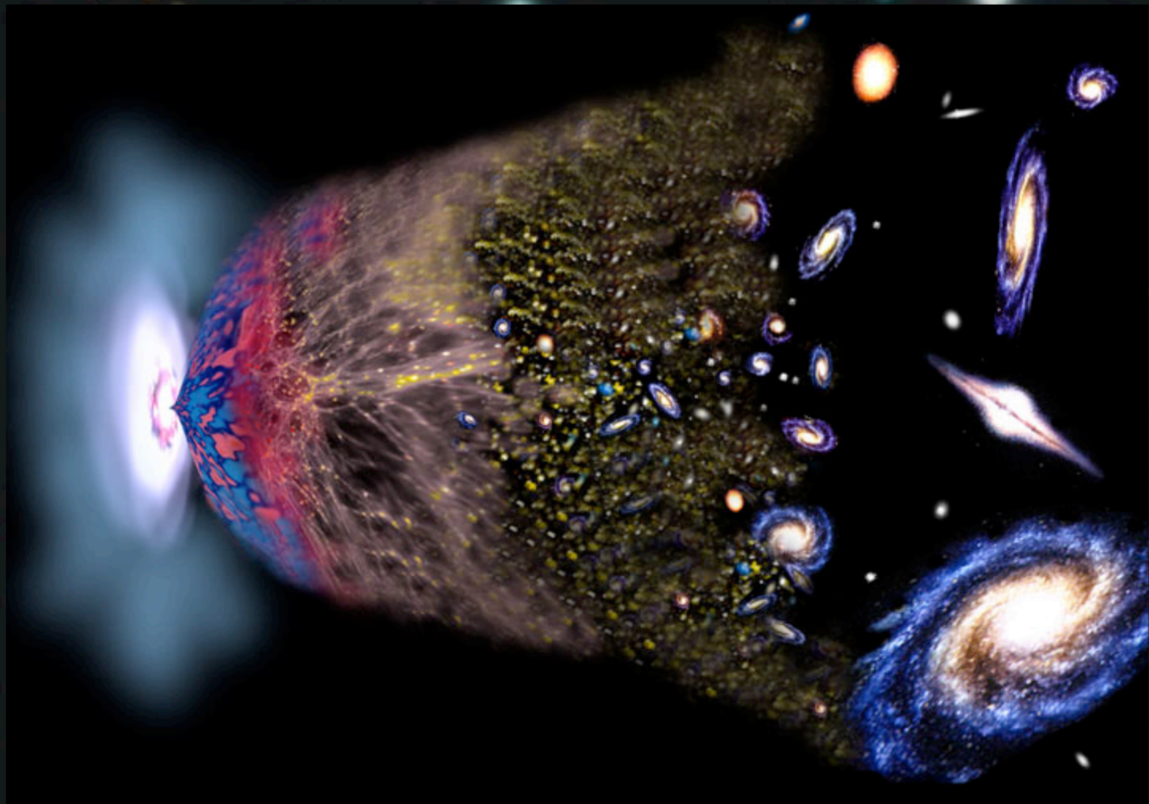
Challenges of the accelerating Universe



Raul Jimenez
Institute of Space Sciences (ICE) ICREA (CSIC-IEEC)

Compare DE with other major discoveries in physics

- ★ Constancy of the speed of light (1887)
- ★ Discovery of the μ-particle (1936)
- ★ Discovery of the Ω^- baryon (1964)
- ★ Cosmic Backgroud Radiation (1965)
- ★ W and Z bosons (1983)
- ☆ Higgs particle ?? (2008/2009 ??)

Compare DE with other major discoveries in physics

- ★ Constancy of the speed of light (1887)
- ★ Discovery of the μ-particle (1936)
- ★ Dark Energy
- ★ Discovery of the Ω^- baryon (1964)
- ★ Cosmic Backgroud Radiation (1965)
- ★ W and Z bosons (1983)
- ☆ Higgs particle ?? (2008/2009 ??)

Michelson & Morley result was against the theoretical expectations (theory of aether)

Nobody expected the muon **Who ordered the muon?** **(I.I. Rabi)**
but it does not challenge the theoretical framework

The DE discovery is also against the theoretical expectations

It likely requires a radical change in our pre -conceptions

A continuation of the cosmological constant problem: why is Λ that small???

The Challenges

Challenge n1: If it's Λ why is it that small?

On this issue astronomers have done their work already (I.e. Λ is non zero)
Now it is the job of theoretical physicists

Although the landscape is getting fashionable

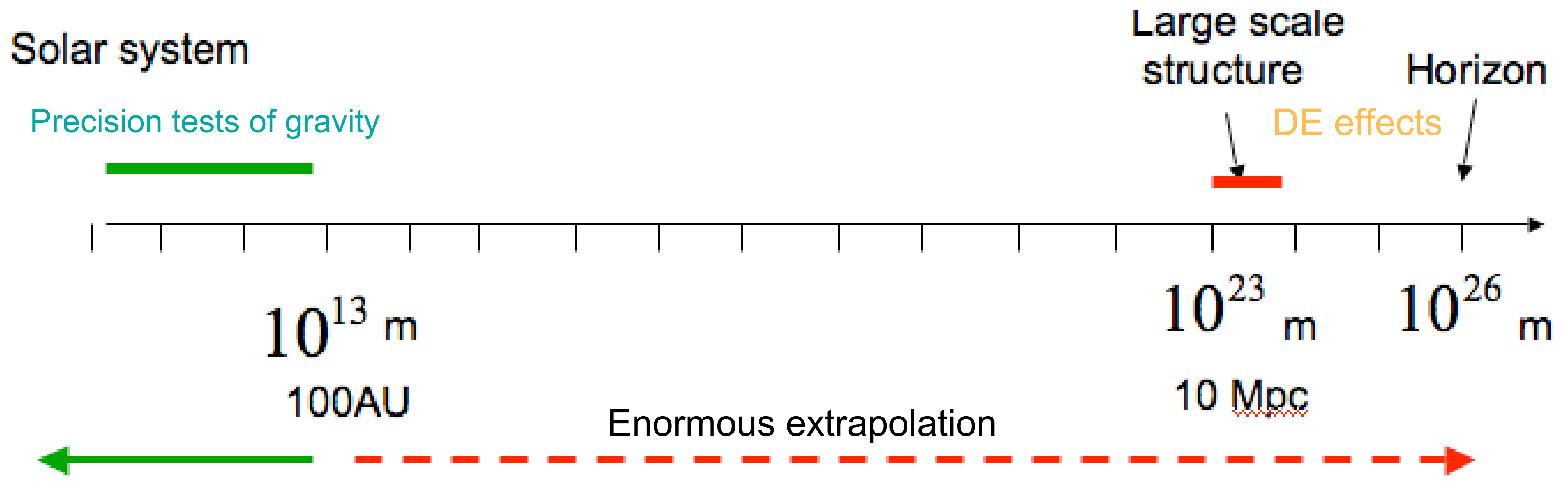
Challenge n2: is it dynamical?

Astronomers: go measure it!

Theoretical physicists: which parameterization?

Challenge n3: are we sure we know gravity?

A few words about challenge n 3….



Any modification of gravity of the form of f(R) can be written as a dynamical DE model for a(t)

The same data for challenge n 2 will do here

In general, this degeneracy is lifted when considering the growth of structure (e.g. Sealfon, Verde, RJ '05)

Otherwhise early/vs late-time observables will discriminate (e.g., Acquaviva & Verde '07)

Challenge n2: is it dynamical?

Theoretical physicists: which parameterization?

To give you a flavor, assume it is a slowly rolling potential and think about inflation

$$\varepsilon_1 = -\frac{\dot{H}}{H^2} = 1 - \frac{\ddot{a}}{a} H^{-2} = \frac{dH}{dz}\frac{(1+z)}{H}$$

Similar to horizon flow parameters (from Simon, Verde, RJ PRD 2005)

$$V(z) = (3 - \varepsilon_1)\frac{H^2}{\kappa} - \frac{1}{2}\rho_m$$

$H(z)$

$\dot{H}(z)$

$$K(z) = \varepsilon_1 \frac{H^2}{\kappa} - \frac{1}{2}\rho_m$$

Just integrate to get $\phi(z)$

But if you have a parameterization (or a model)

$$3H^2(z) - \frac{1}{2}(1+z)\frac{dH^2(z)}{dz} = \kappa\left(V(\alpha_i,\, z) + \frac{1}{2}\rho_m(z)\right) \equiv g(\alpha_i,\, z)$$

Can be integrated analytically!

Challenge n2: is it dynamical?

Astronomers: go measure it!

CMB (only secondary anisotropies will help: ACT, SPT, APEX, etc…)

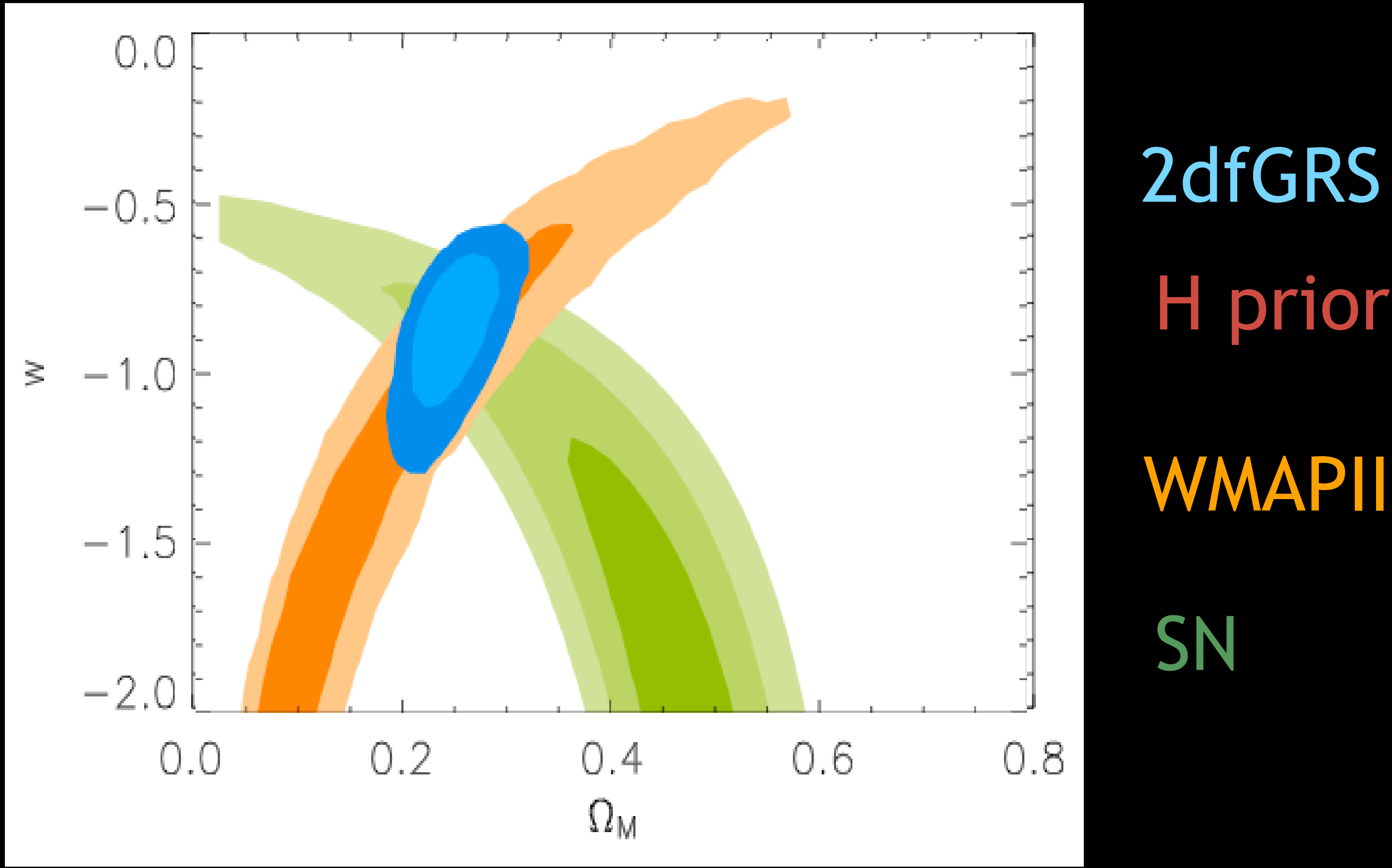
SNe (SLNS, ESSENCE, SNAP, LSST, SDSSII, etc.)

Gravitational Lensing (DES, Panstarr, LSST, DUNE,…)

Galaxy Clusters (ACT, SPT, APEX…)

BAO… (DES, WFMOS, VISTA, AAO, BOSS, ADEPT, SPACE…)

Dark energy so far...



With DE clustering

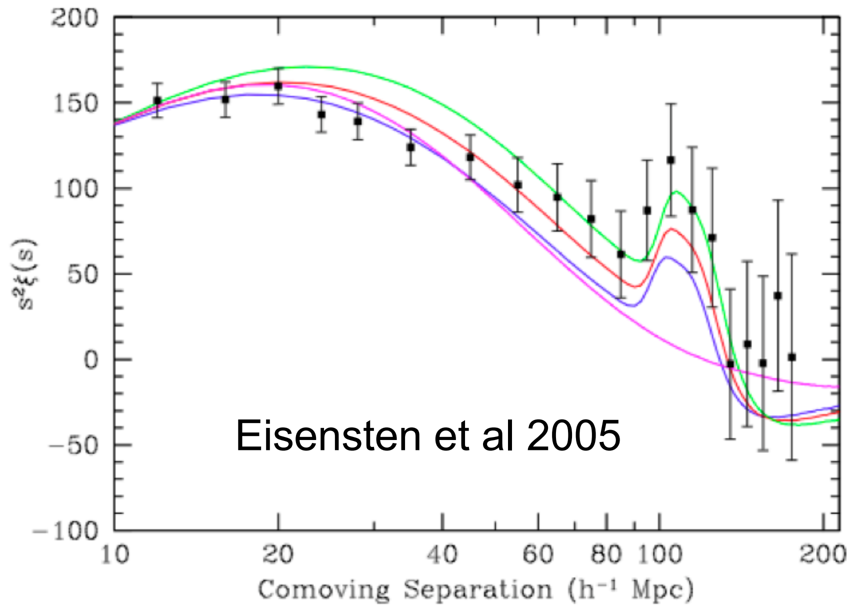
Why so weak dark energy constraints from CMB?

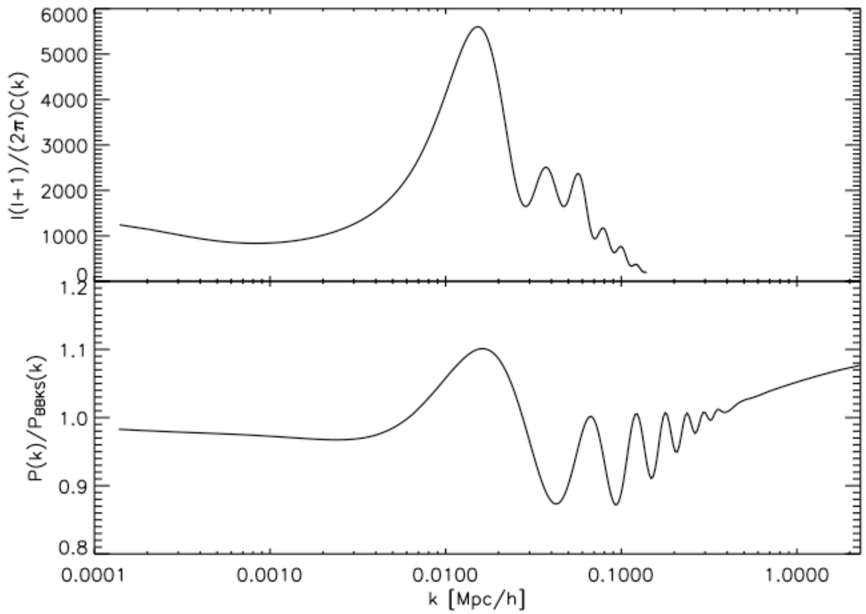
The limitation of the CMB in constraining dark energy is that the CMB is located at $z=1090$.

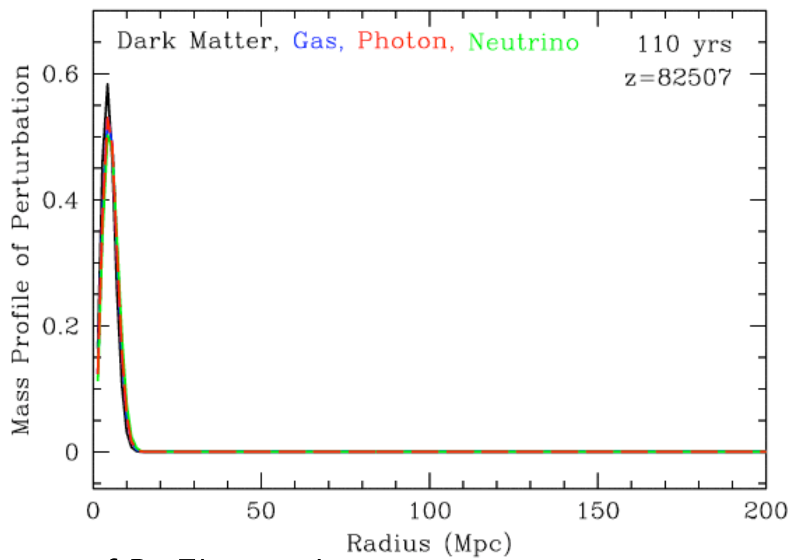
We need to look at the expansion history (I.e. at least two snapshots of the Universe)

What if one could see the peaks pattern also at lower redshifts?

Baryonic Acoustic Oscillations







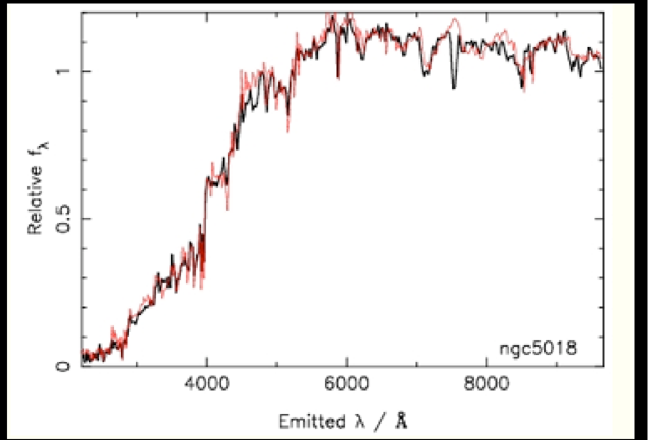
Evolution of a single
perturbation,
Imagine a superposition

Courtesy of D. Eisenstein

Spectroscopy or photometry?

AAOmega 600K galaxies, z~1 (10% error on w)

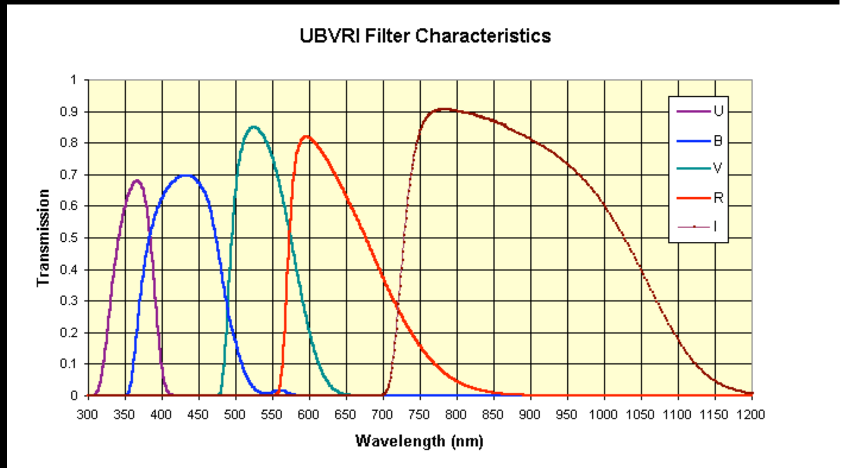
WFMOS several million galaxies >2012



VISTA, DES, LSST

Degrade information in the z direction but is faster & can cover more sky

Could do weak lensing almost for free



The debate is still open!

PAU

http://www.ice.csic.es/research/PAU/PAU-welcome.html

Close collaboration between particle physicists (theorists and experimentalists) and astrophysicists (theorists and observers)

Awarded consolider-ingenio 2010, E. Fernandez, PI

"Hybrid" technique: narrow band photometry (the best of both worlds?)

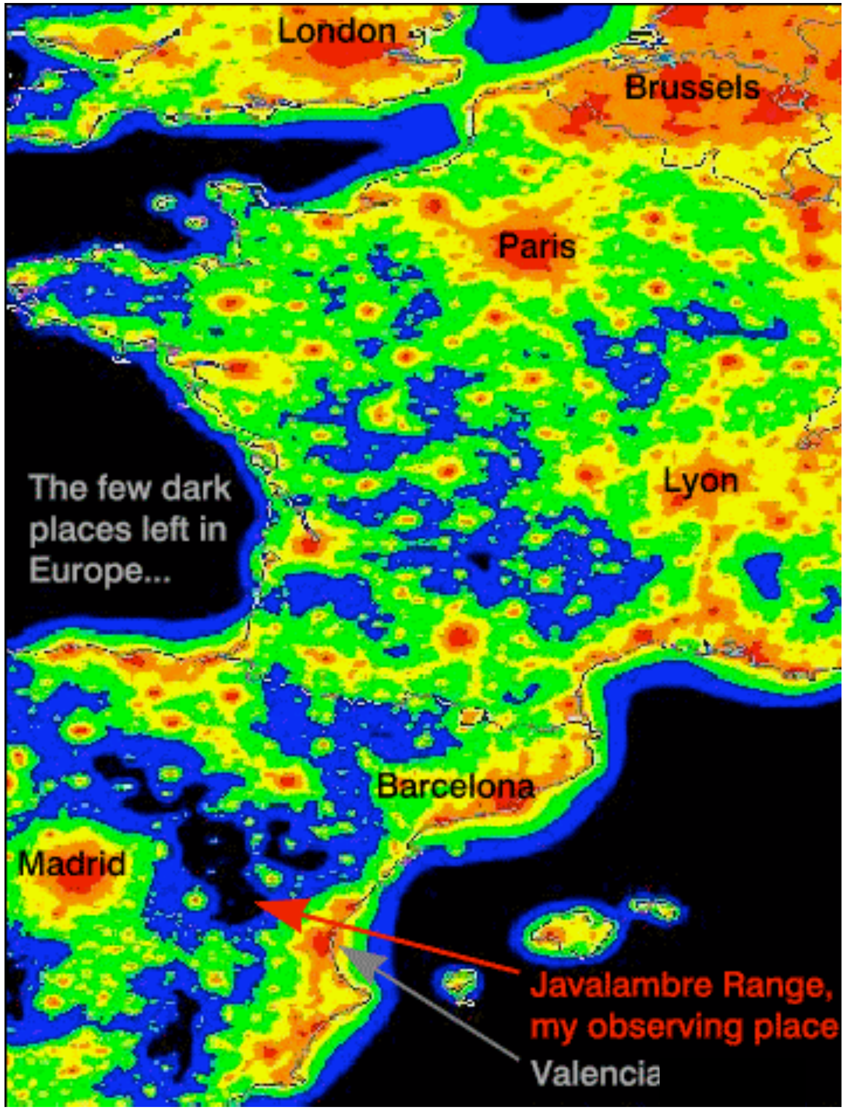
Survey ~10000 deg^2 $0.1<z<1.0$,   ~40M galaxies

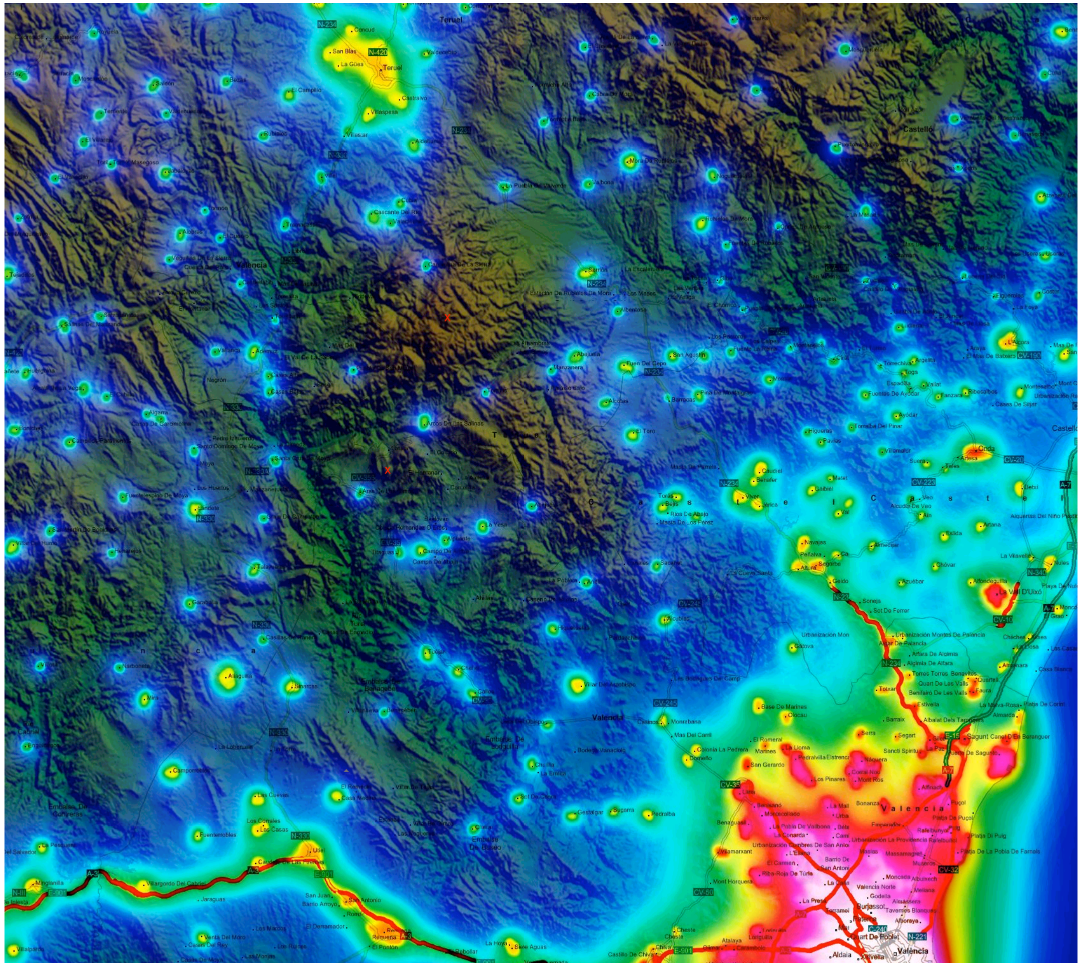
Dedicated telescope, 7 sq º FoV. New camera (~3500-9000 AA)

Measures both H(z) and Da

Instituto de fisica de alta energias (IFAE-Barcelona)
Instituto de ciencias del Espacio (ICE-Barcelona)
Instituto astrofisico de Andalucia (IAA-Granada)
Instituto de fisica teorica (IFT-Madrid)
Centro de investigaciones[…] (CIEMAT-Madrid)
Instituto de fisica corpuscolar (IFIC -Valencia)
Puerto de informacion Cientifica(PIC-Barcelona)

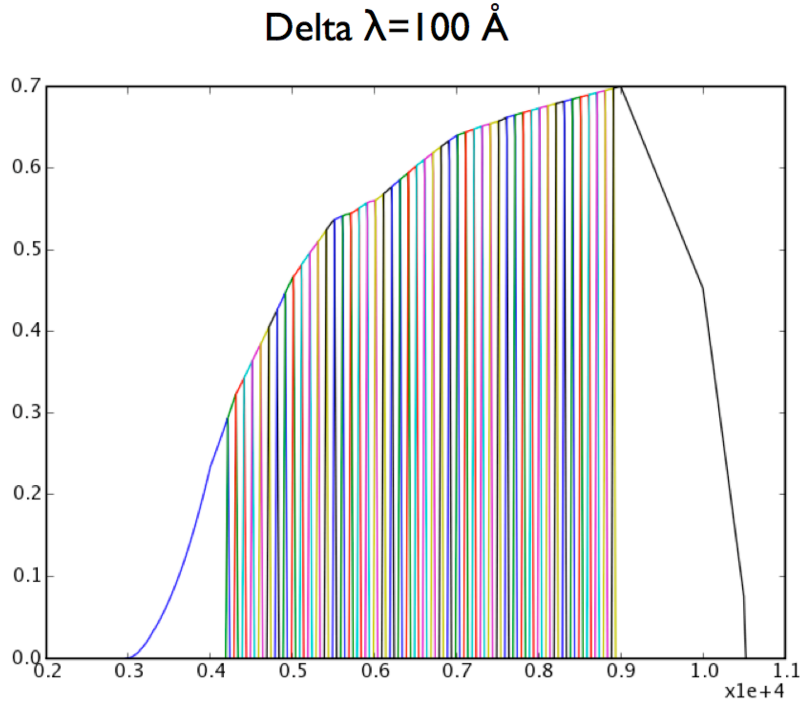
Location, location,location….

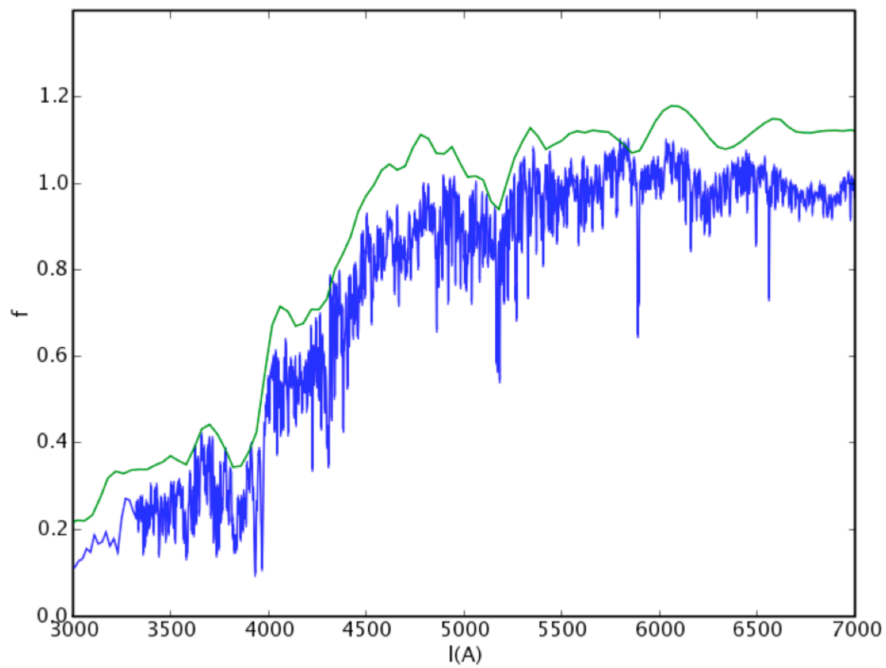




THE IDEA:

New
photometric system

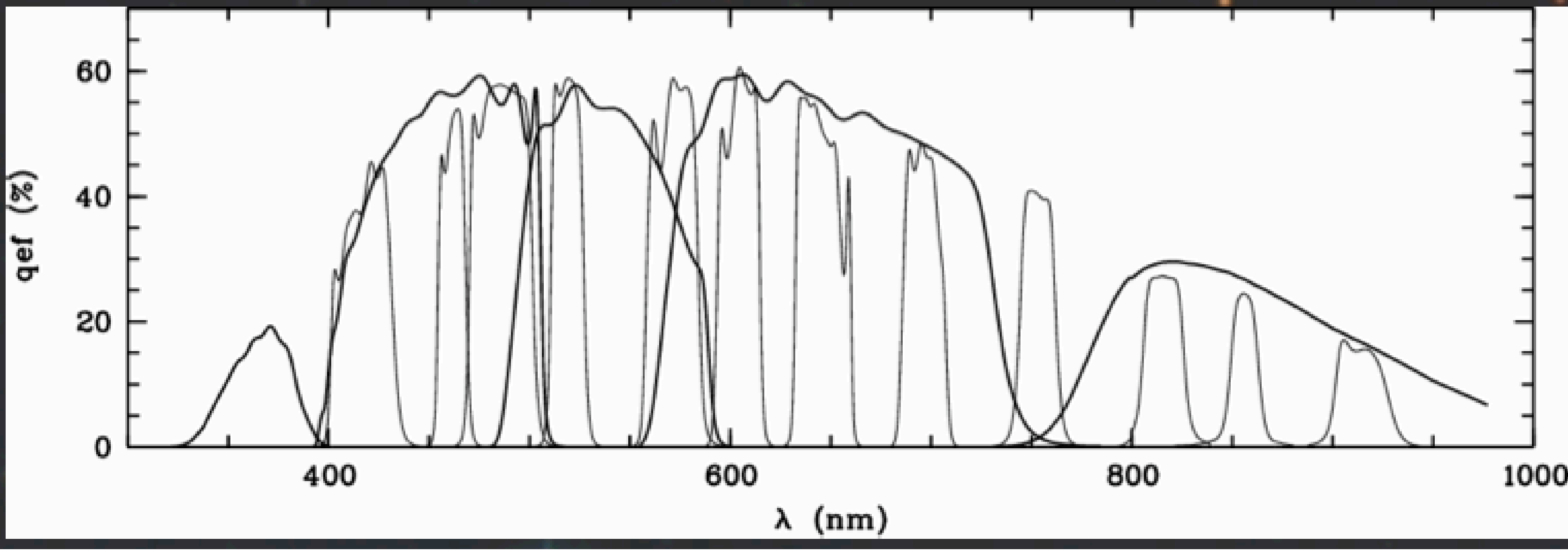




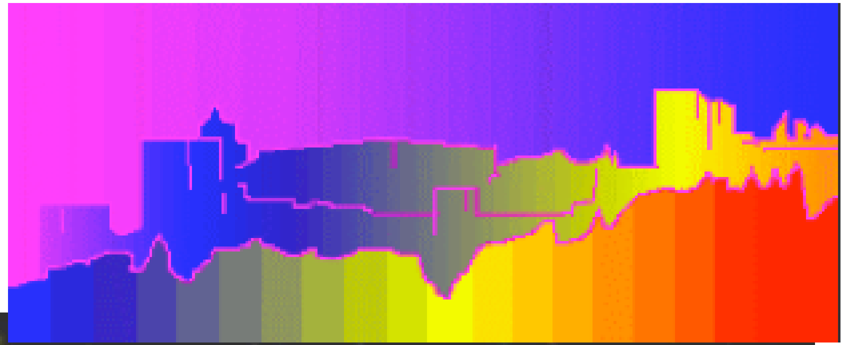
Bruzual & Charlot
11 Gyr @ z=0.2

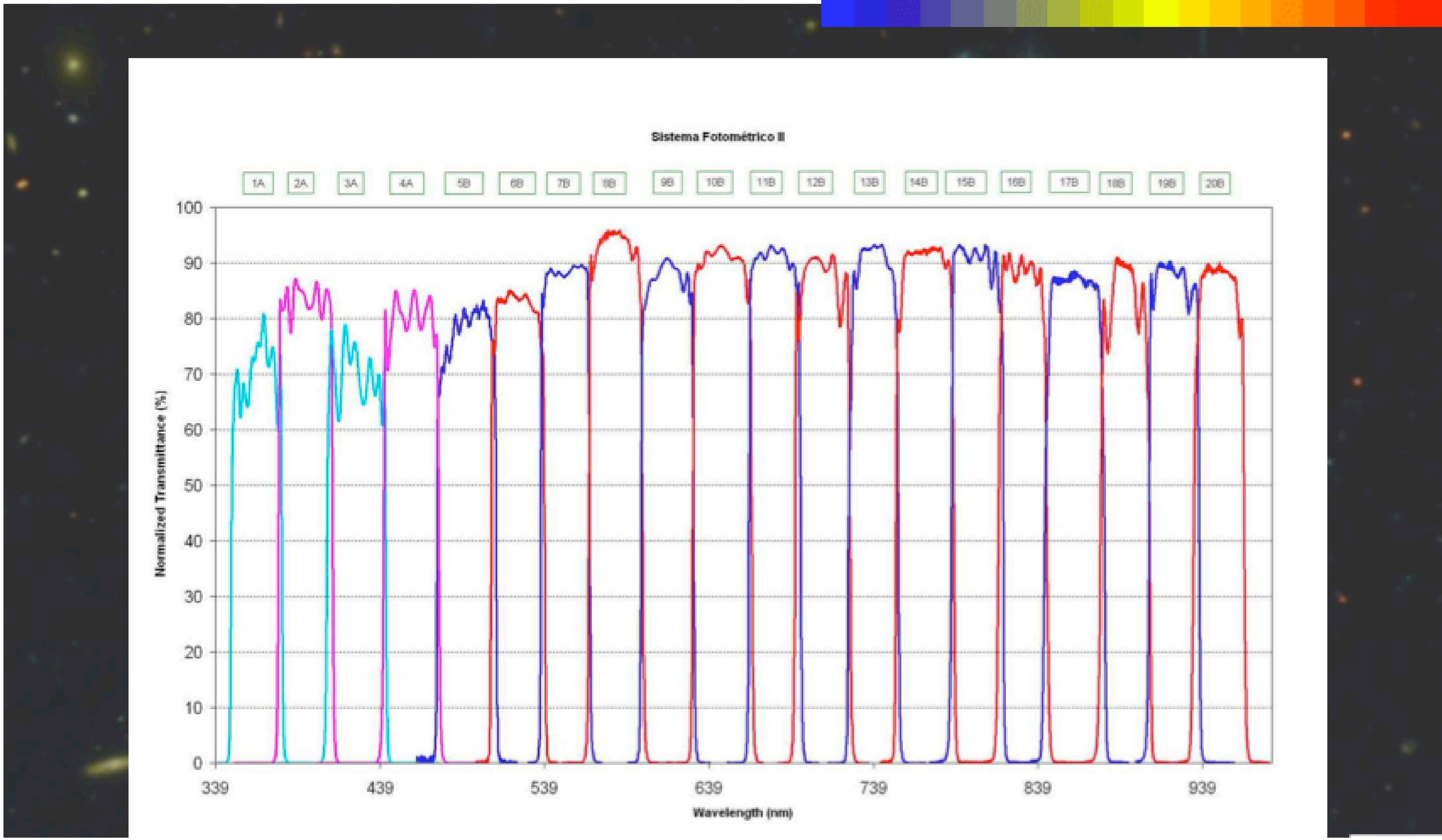
Comparison to COMBO - 17

- 1□ observed through 17 assorted filters
- ESO 2.2m + WFI
- Added value: CADIS (deeper + NIR + emission)



ALHAMBRA



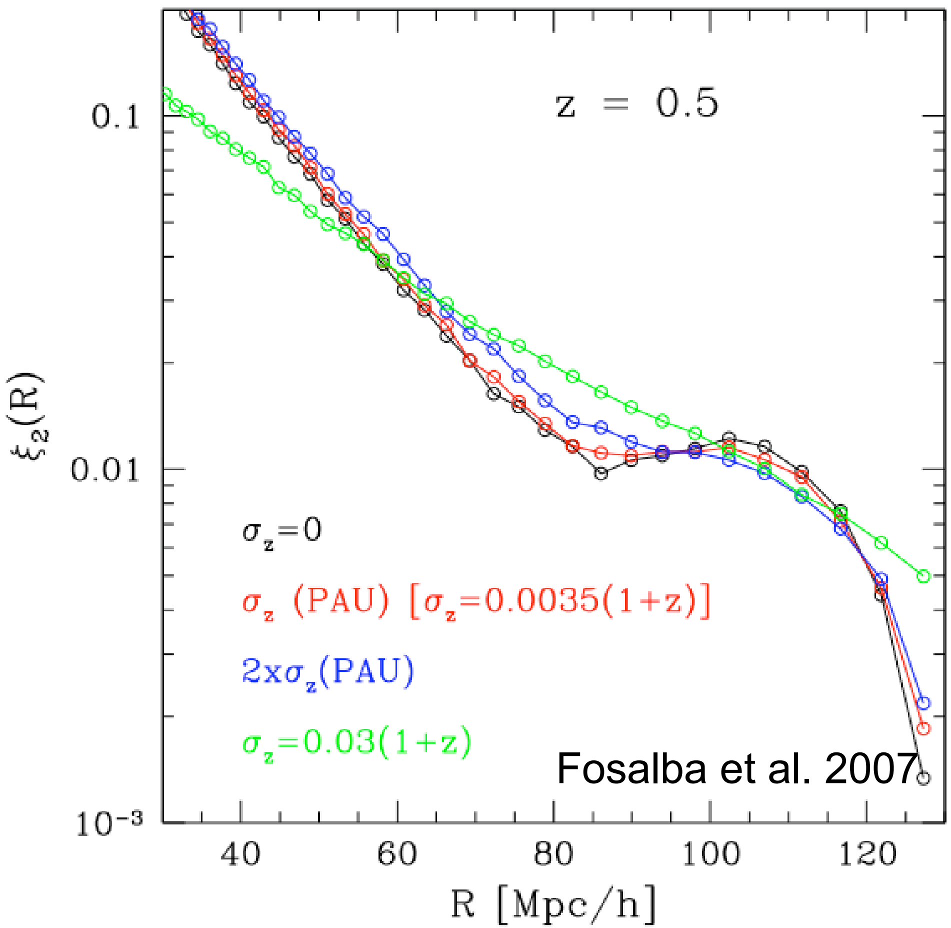

Sistema Fotométrico II
1A 2A 3A 4A 5B 6B 7B 8B 9B 10B 11B 12B 13B 14B 15B 16B 17B 18B 19B 20B
Normalized Transmittance (%)
0 10 20 30 40 50 60 70 80 90 100
339 439 539 639 739 839 939
Wavelength (nm)

Redshift error degradation

Feature width~15Mpc (comoving)

↕

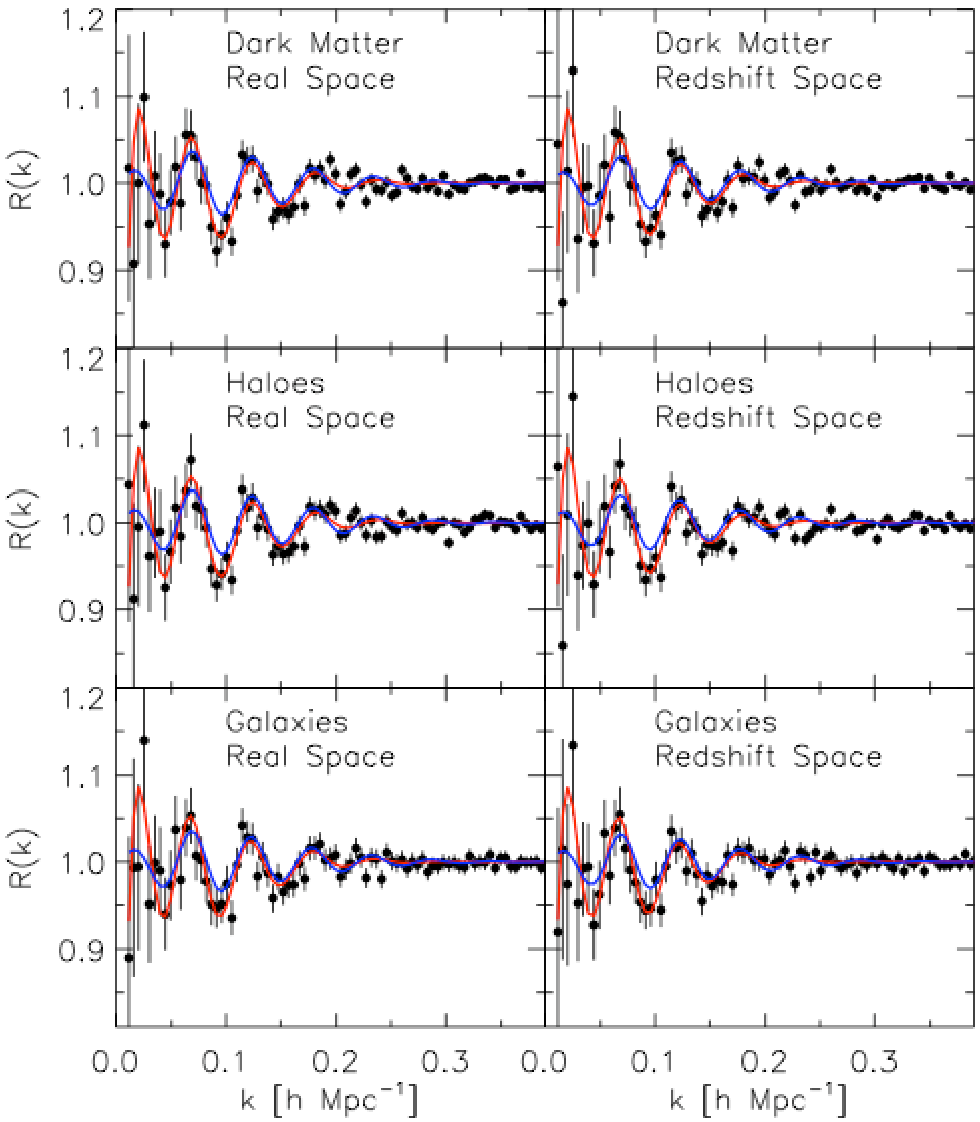
$$\sigma(z) = 0.0035(1+z)$$



1M halos, M>3.7d13Msol

from MICE simulation of 27 (Gpc/h)^3

In Fourier Space



$$\frac{P_{BAO}(k)}{P_{smooth}(k)} \sim 1 + A\cos(r_{BAO}\, k)$$

$$\sigma_P \equiv \frac{\Delta P(k)}{P(k)} \simeq \sqrt{\frac{2}{N_m(k)}}\left(1 + \frac{1}{P(k)\bar{n}}\right)$$

$$N_m(k) = V(4\pi k^2 \Delta k)/(2\pi)^3$$

$$\Delta\chi^2 \simeq \sum_i \frac{\Delta \hat{P}^2(k_i)}{\sigma_P^2(k_i)} \simeq \Delta_{BAO}^2 A^2 \left(\frac{V}{r_{BAO}^3}\right) I^2[n]$$

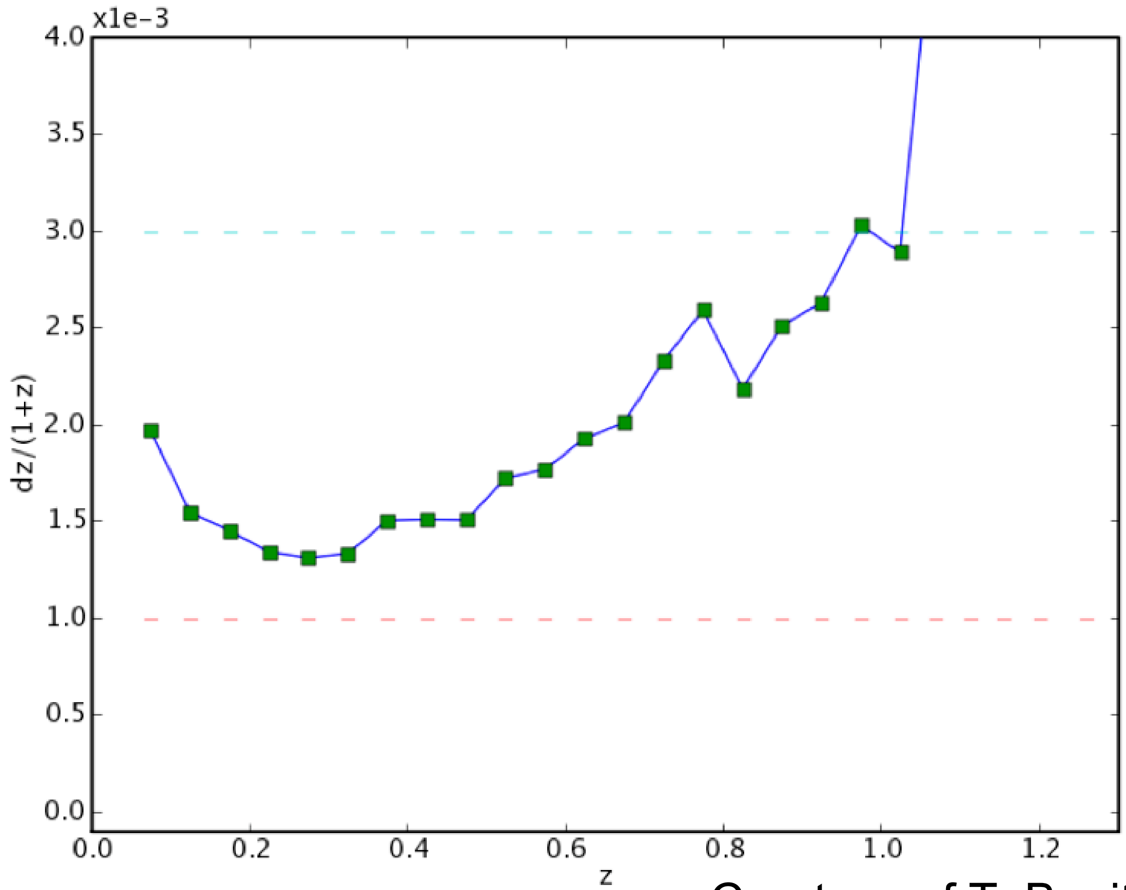
$$I^2[n] = \frac{1}{(2\pi)^2} \int_0^{2\pi n} x^4 \sin^2(x)\, dx$$

$$\Delta_{BAO} \equiv \Delta r_{BAO}/r_{BAO}$$

$$\Delta_{BAO}|_{\Delta\chi^2=1} = \left(\frac{r_{BAO}^3}{V}\right)^{1/2} \frac{1}{I[n]A}$$

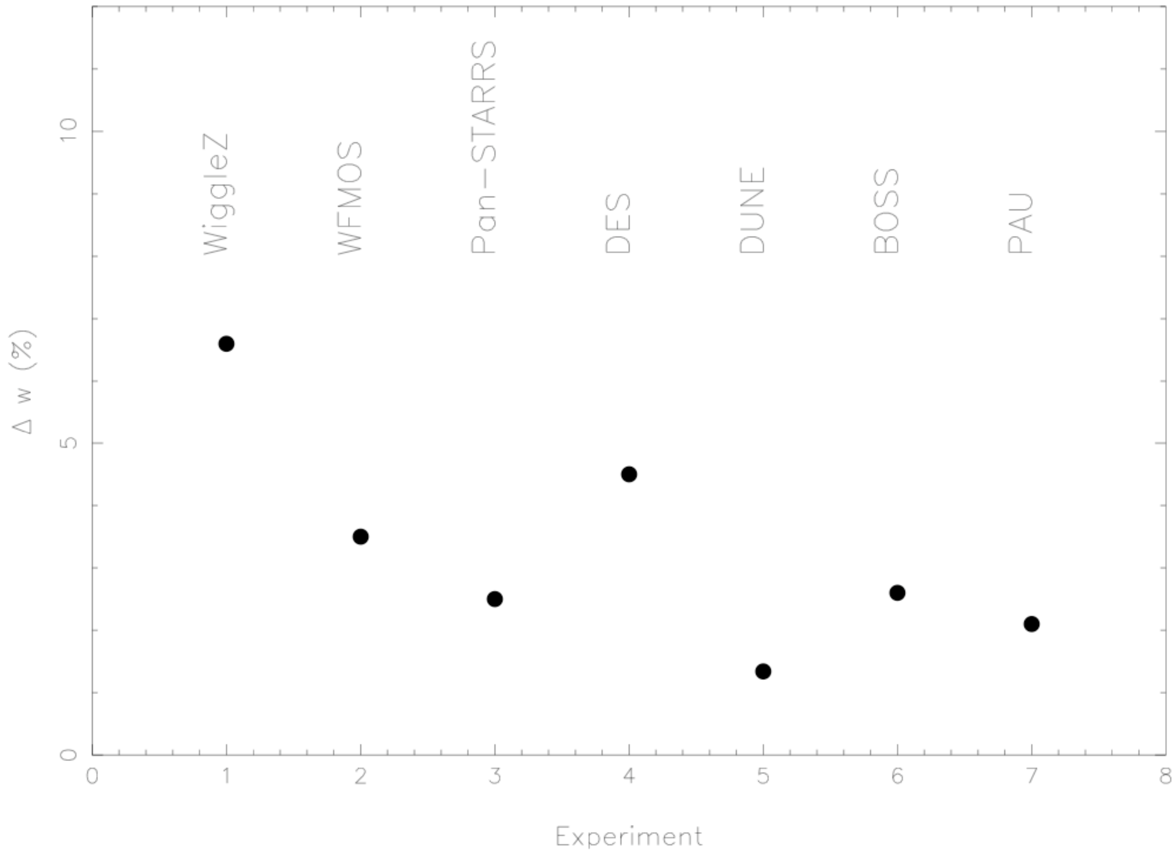
Angulo et al 2007

dz/(1+z) < 0.003 redshifts are feasible



Courtesy of T. Benitez

93AA width, 4200-8200AA NB range, 44 filters in total



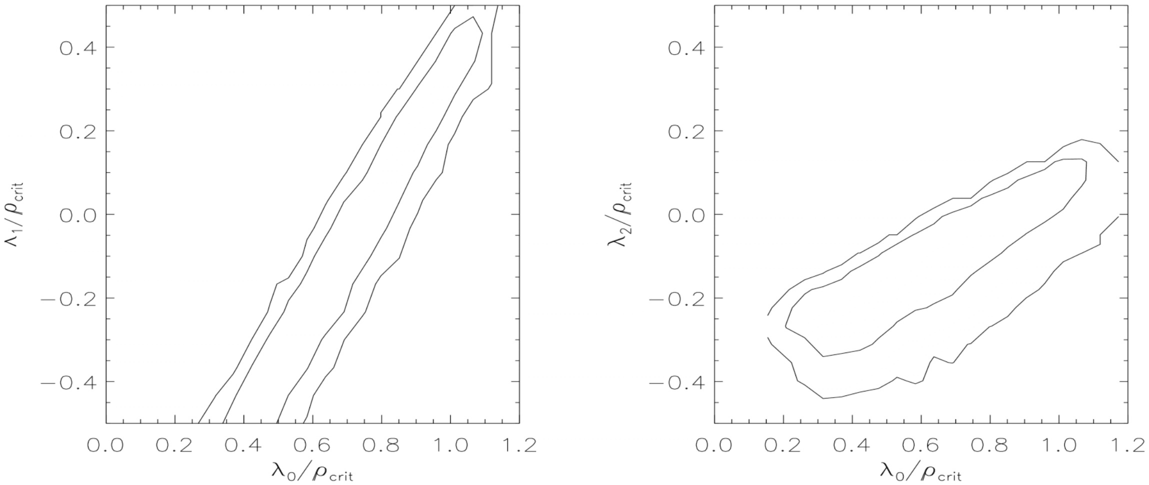
+ other science: galaxy formation and evolution, accurate measurement of P(k) and growth through higher-order correlations, primordial non gaussianity, redshifts for lensing surveys, galactic science, Etc…

Current constraints (SN)

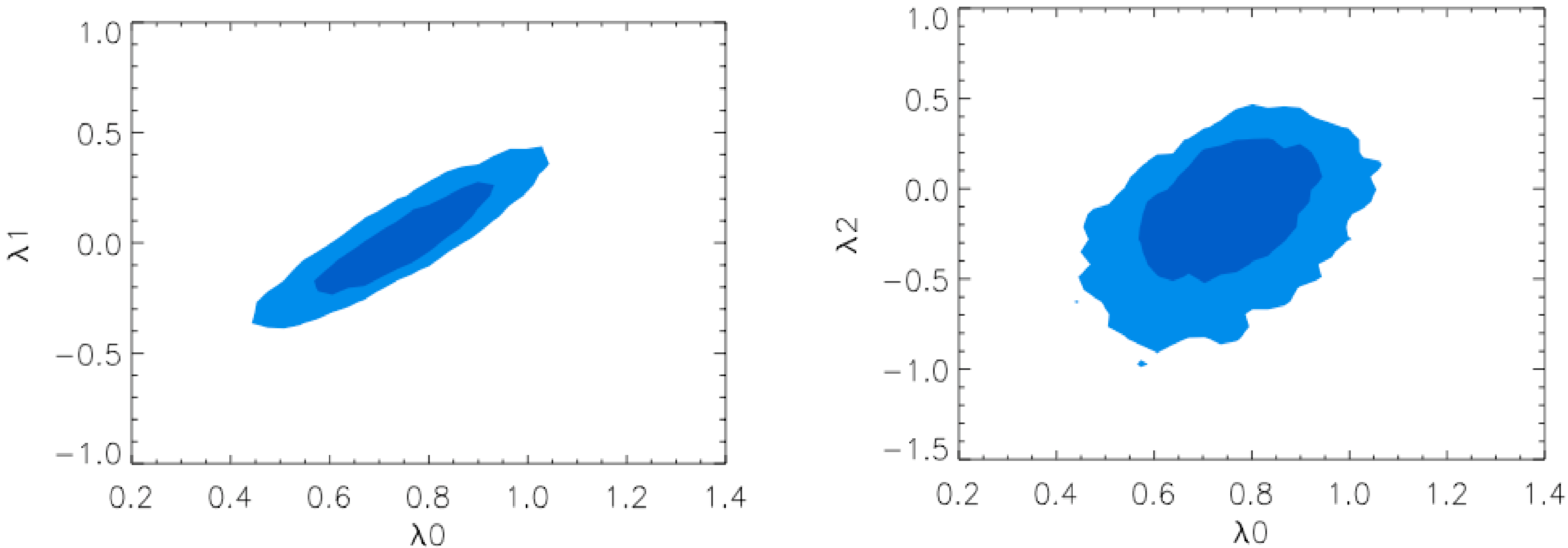
Simon, Verde, RJ '05

$$3H^2(z) - \frac{1}{2}(1+z)\frac{dH^2(z)}{dz} = \kappa\left(V(\alpha_i, z) + \frac{1}{2}\rho_m(z)\right) \equiv g(\alpha_i, z)$$

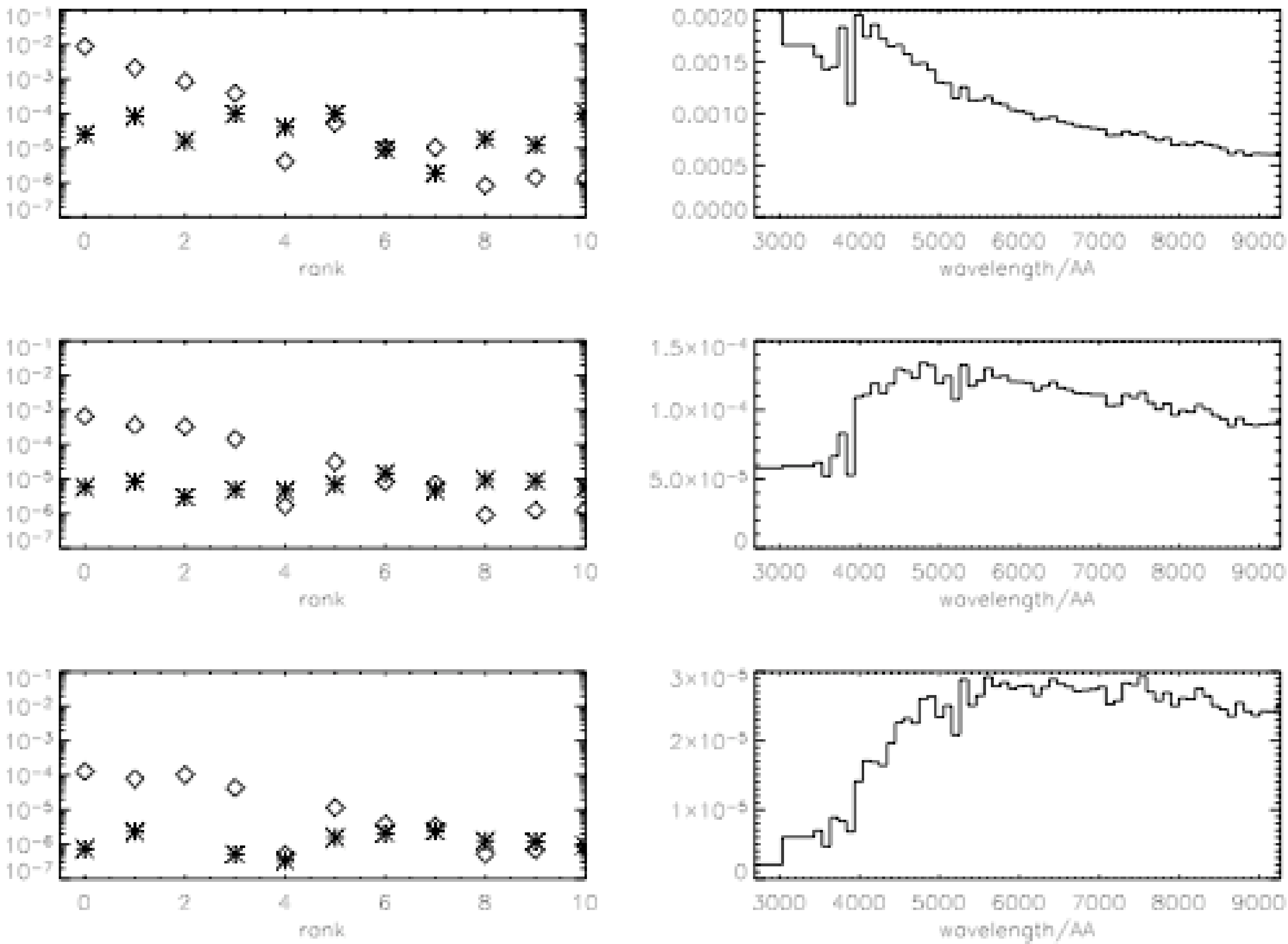
Use Chebyshev expansion of V



Fernandez-Martinez, Verde '08 **What PAU can achieve (no flatness prior!)**



Number of components recovered from PAU observations



Conclusions:

Zero order challenge: create a new culture of particle physicists and astronomers working together, theorists and experimentalists

First order challenge: why is Λ so small?

Second order challenge: is it dynamical?
And if so how does it evolve?

Third order challenge: did Einstein had the last word on gravity?

Avalanche of data coming soon
PAU will add ~ Pb to that…