G6 : Cosmologie et Matière Noire

- etat de lieu
- l'avenir

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ΛCDM model

- Baryons,electrons,photons,neutrinos
  $\Omega_{baryon} = 0.0456 \pm 0.0015$
- Cold Dark Matter
  $\Omega_{CDM} = 0.228 \pm 0.013$
- Dark Energy (expansion is accelerating !)
  $\Omega_{\Lambda} = 0.726 \pm 0.015$
- Critical density (spatially flat universe)
  $\Omega_{T} = 1.01 \pm 0.01$
- Inhomogeneities : gravitational potential fluctuations
  $\sqrt{\langle \Phi^2 \rangle} \sim 10^{-5}$

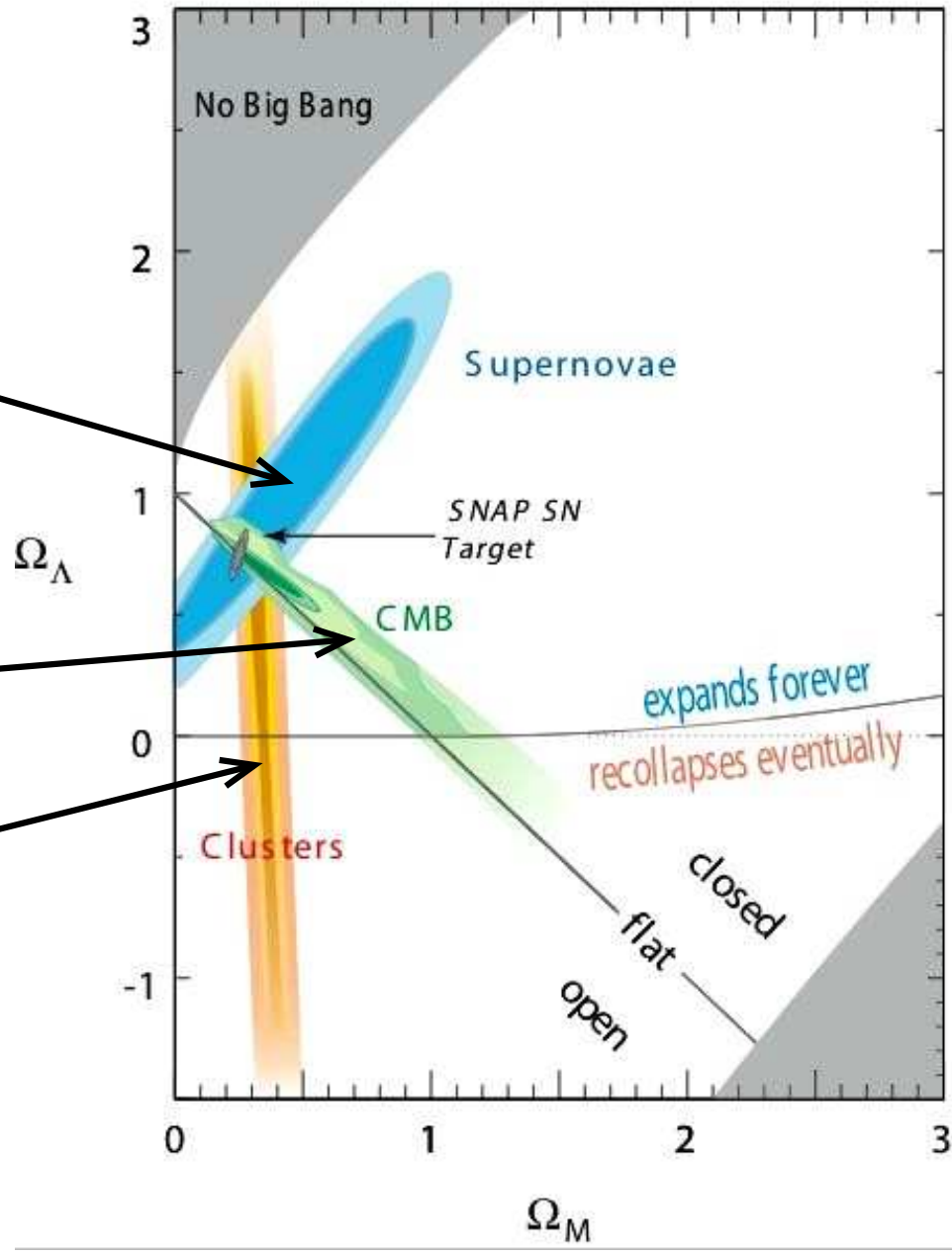
None are predicted by standard particle physics !

$(\Omega_M, \Omega_\Lambda)$ constraints (2003)

Supernova Cosmology Project

CMB (WMAP)

Baryon fraction in galaxy clusters



Evidence for ΛCDM

- Ω_Λ : things are very far away (very small and faint)
  Supernovae IA, CMB and BAO acoustic peaks
  $\Rightarrow$ accelerated expansion $\Rightarrow$ Dark energy
- (Ω_{cdm}, Ω_b) : observed inhomogeneities those of a primorial photon-baryon fluid moving in passive (CDM) gravitational potential.
  CMB anisotropies, BAO

Plus

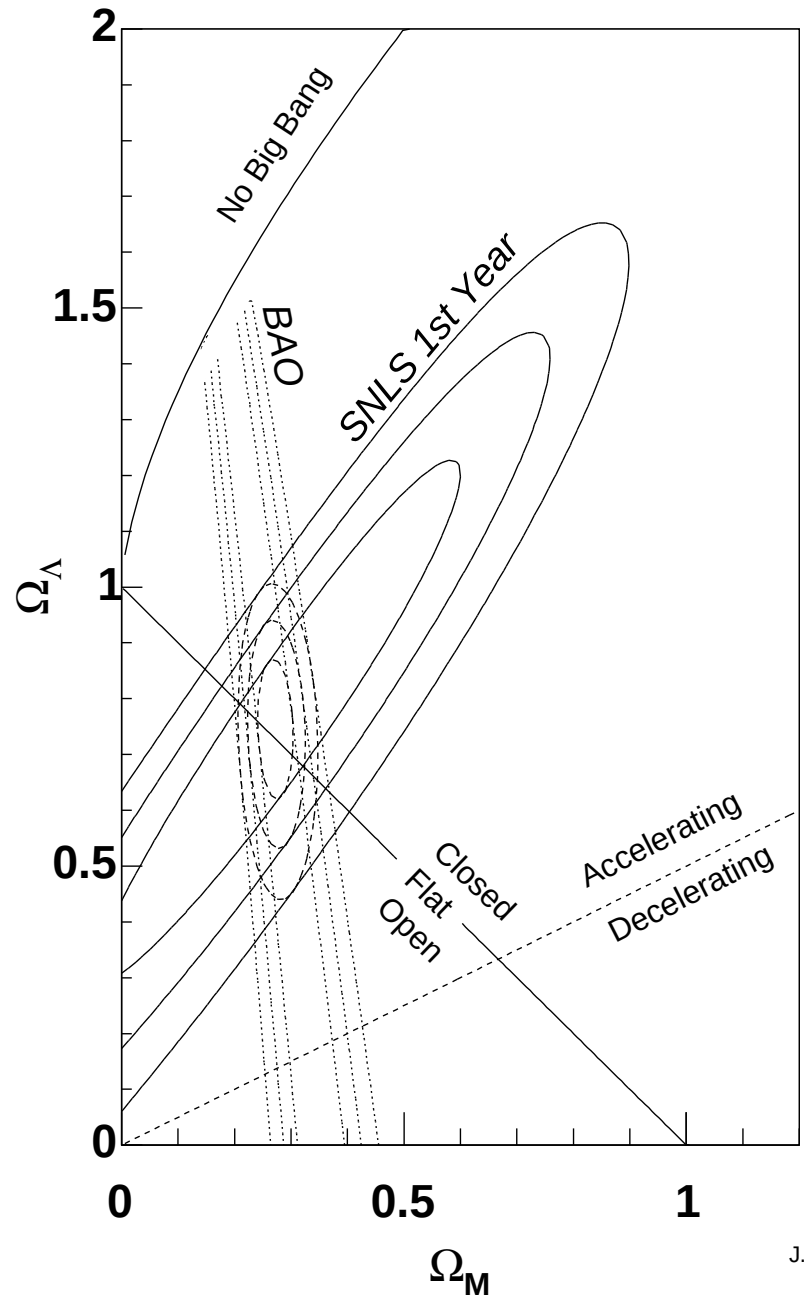
- Elemental abundances (hydrogen, deuterium, helium) require low baryon density
- Galaxies and clusters not made of normal baryons
  microlensing (compact objects)
  x-ray emission (hot gas)

Progress since 2005

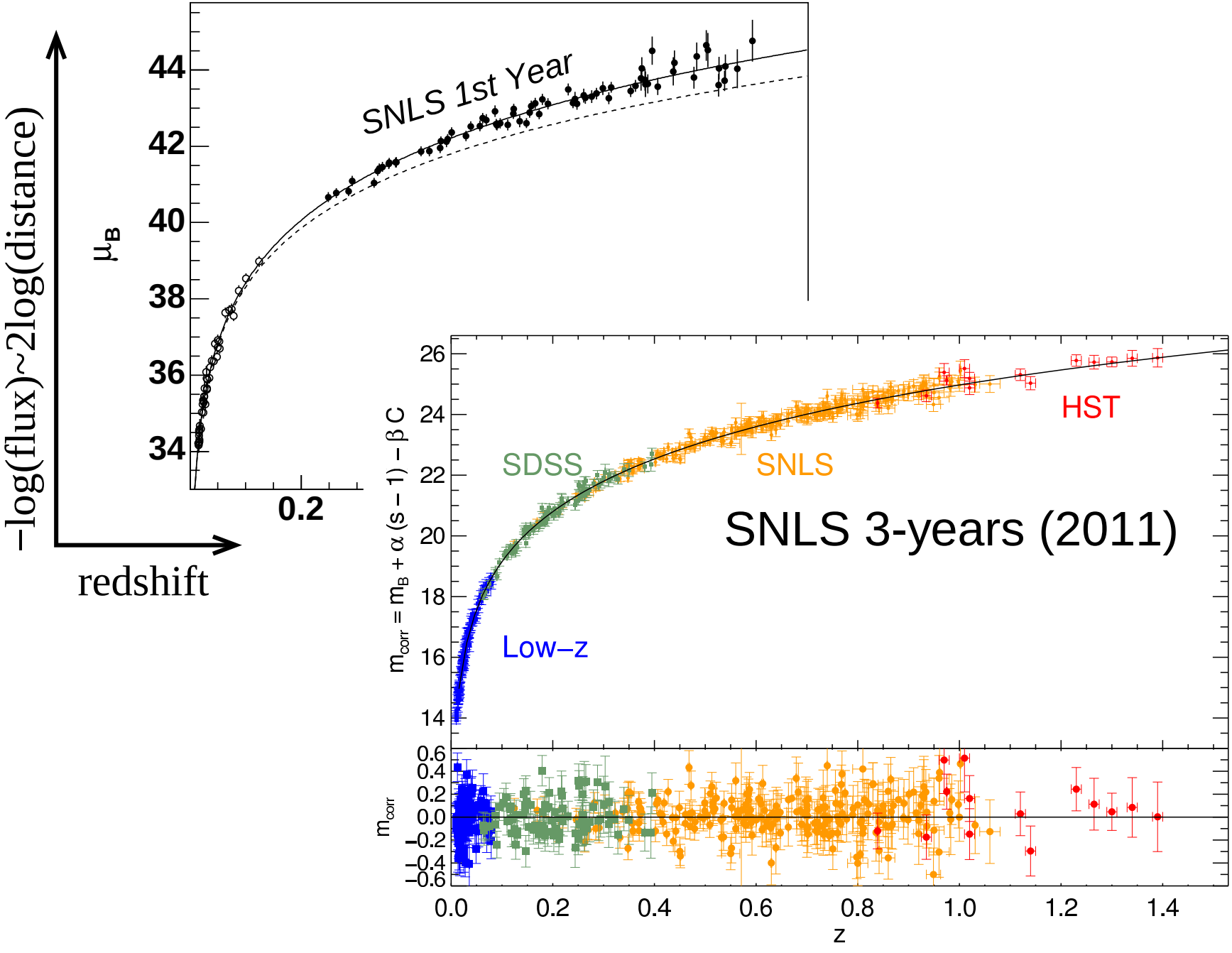
- Quality and Quantity of SN data (SNLS)

- BAO (SDSS)
  Not mentioned in Prospectives 2005 !

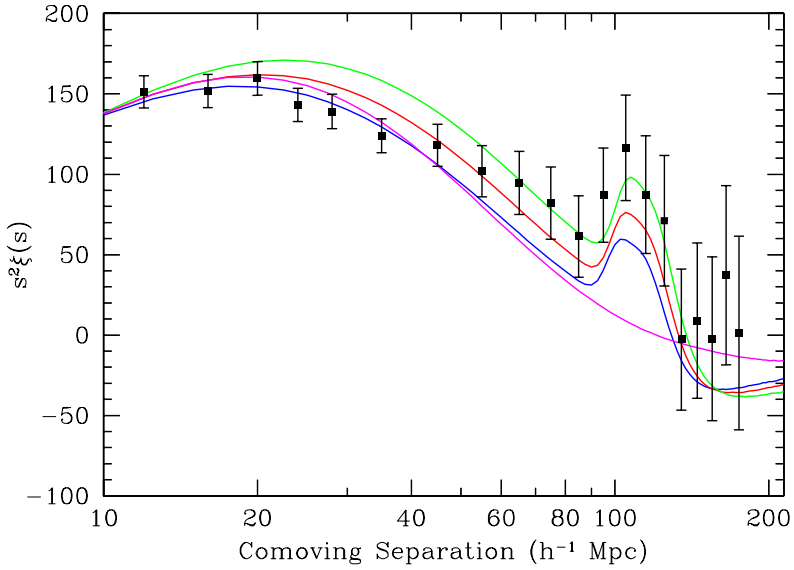
SNLS : (France,Canada)
Astier et al. (2006)
1485 citations
Guy et al. (2005)
125 citations
Megacam (IRFU)



SNIa Hubble diagram

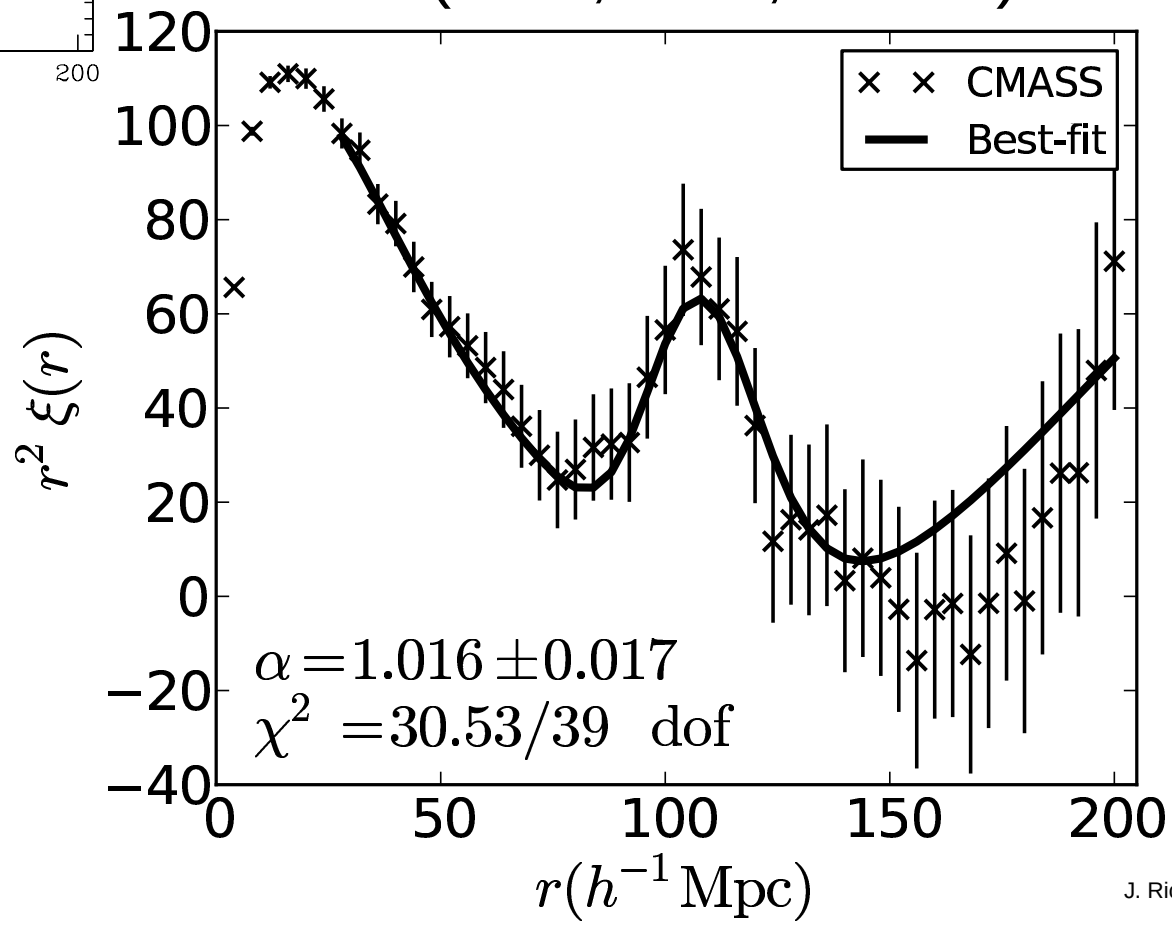


BAO Peak in galaxy correlation function



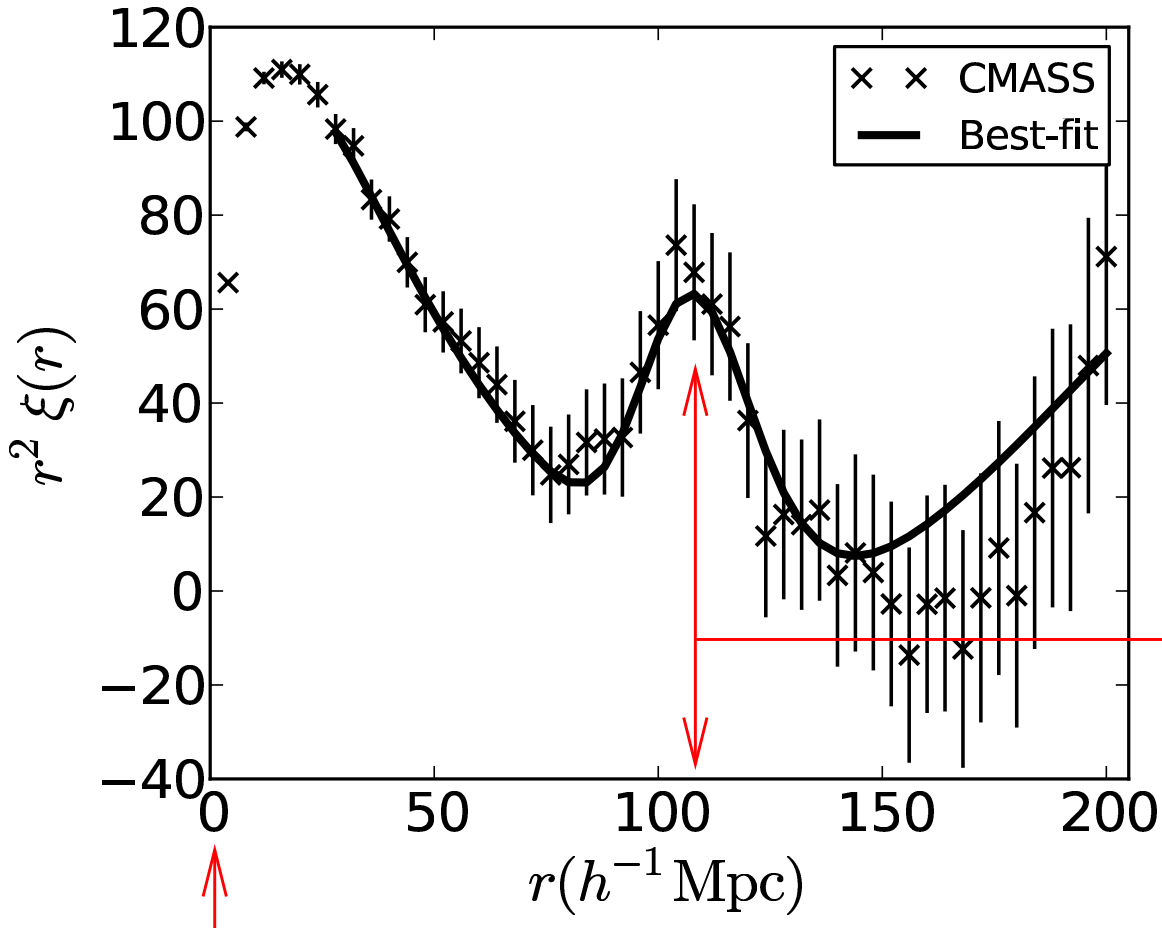
SDSS (2006)

BOSS/3 (arXiv :1203 :6594)
(APC,IRFU,IAP.....)



BAO Standard ruler

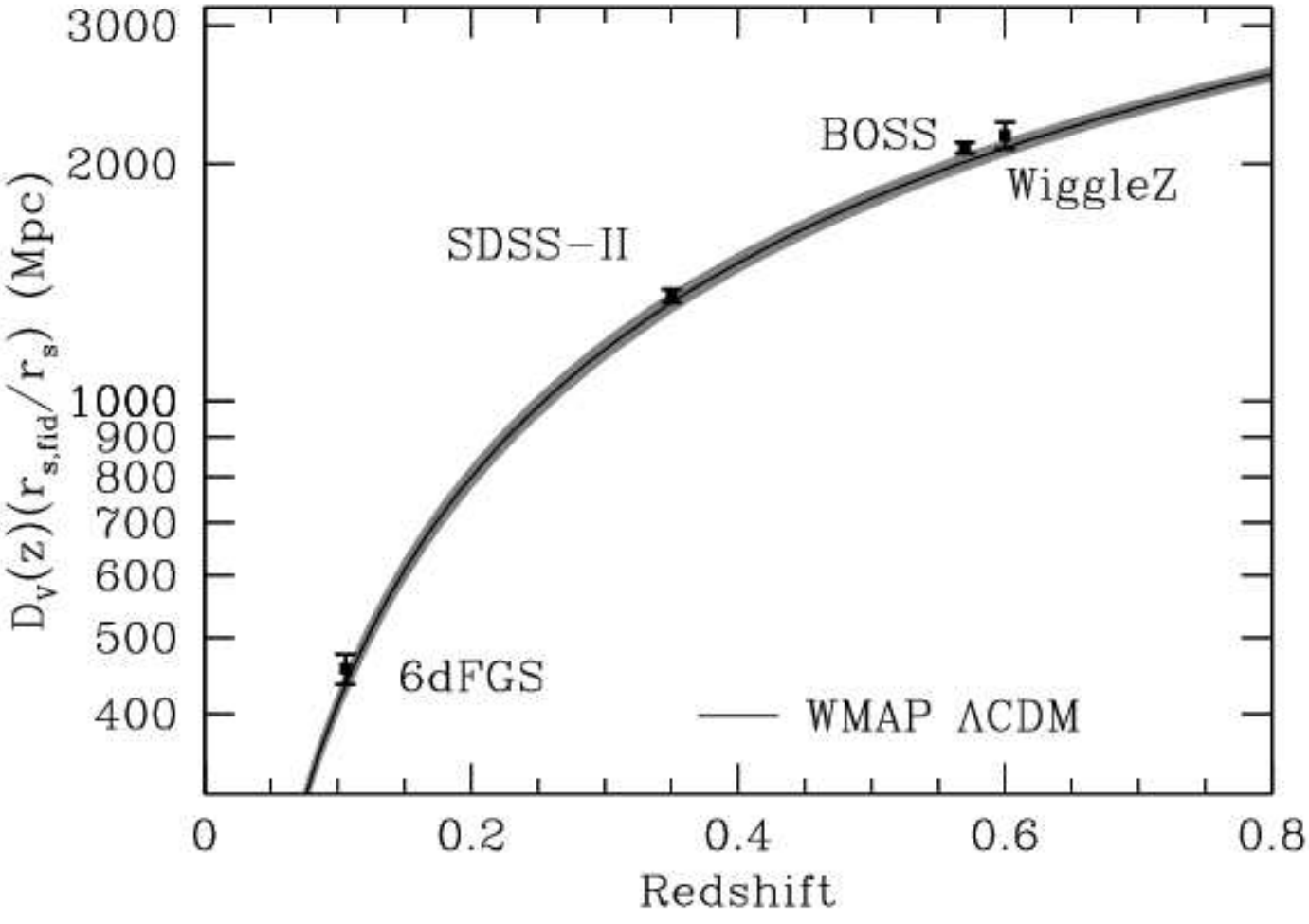
Calculable to 1% accuracy from “first principles” : primordial baryon-photon perturbations separate from CDM perturbations at the speed of sound $\sim c/\sqrt{3}$ $\Rightarrow$ r=105Mpc/h



position of baryon sound wave at recombination

position of initial CDM−baryon perturbation

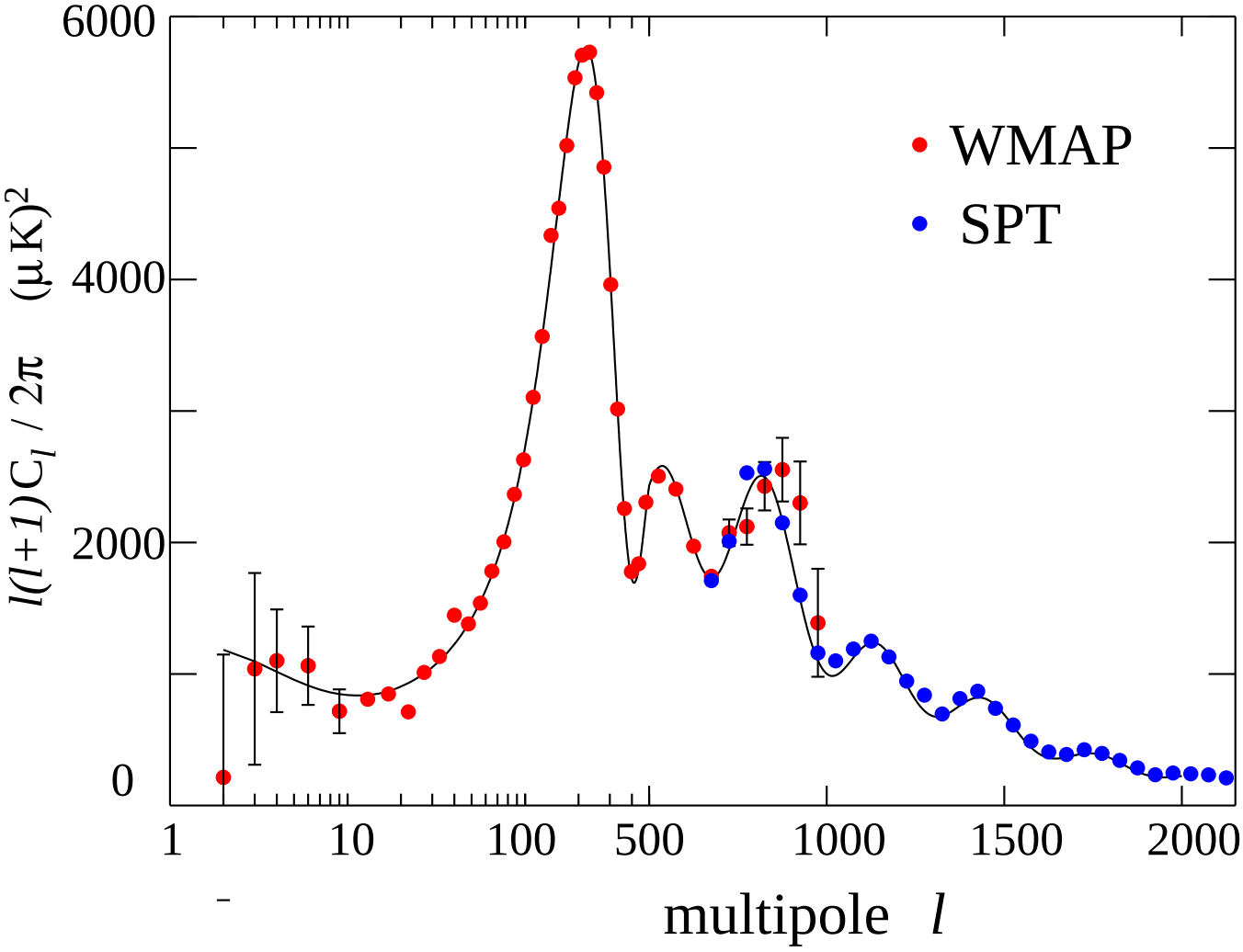
BAO standard ruler



CMB Anisotropies

(Same simple physics as BAO)

WMAP(2009) + South-Pole Telescope (2011),
soon (2013) to be replaced with exquisite Planck data.



Future (1)

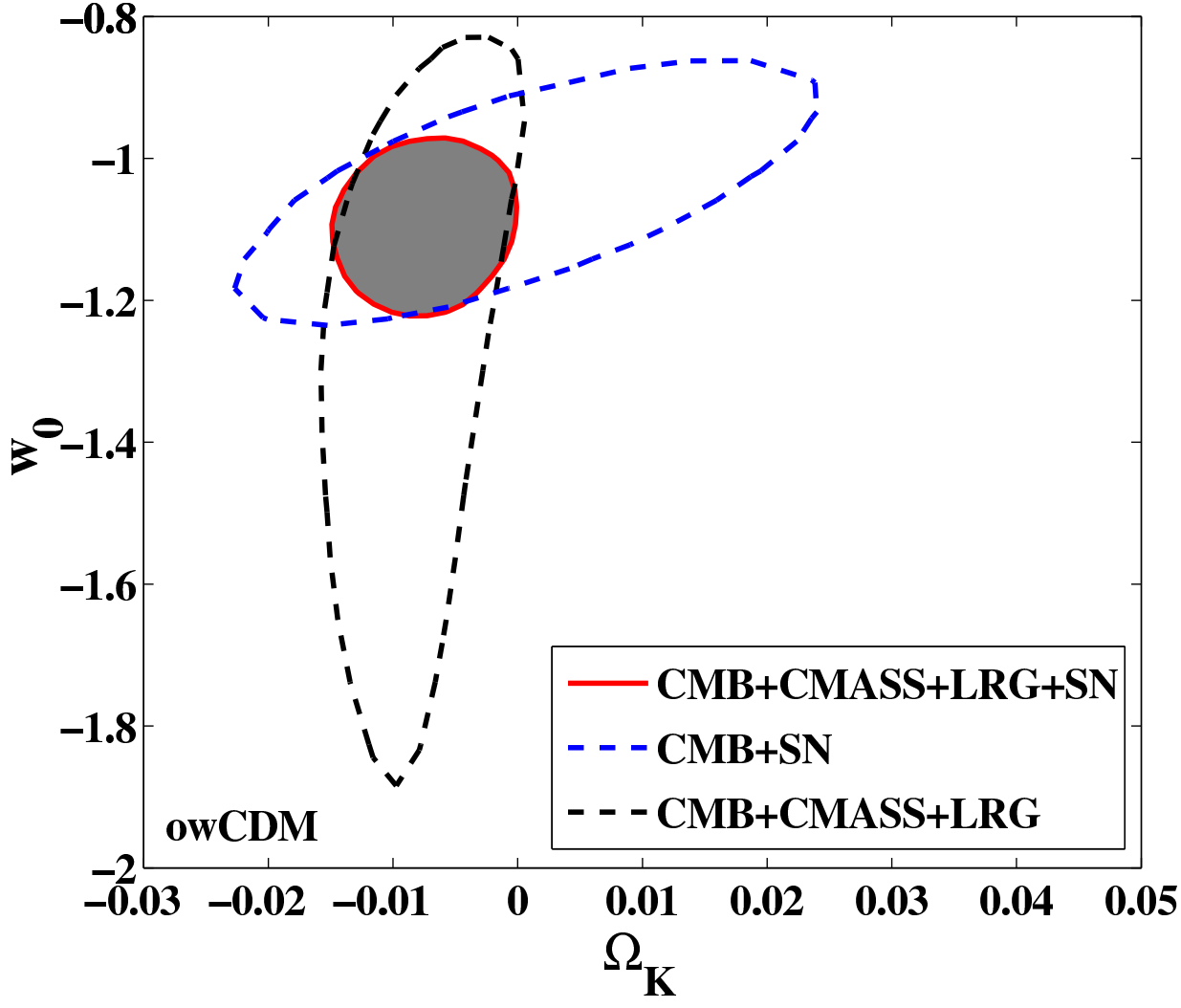
- Search for deviations from ΛCDM

e.g. time variation of ρ_Λ ; non-zero curvature

Need (for example)

- Better CMB anisotropy data (Planck, 2013,2014)
- Better BAO Hubble diagrams
  eBOSS, Big-BOSS, 21-cm surveys,
  $\rightarrow$ EUCLID (2019)
- Better understanding of SN systematics
  SNFactory
  plus more data : DES(2013), LSST(2019)

Curvature and $d\rho_V/dt$ limits



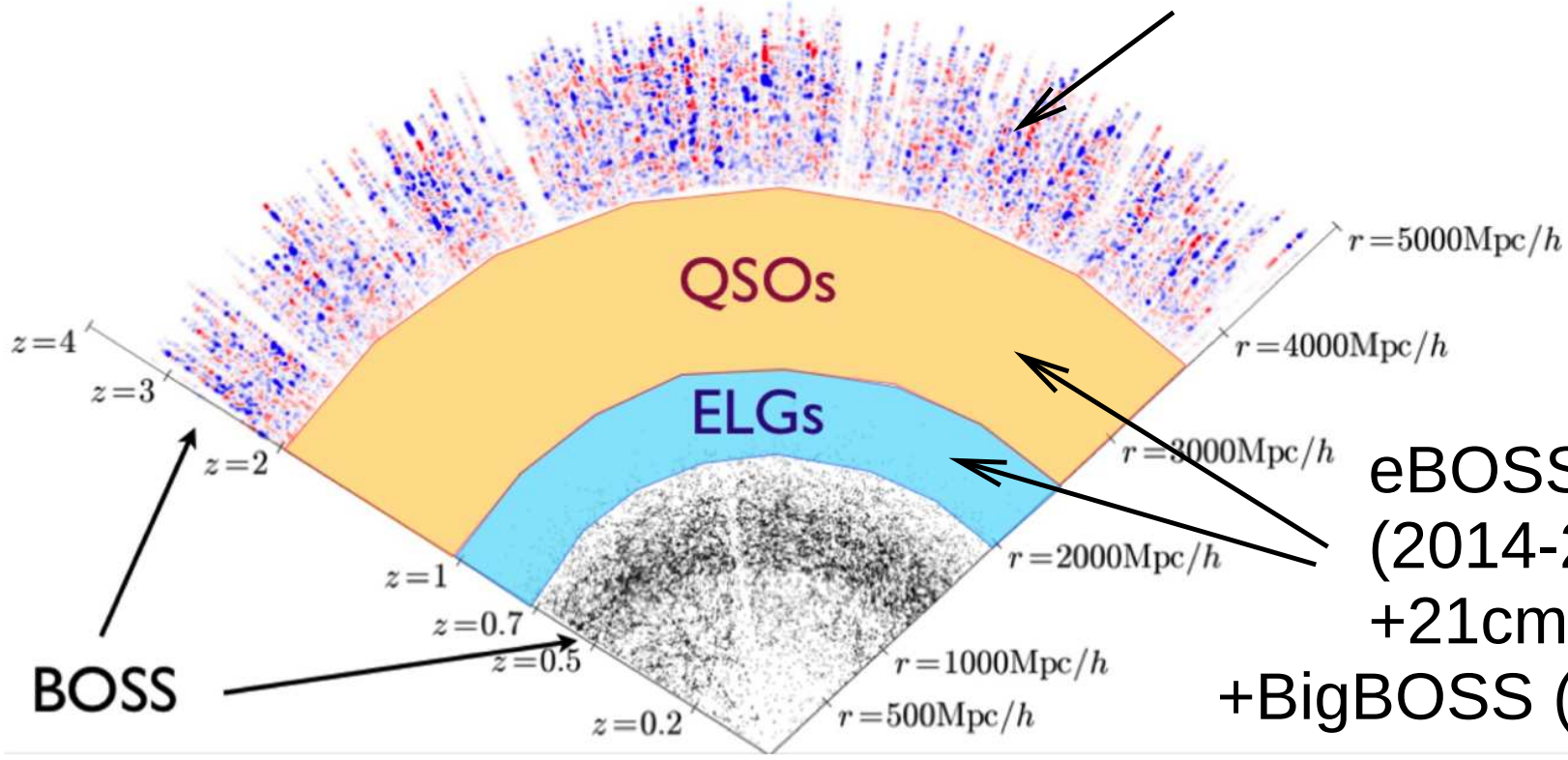
BOSS+SNIa

$(w_0, \Omega_k) = (-1, 0)$ for ΛCDM

Near-future redshift surveys

map redshift range $0 < z < 4$. (half way to horizon)

Quasar absorption spectra
BOSS and eBOSS



eBOSS
(2014-2018)
+21cm surveys
+BigBOSS (2018-)

Future (2)

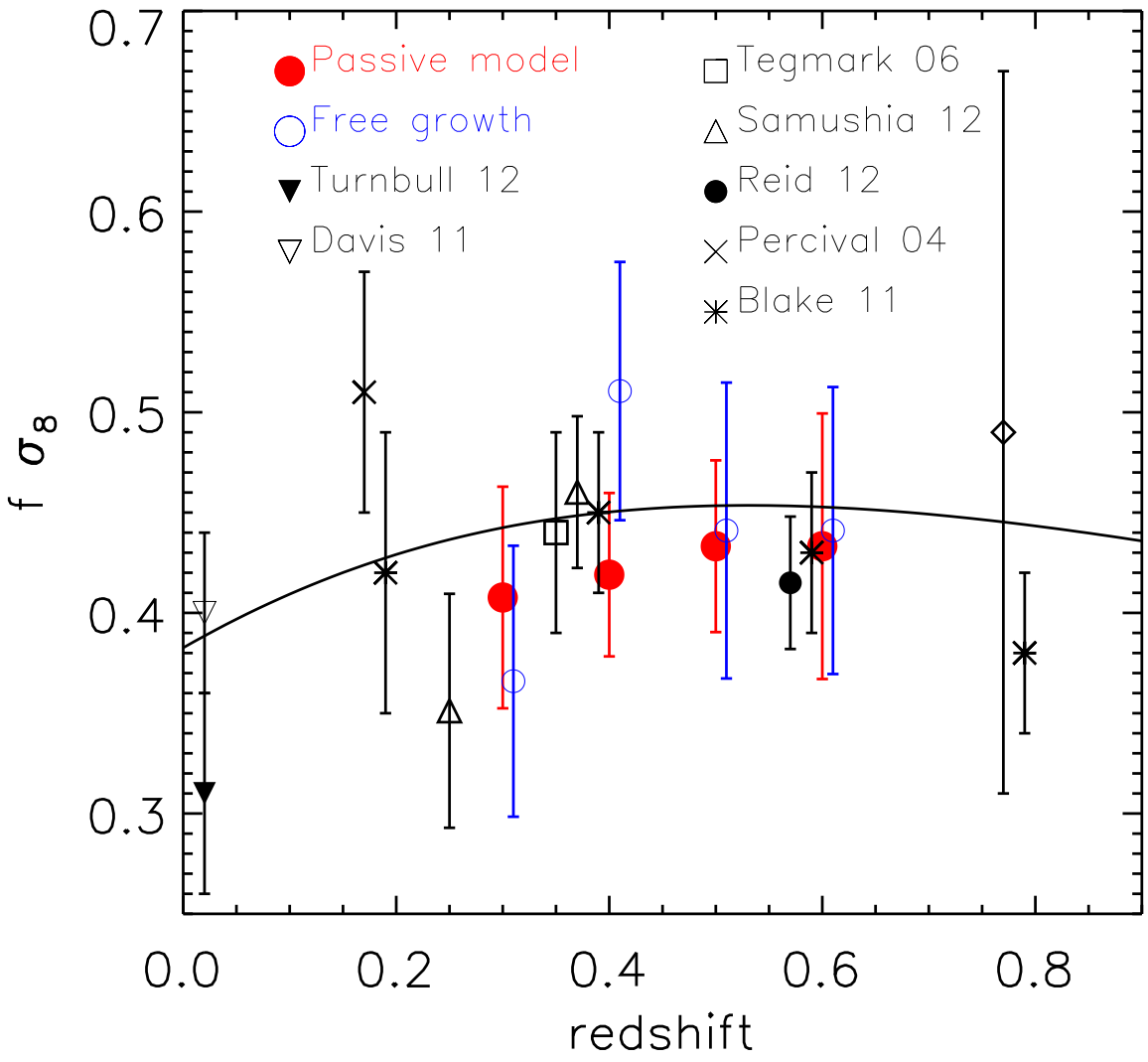
- Verify that growth of structure consistent with ΛCDM

[Is the gravity law that causes structure formation consistent with the law that governs the expansion of the universe ?]

- Weak gravitational shear : LSST (2019), Euclid (2019)
- Matter power spectrum : Euclid (2019)
- Galaxy cluster counts :
  need better mass-luminosity relations
- Better simulations of structure formation

Rate of structure growth

Present measurements at 10% level [arXiv :1203.6641,6565]



ΛCDM
+ General Relativity

Future (3)

- Find direct evidence for inflation

Search for “B-mode polarization of CMB”

Planck (2014)

Qubic (ANR financing)

Participation in Polarbear, Ebex.....

Future (4)

- Understand formation of first stars, quasars
  JWSpaceTelescope

Future (5)

- Find particle dark matter ($\rightarrow$J. Gascon)

WIMPs ?

direct detection

indirect detection : detection of annhilation products :

HESS, Antares, AMS

Significant limits ;

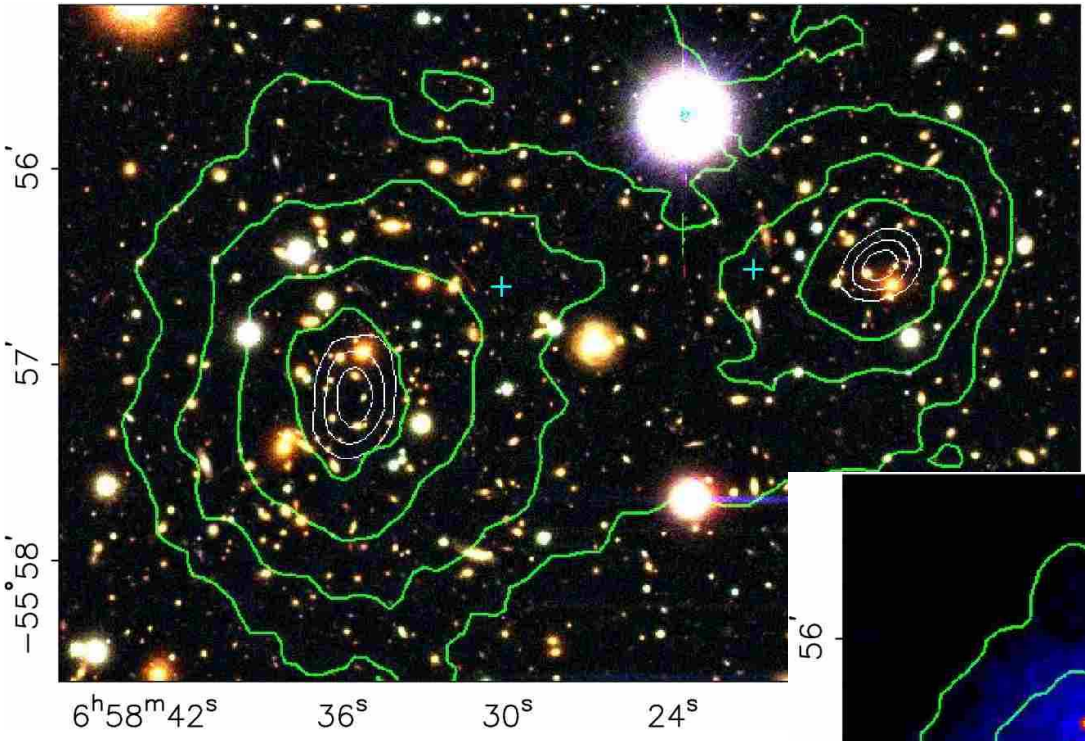
Signals require understanding of

astrophysical backgrounds.

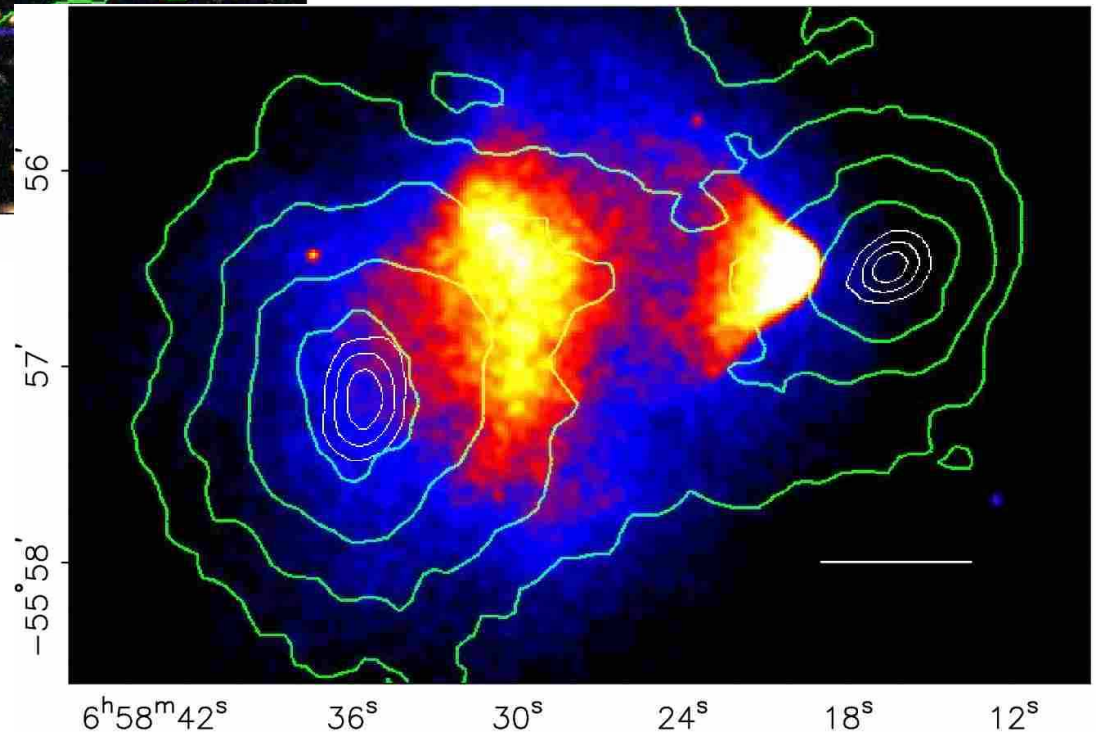
Axions ?

detection of cosmic or solar axions (CAST)

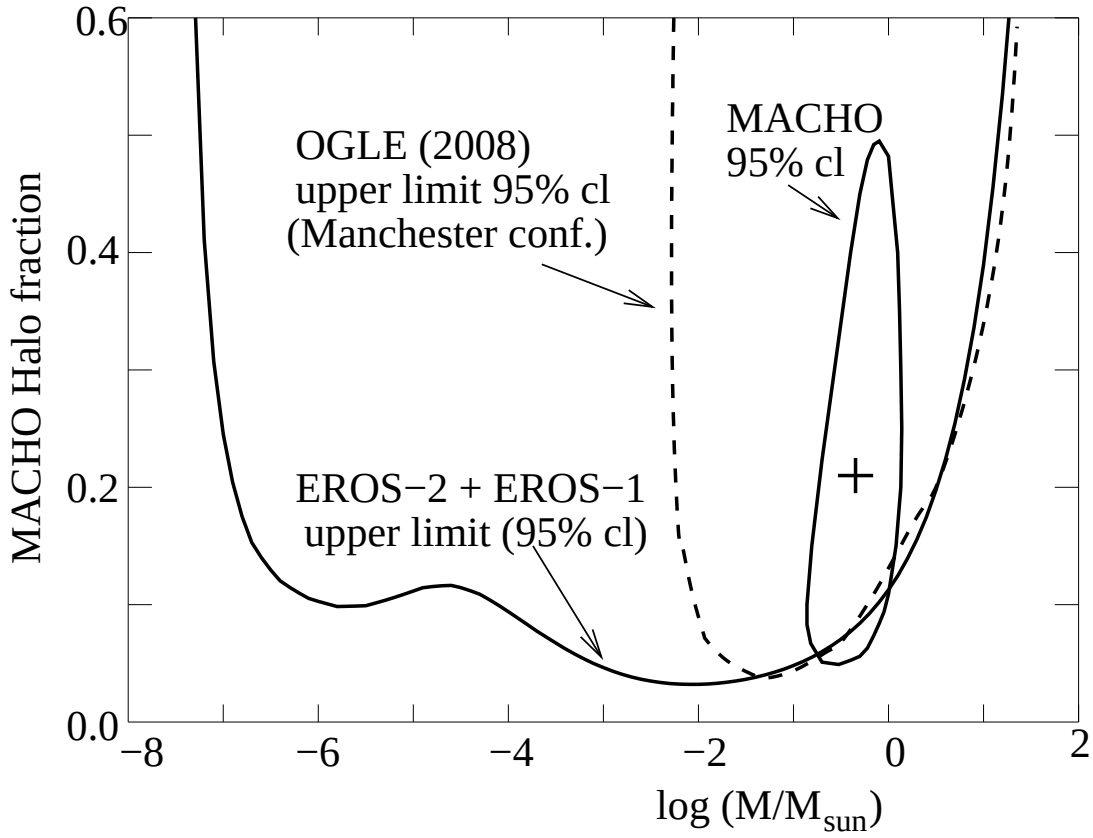
It’s not gas



Bullet Cluster :
Gas separated from CDM during collision



It's not MACHOs



MACHO(2000) :
10%-50% of dark matter made of machos

EROS(2007)<10%

OGLE(2010)<10%

Future (the end)

Some things for particle physicists to understand :

- $\rho_{baryon}/\rho_{cdm} \sim 1/5$
- $n_{baryon}/n_{photons} = 6.2 \times 10^{-10}$
- $\rho_V = (0.67 \pm 0.02) \times 10^{-26} kg\, m^{-3}$
- $\rho_V \sim \rho_{cdm}(now)$
- $\langle \Phi^2_{grav} \rangle^{1/2} \sim 10^{-5}$