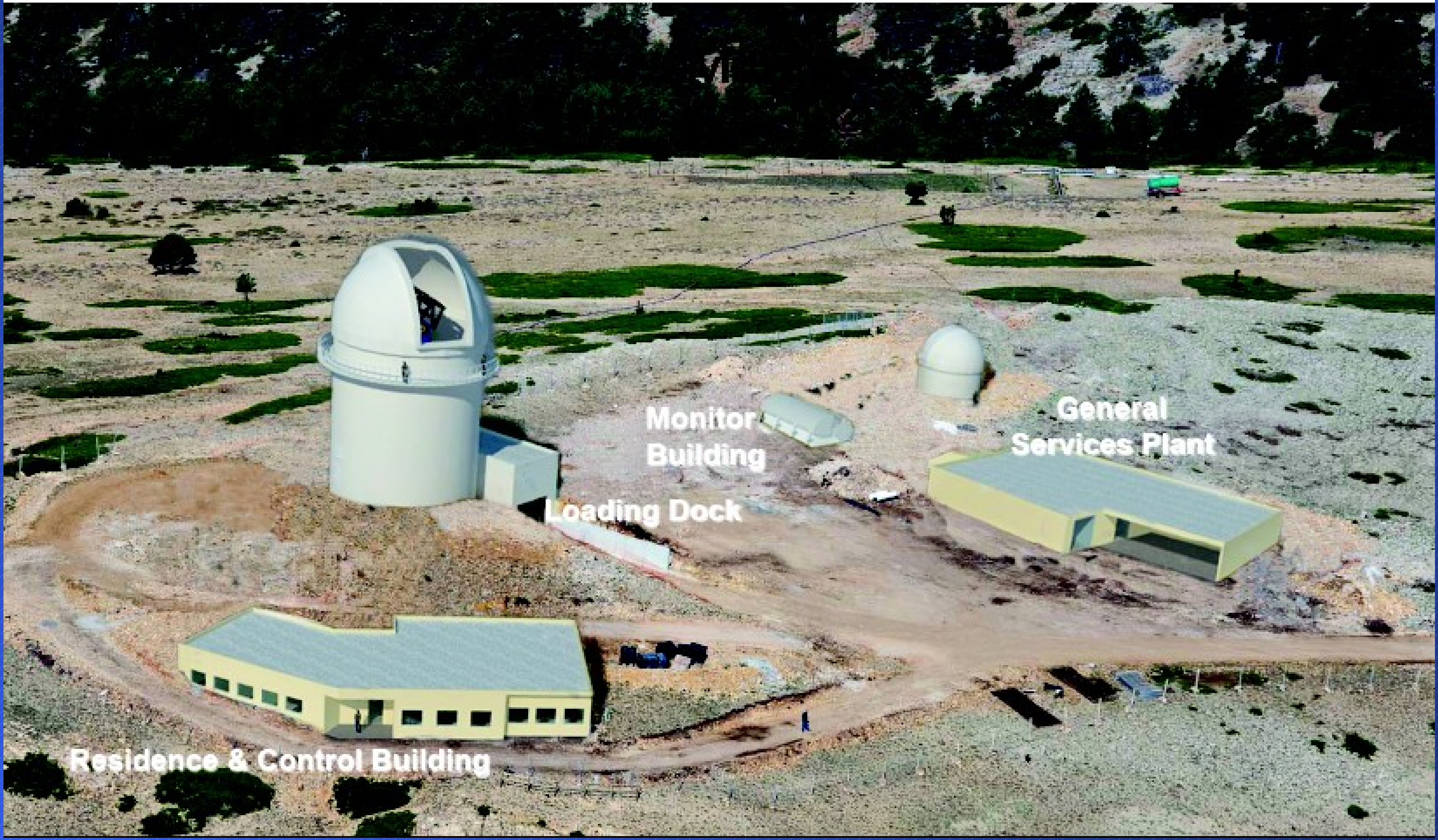
SWGs ranging from Theory to Solar System (R. Abramo, J. Alcaniz, T. Broadhurst, E. Martin, J. Carvano, J. Gorosabel)

~70 astronomers (and some physicists) from most Spanish and Brazilian institutions

FULLY FUNDED: total budget **~30M€** (includes observatory construction and running costs; hardware costs for T250+camera **~ 15M€**)


The Javalambre-PAU Astrophysical Survey
CEFCA
T250
T80
Monitor Building
General Services Plant
Loading Dock
Residence & Control Building


The Javalambre-PAU Astrophysical Survey
CEFCA


Monitor
Building
General
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Loading Dock
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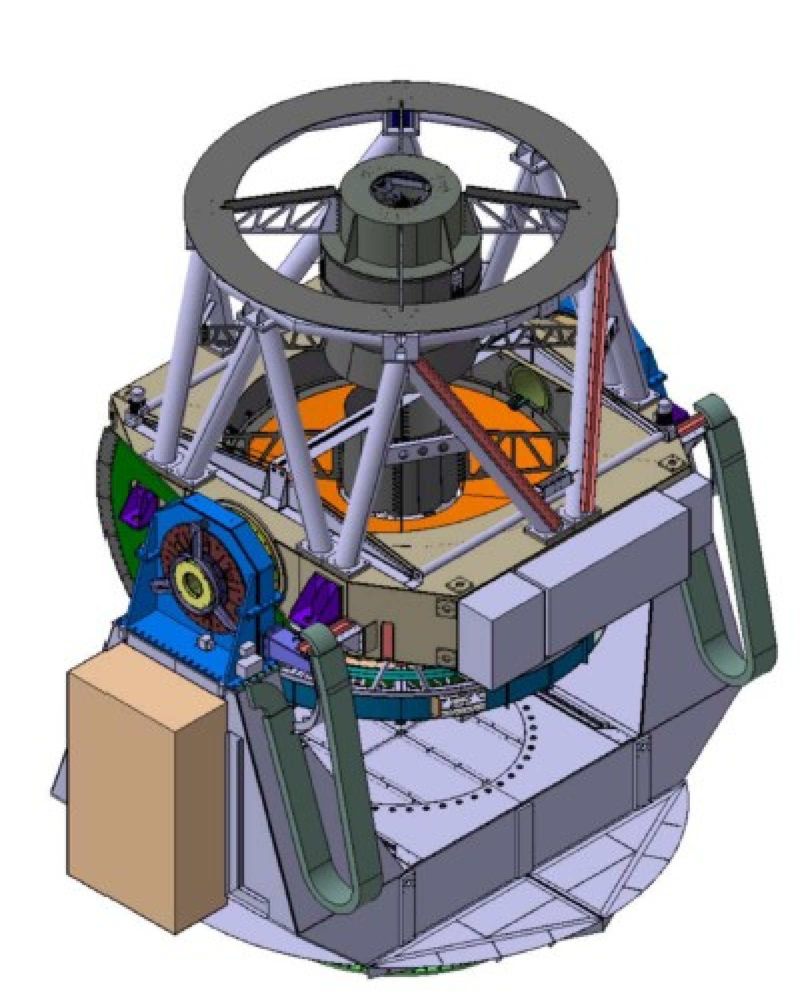
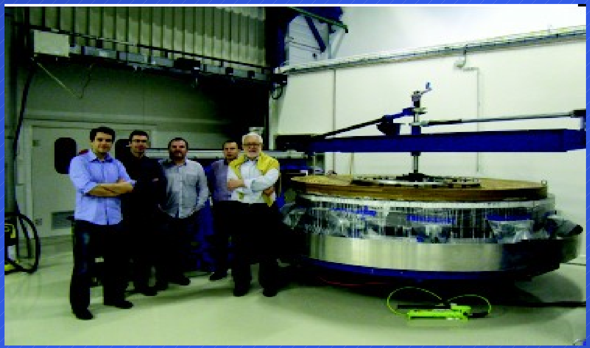


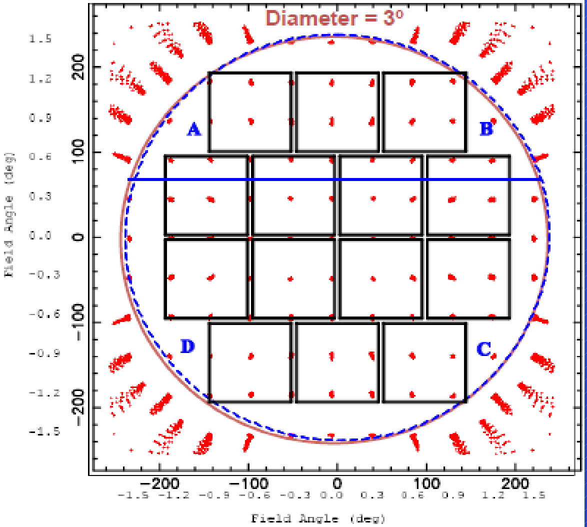


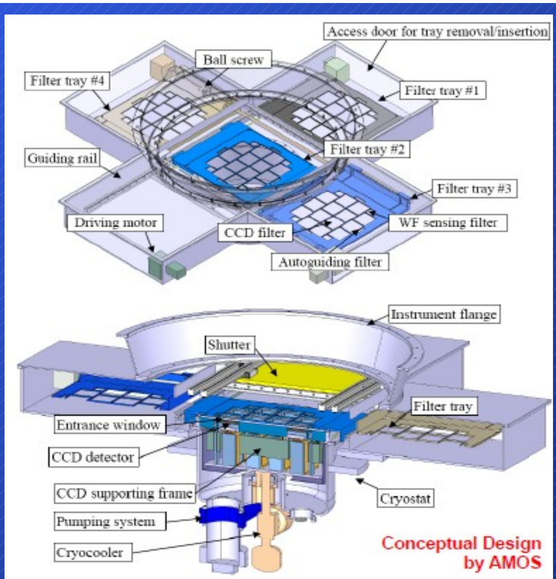
5 sq.deg. / 1.2Gpix

-14 different filters per tray

- Each CCD only “sees” 1 filter per tray

-J-PAS requires 56 narrow band filters (4 trays x 14 CCD/tray)





WHEN?

T250

March 2010: T250 contracted with AMOS

August 2011: T250 camera contracted

February 2012 : 1st E2V CCD

August 2012 : T250 telescope delivered

November 2012 : 16th CCD delivered

August 2013: T250 operational

August 2013: T250 camera delivered

Beginning 2014: JPAS survey starts

End 2016: $0.6 < z < 1.3$ BAO survey finished

End 2018: Full survey finished

T80:

July 2011: T80 Camera contracted

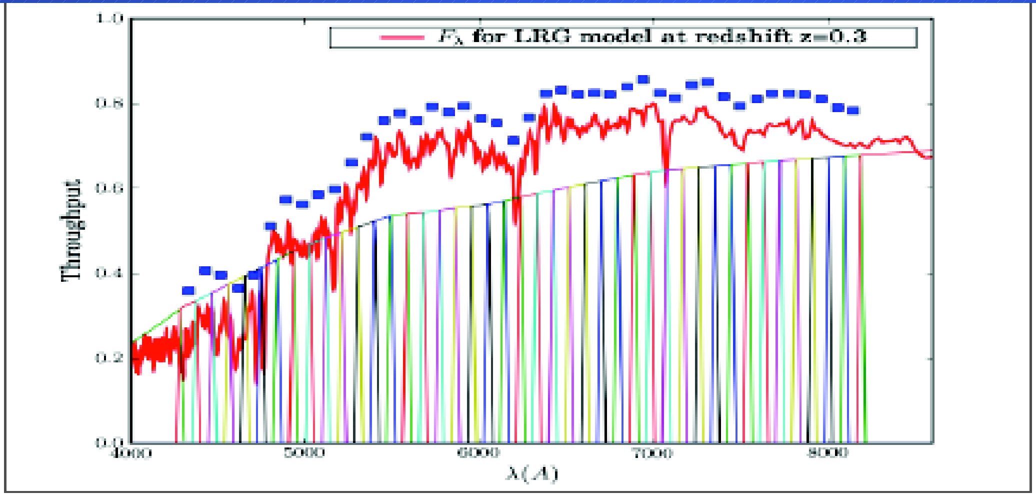
August 2011: T80 delivered

March 2012: T80 operacional

July 2013: T80 camera delivered

October 2012: T80 camera operational, miniJPAS starts

JPAS =
ALL SKY IFU



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Clusters, Weak lensing, SN, QSOs, Galaxy evolution, Stars, Solar system

Start=2013-2014 End= 2017-2018

Benítez 2009, ApJ, 691, 241

Projeto Pau-Brasil Sul

- Idéia básica: "clonar" os telescópios, câmeras, etc do J-PAS
- Instalar os telescópios em um sítio de primeira linha no Chile ou Argentina

Vantagens:

- Aceleração na obtenção dos resultados científicos e portanto no impacto do J-PAS
- Além de conduzir um survey semelhante ao J-PAS, junto com este poderemos conduzir um survey de TODO o CÉU!
- Arqueologia estelar: populações e satélites da Via Láctea
- Sinergia com outros projetos: robótico (tecnologia), LSST (redshifts – *CONTRIBUIÇÃO ÚNICA!*)
- Custo (incluindo 7 anos de operações): < US$32M (parcerias?)

Oportunidade de ouro para nossa astronomia: permitirá fazer big science, construir e gerenciar grandes equipamentos e um grande levantamento, produzindo um legado que dará extraordinária visibilidade à astronomia brasileira!

SuMIRe/PFS

Subaru Measurement of Images & Redshits
Prime Focus Spectrograph

- Project leaded by IPMU/Tokyo (PI: Hitoshi Murayama)

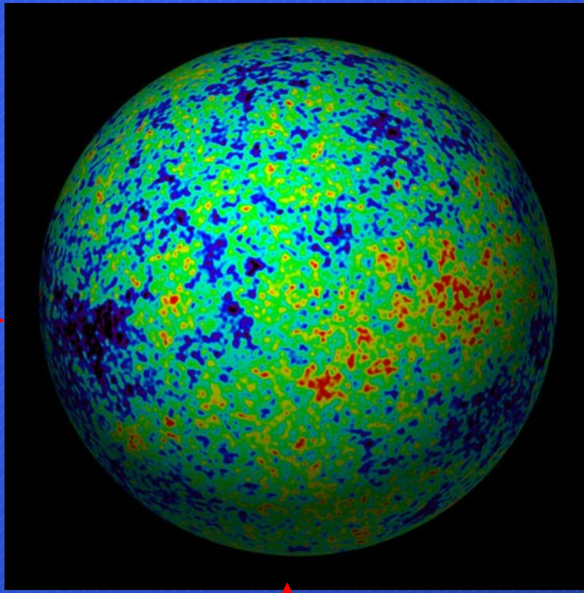
(+ NAOJ, Princeton, Caltech, Marseille, Edinburgh, Taiwan, IAG, LNA)

- Subaru: 8m telescope; 1.77 sq. deg. FOV
- HyperSuprimeCam imaging survey from 2011;
  2000 sq. deg.; 0.9B pixels
- Prime Focus Spectrograph follows ~2017
- PFS: ~2500 simultaneous spectra!
- Surveys:
  - 2000 sq. deg. @ z=0.6-1.6; ~2M objects
  - 300 sq. deg. @ z=2.3-3.3; ~0.6M objects
  - 100 dark nights

Dark Matter and galaxy formation

basic hypothesis:

just after the Big Bang the Universe was very homogeneous, with small density fluctuation produced during inflation;



these fluctuations are the seeds of galaxies and large scale structures and grow by gravity

$\approx 10^{-5}$

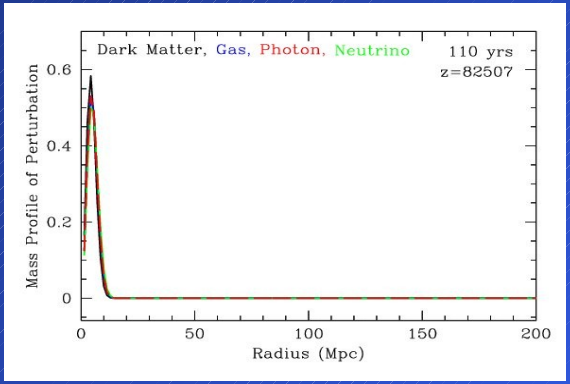
$$(\Delta\rho/\rho)_o \approx (\Delta\rho/\rho)_{rec}\,(1+z_{rec})$$

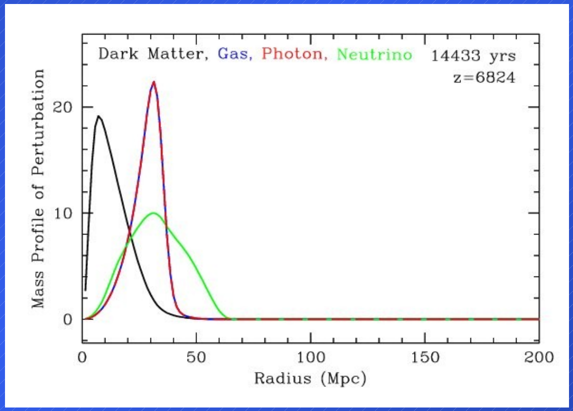
10^{-2}!!

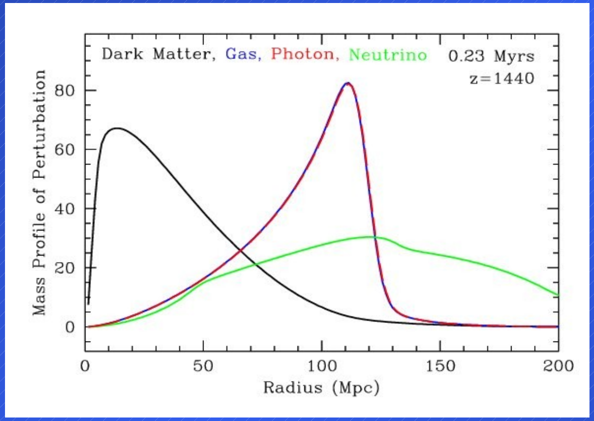
1000

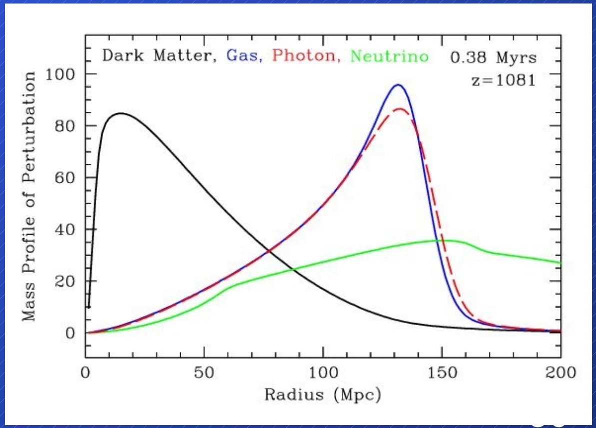
problem: in a purely baryonic universe, galaxies do not have time to form!! A material, non-baryonic component is necessary: *dark matter*

Structure Formation: BAOs evolution of the density profile $\rho(r)r^2$









recombination