The Abdus Salam
International Centre
for Theoretical Physics

2419-22

Workshop on Large Scale Structure

30 July - 2 August, 2012

X-ray Galaxy Clusters as Cosmological and Astrophysical Probes

H. Boehringer
Max Planck Institute for Extraterrestrial Physics

Strada Costiera, 11 - 34151 - Trieste - Italy • Tel. +39 0402240111 • Fax. +39 040224163 • sci_info@ictp.it • www.ictp.it
ICTP is governed by UNESCO, IAEA, and Italy, and it is a UNESCO Category 1 Institute

X-ray Galaxy Clusters as Astrophysical Laboratories and Cosmological Probes

Hans Böhringer

Max-Planck-Institut für extraterrestrische Physik, Garching

Gayoung Chon (MPE), Luigi Guzzo (Merate), Chris Collins (Liverpool), Gabriel Pratt (Saclay) Monique Arnaud (Saclay)

Overview

- Galaxy Clusters and Large-scale Structure (LSS)
- Assessing the LSS with X-ray Galaxy Cluster Surveys
- Testing Cosmological Models
- eROSITA

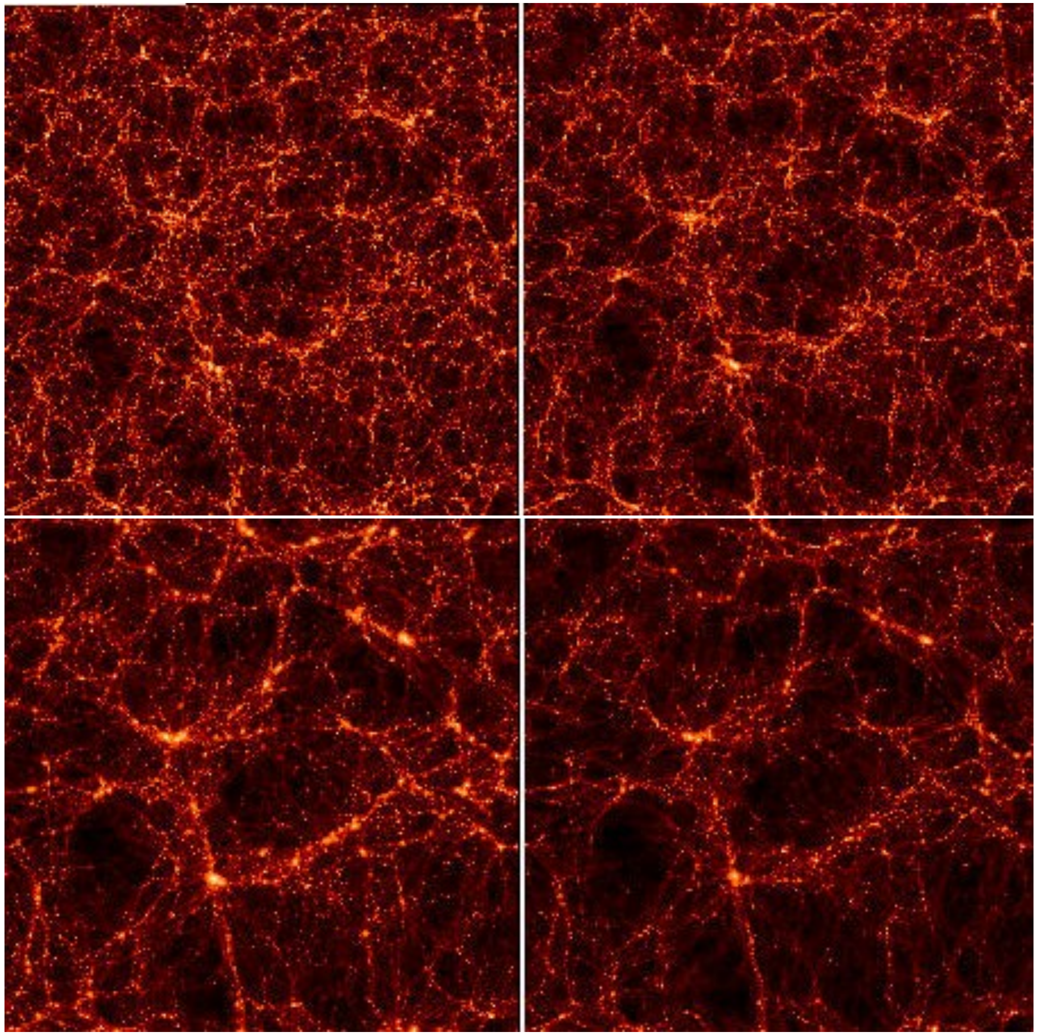
Different LSS for Different Cosmological Models

SCDM

Ω_m=1

τCDM

Ω_m=1



ΛCDM

Ω_m=0.3

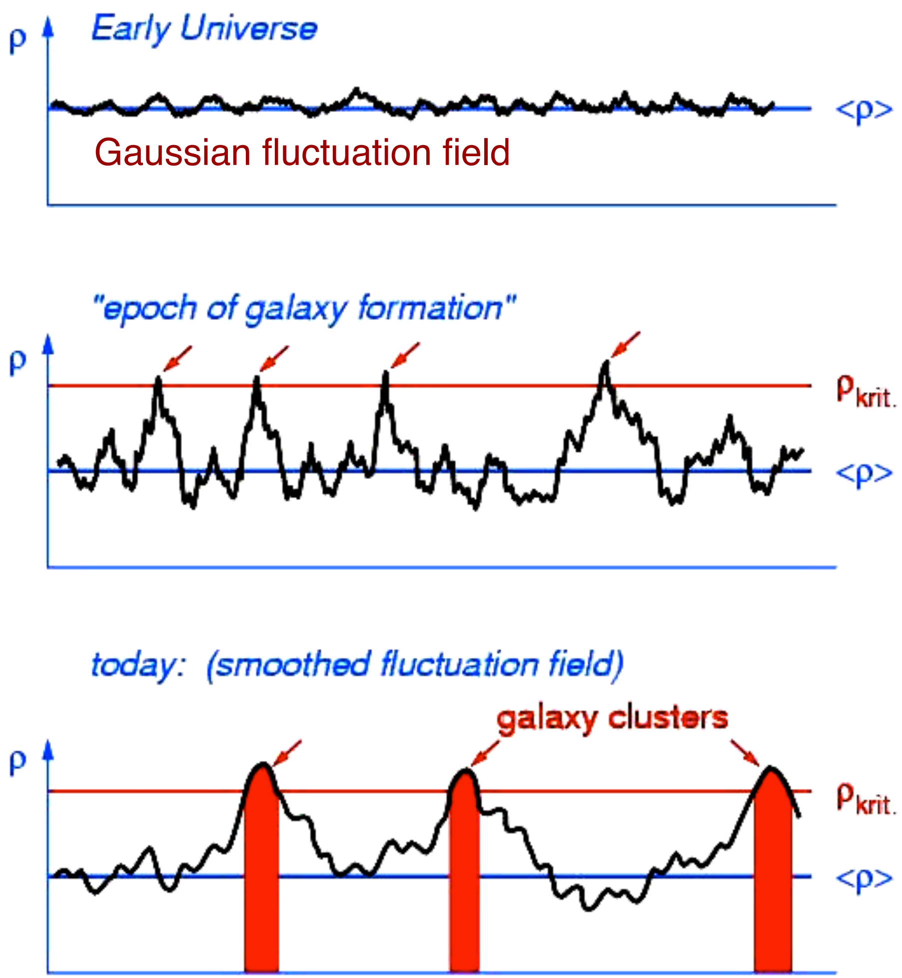
Ω_Λ=0.7

OCDM

Ω_m=0.3

MPA , Garching & Virgo Consortium

The Role of Galaxy Clusters in the Hierarchy of Large-Scale Structure

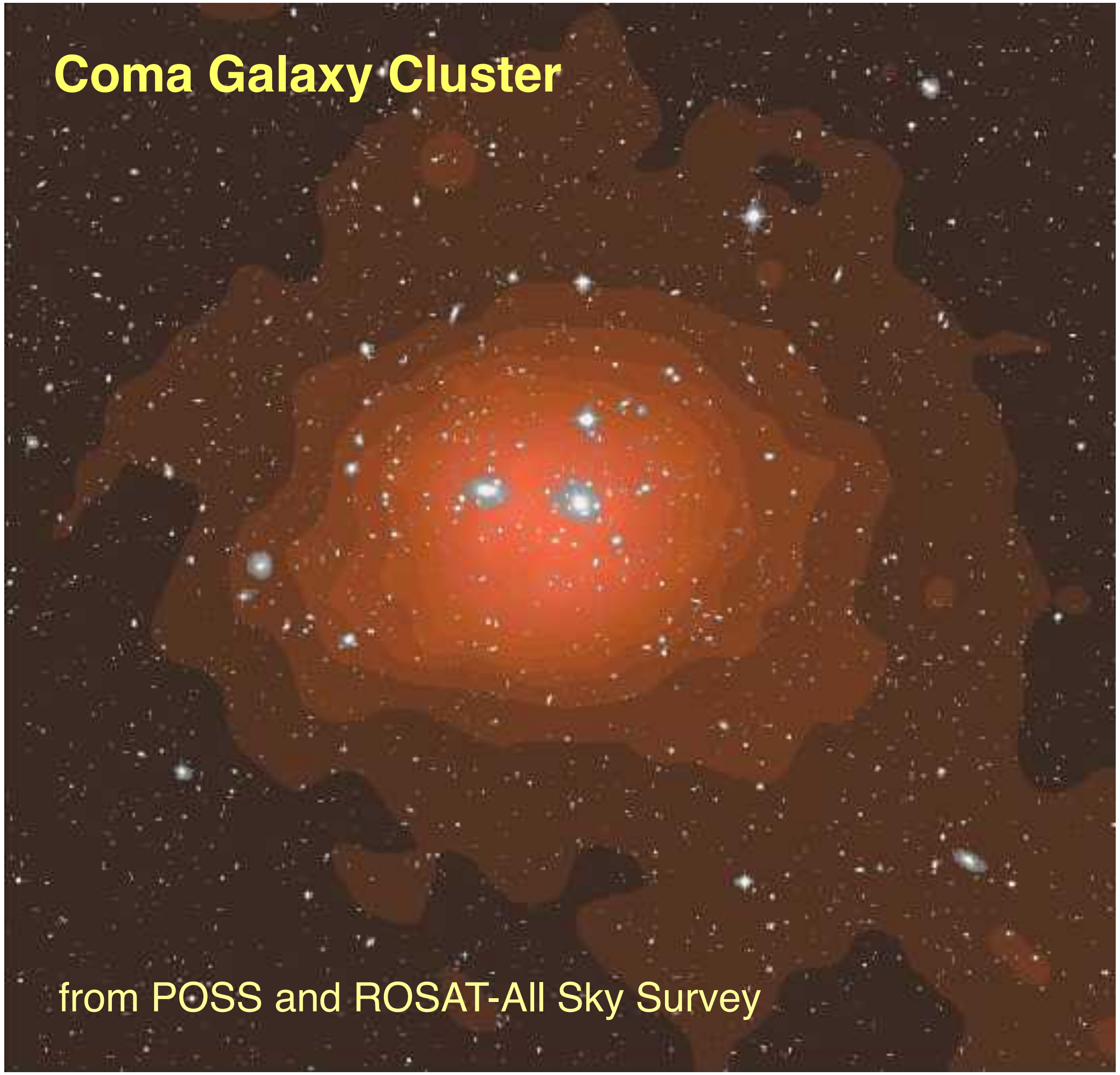


mass of galaxy clusters ~ 10^{14} – 10^{15} M_{sun}

From the cluster population:

1) Fluctuation amplitude and shape of $\mathbf{P(k)_{DM}}$ (over few Mpc range) by cluster **abundance**
2) Large-scale cluster density distribution $\mathbf{P(k)_{CL}}$ and its **bias** above $P(k)_{DM}$
3) The **evolution** of the cluster population – testing the growth of structure
4) Evolution of internal cluster properties

The Role of X-ray Galaxy Clusters in Cosmological Studies



Galaxy Clusters, the largest well defined objects in the Universe. The form a well understood integral part of the cosmic large-scale structure.

Therefore they are ideal probes to study cosmic evolution and to test cosmological models.

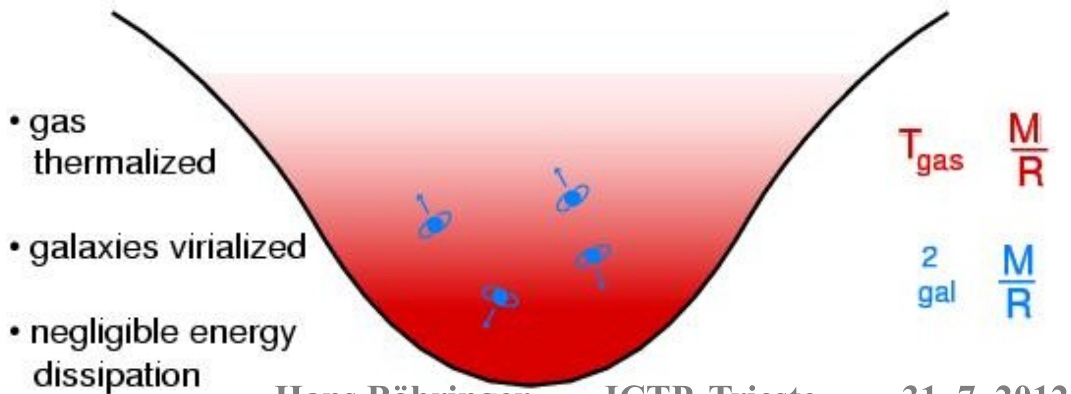
82 – 87% = Dark Matter
11 – 13% = hot gas
2 - 5% = galaxies
(for $H_0 = 70$)

Comparison of Galaxies and Clusters as Dark Matter Halos

Galaxies

Complex relation between observable stellar population and dark matter halo

Clusters



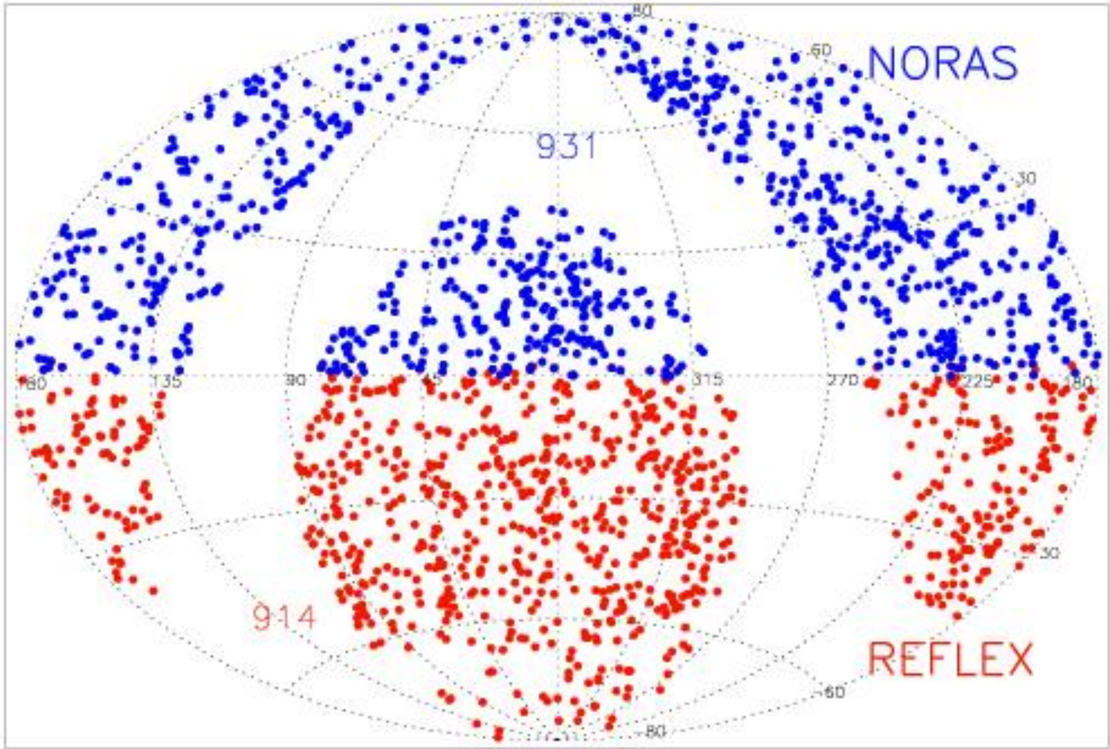
The intracluster gas is heated when the cluster forms and does not cool – it still reflects the potential depth.

Assessing the LSS with X-ray Galaxy Cluster Surveys

and Testing Cosmological Models

Combined REFLEX & NORAS Survey

Extragal. ALL-SKY RASS Survey



REFLEX II 918 clusters

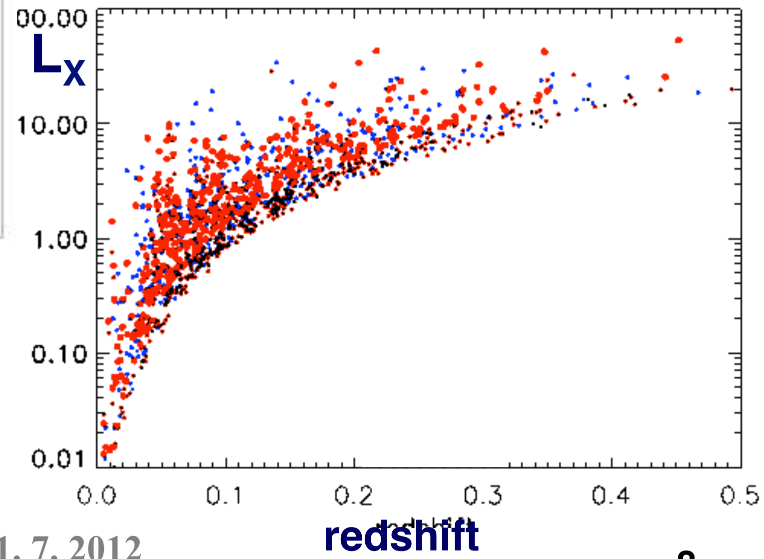
NORAS II 934 clusters

F> 1.8 10^{-12} erg s^{-1} cm^{-2}

REFLEX 1: 18 runs La Silla

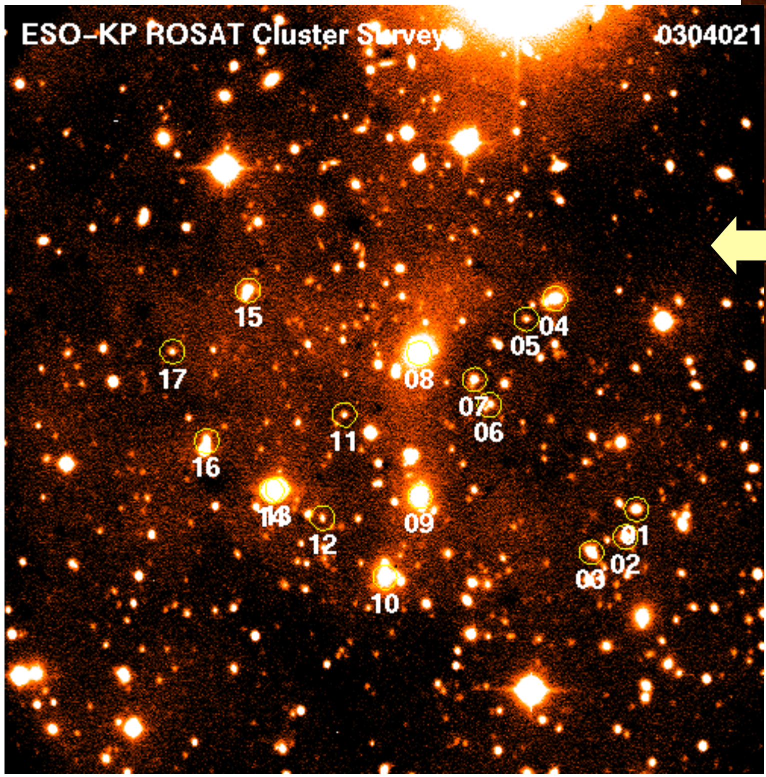
REFLEX 2:   8 runs ESO 3.6m

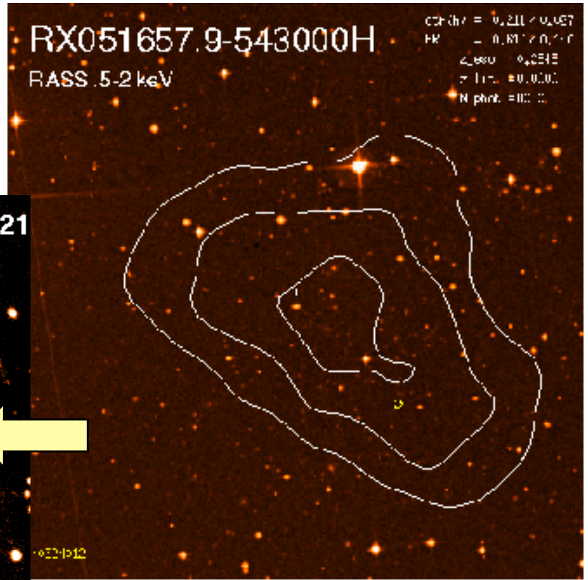
NORAS 10runs C.A. 2 runs K.P.

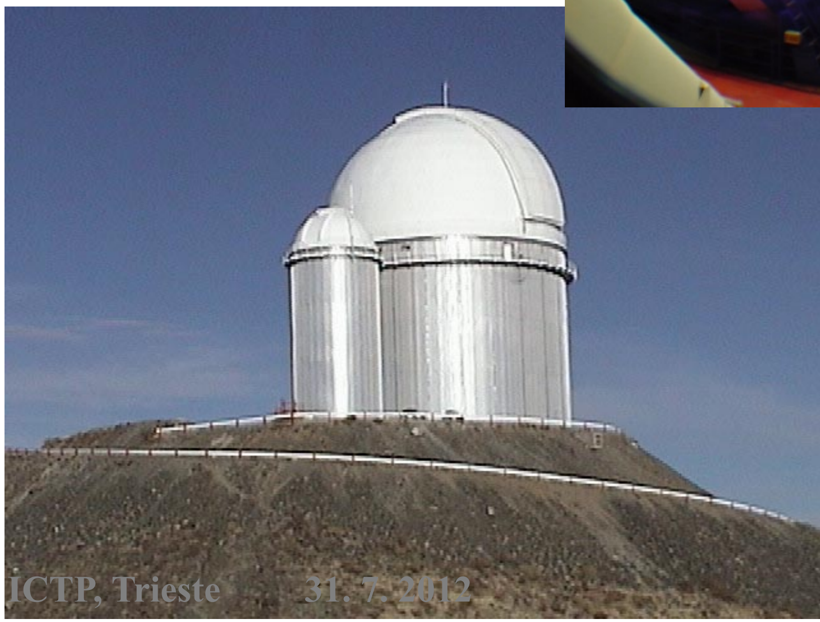


Böhringer et al. 2000, 2001, 2004, 2012

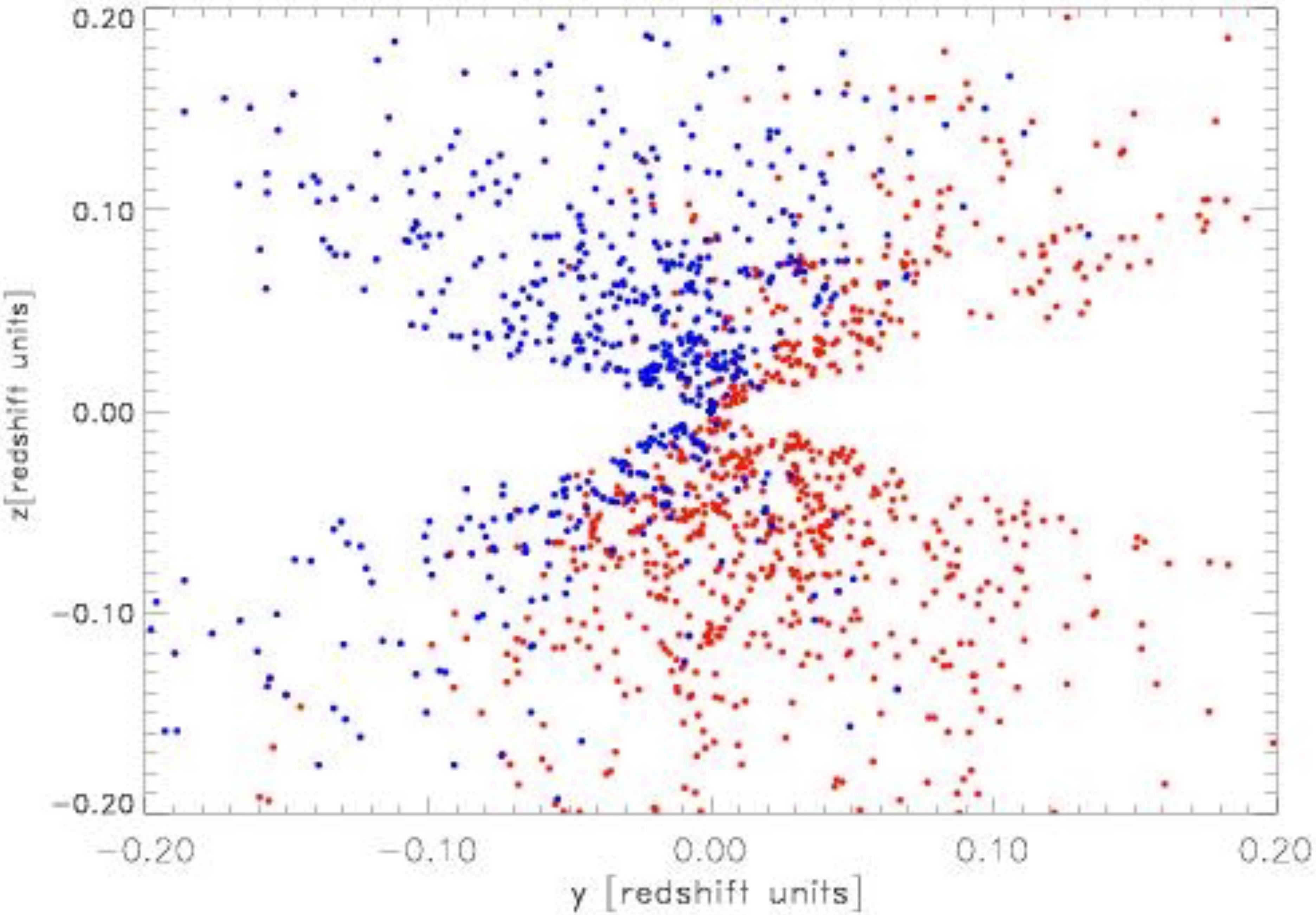
ESO – Key Program
conducted at La Silla 1992 - 99 (II) - 2011



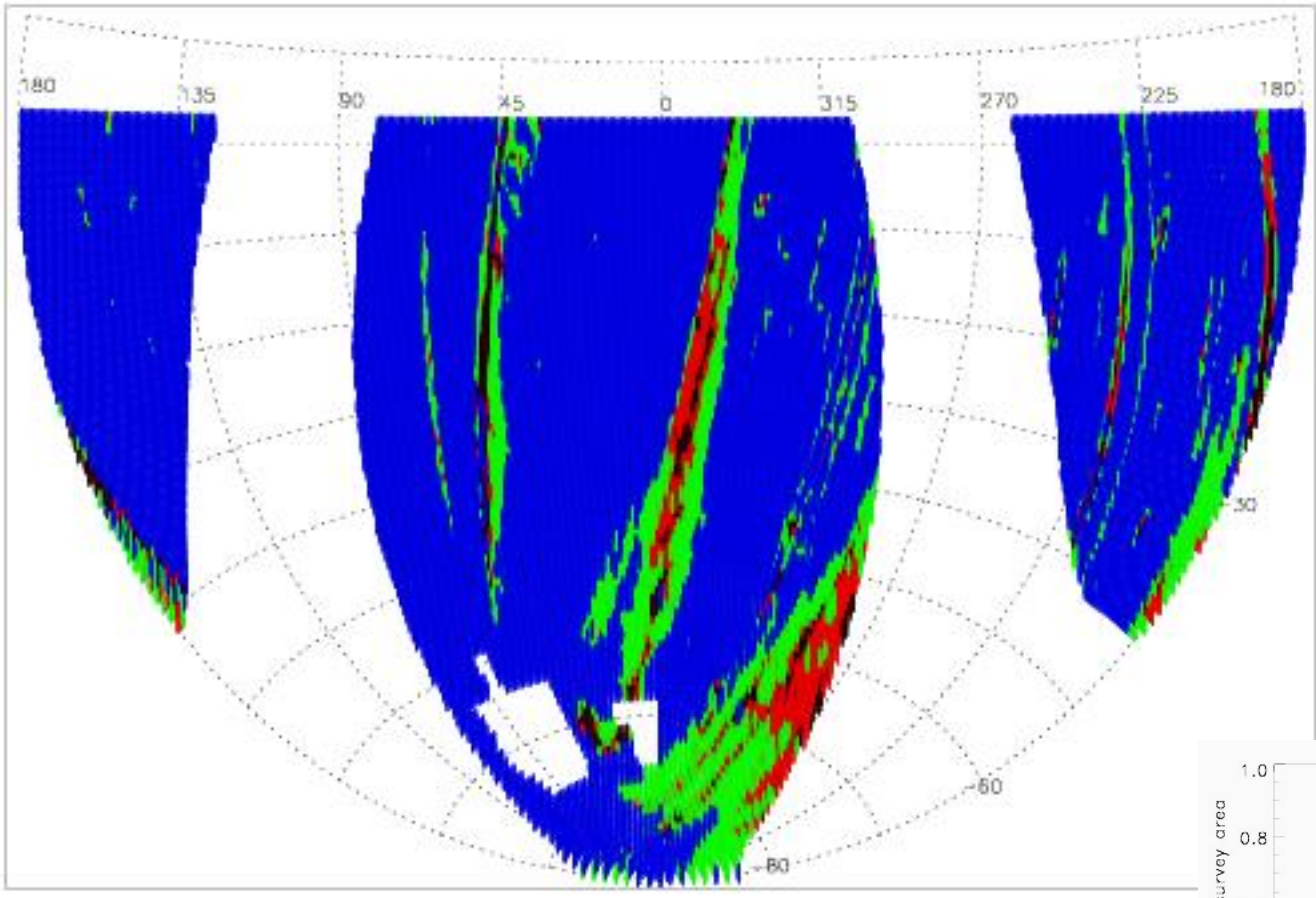




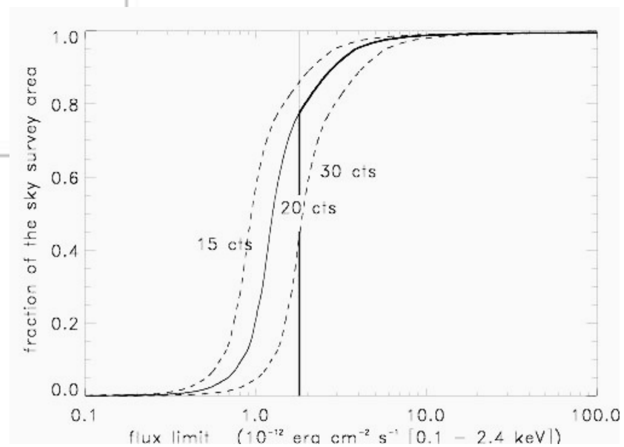
ESO 3.6m Teleskop


0.20
0.10
0.00
−0.10
−0.20
z[redshift units]
−0.20
−0.10
0.00
0.10
0.20
y [redshift units]

REFLEX II Selection Function



effective flux limit



Blue = flux limit of 1.8 10^{-12} erg/s/cm^2 for > 20 source counts, other color higher flux limit

Böhringer et al. 2012 in prep

Cosmological model

$H_0 \quad \Omega_m \quad \Omega_\Lambda \quad \Omega_B$ (w)

← **cosmological parameters**

↓

Generation of density fluctuations

$\sigma_8 \quad P_0(k)$

← **primordial P(k)**
Test of inflation

↓

Nature of the Dark Matter

CDM (HDM) ? (transfer fct.)

← **form of DM (e.g. neutrinos)**

↓

Structure evolution

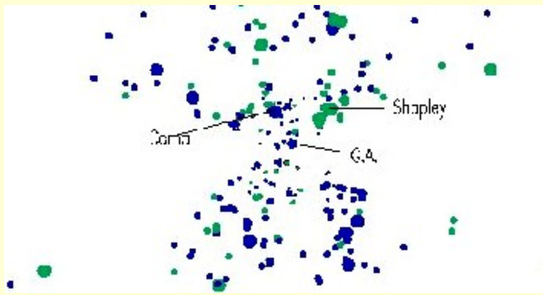
(gravitational effect)

← **effect of Dark Energy**

↓

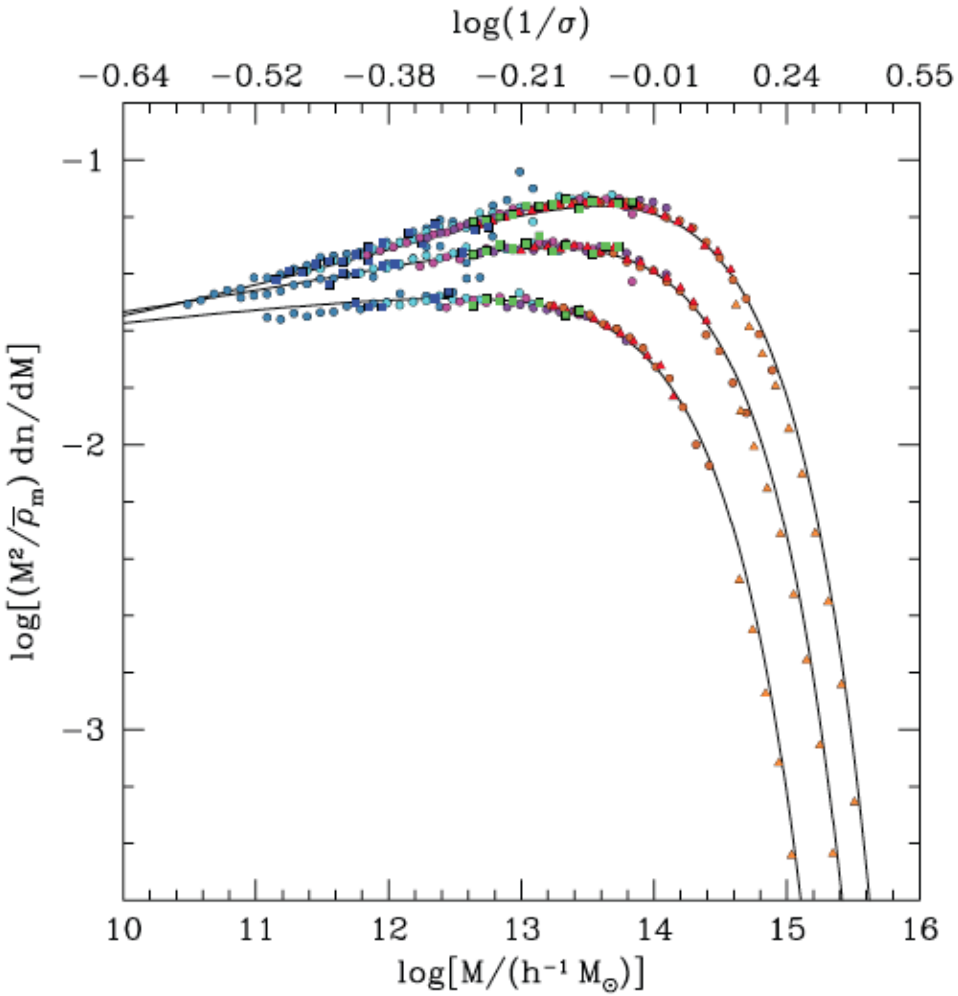
Galaxy clusters mass function | Large-scale galaxy/cluster distribution

$$\frac{d^2N}{dMdz}$$



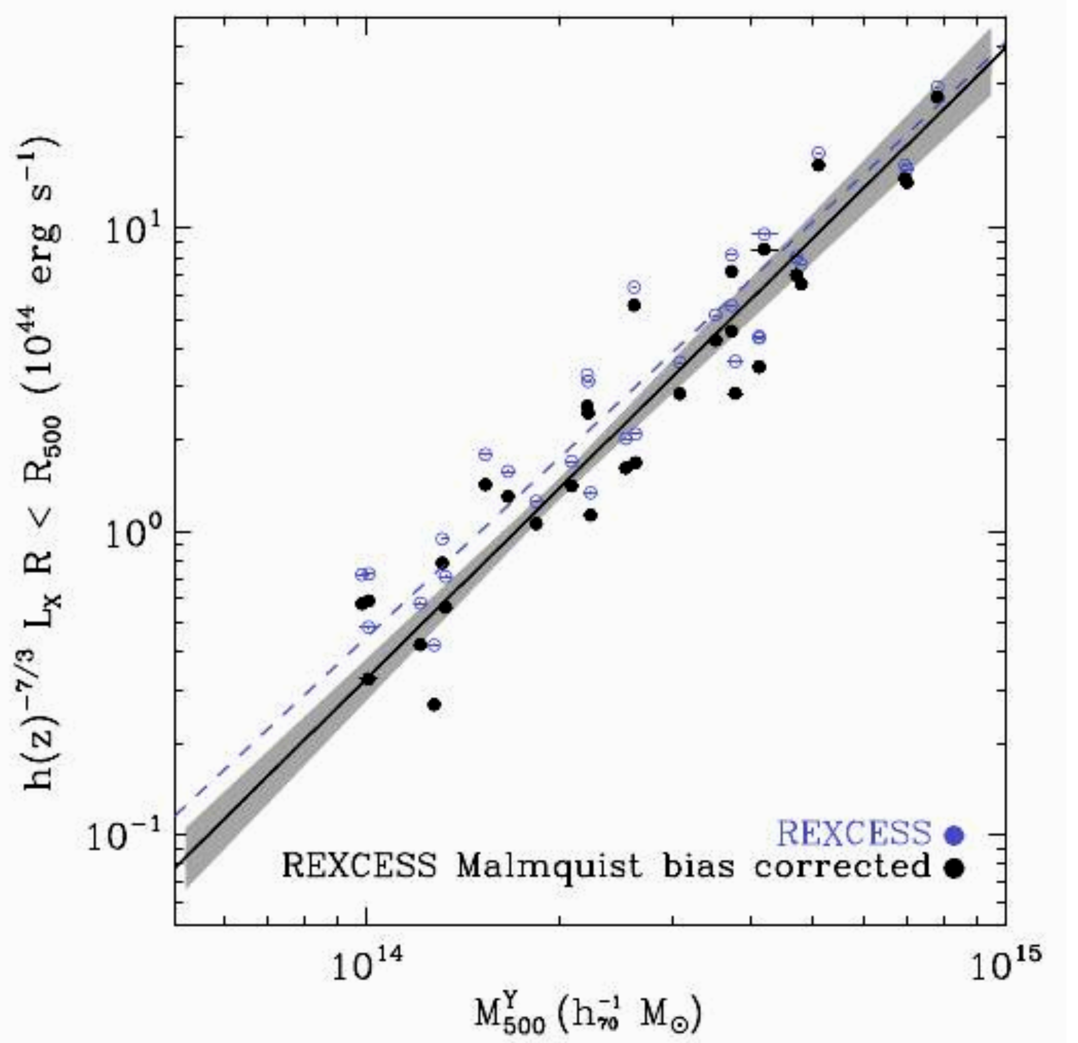
$P(k)_{clus}$

Mass Function from Cosmological Simulations



Universal mass function from Tinker et al. (2008) for D = 200, 800, 3200

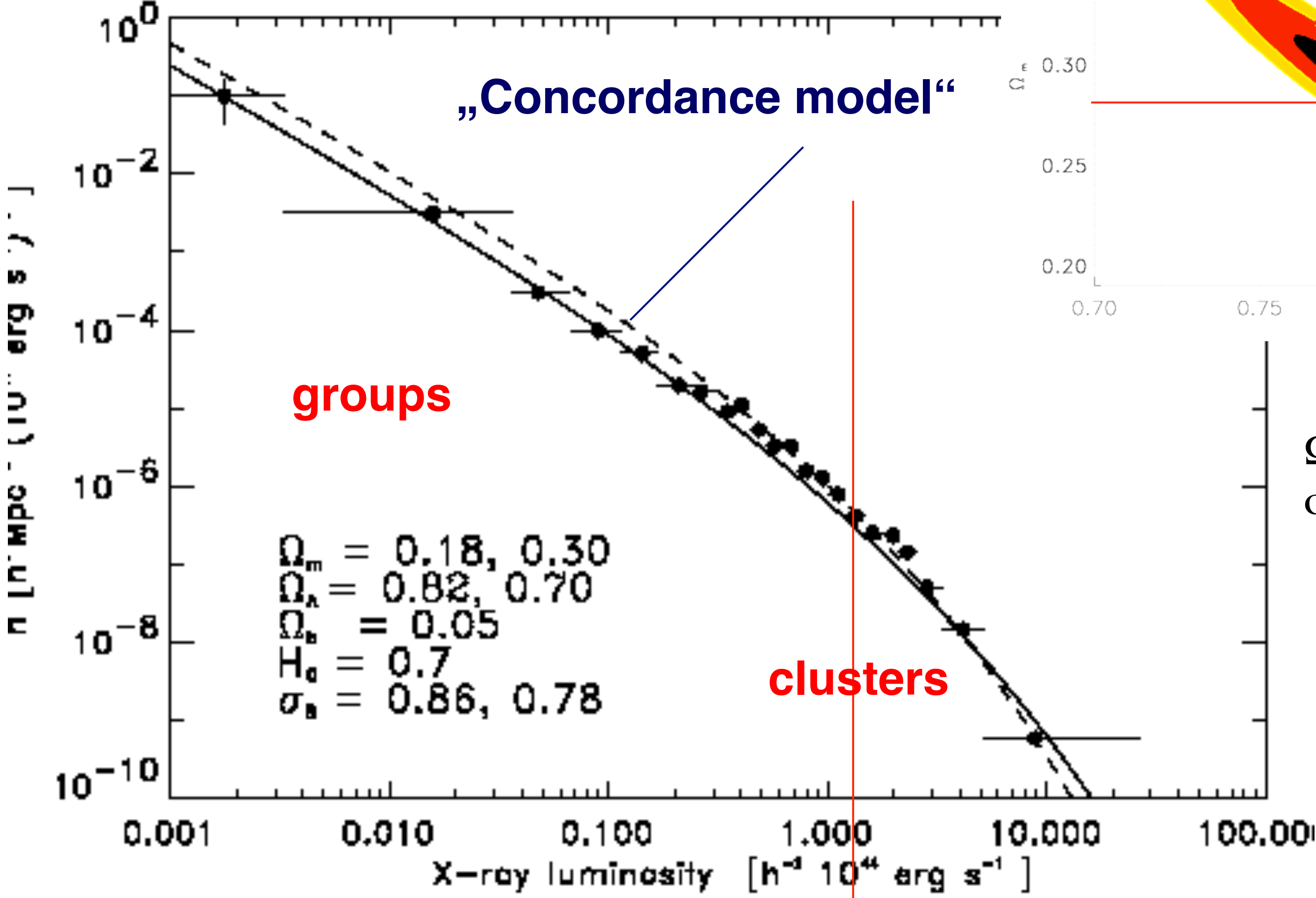
Empirical X-ray Luminosity Mass Relation

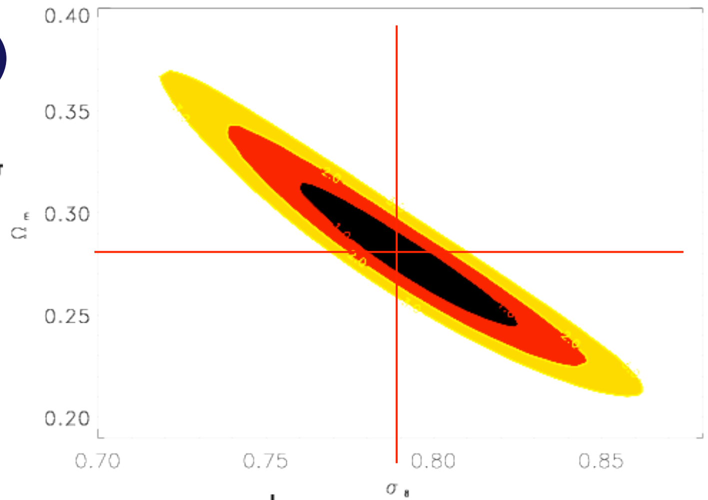


L_X – M relation from REXCESS sample [Pratt et al. 2009]

From cosmological model predicted and observed X-ray luminosity function

REFLEX I survey (Böhringer et al. 2002, 2010)



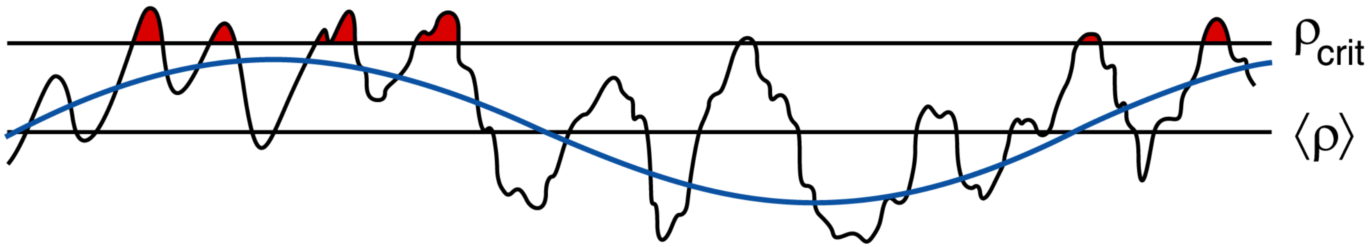


Ω_m = 0.28 +- 0.05

σ_8 = 0.79 +- 0.04

Probing the large-scale matter distribution with galaxy clusters

Spatial modulation of the density of peaks (clustering) :



→ The cluster distribution traces the matter distribution in a „biased“ (amplified) way

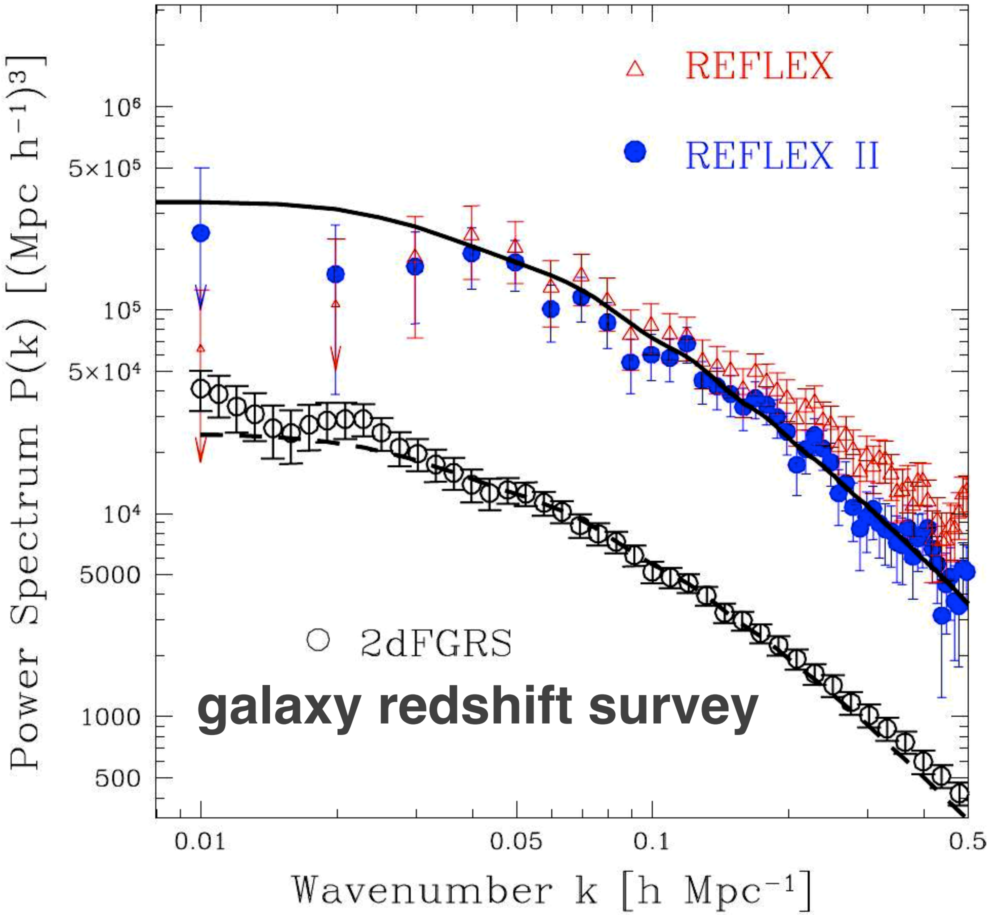
Biasing : $$\widetilde{P}(k) = b^2 \cdot P_{DM}(k)$$

$$b(M,z) = 1 + \frac{\Delta_*}{\sigma^2(M,z)} - \frac{1}{\Delta_*}$$

[Mo & White 1996, Sheth & Tormen 1999]

➡ biased (amplified) probe of very large scales

REFLEX II Power Spectrum (ΛCDM-Cosmology)

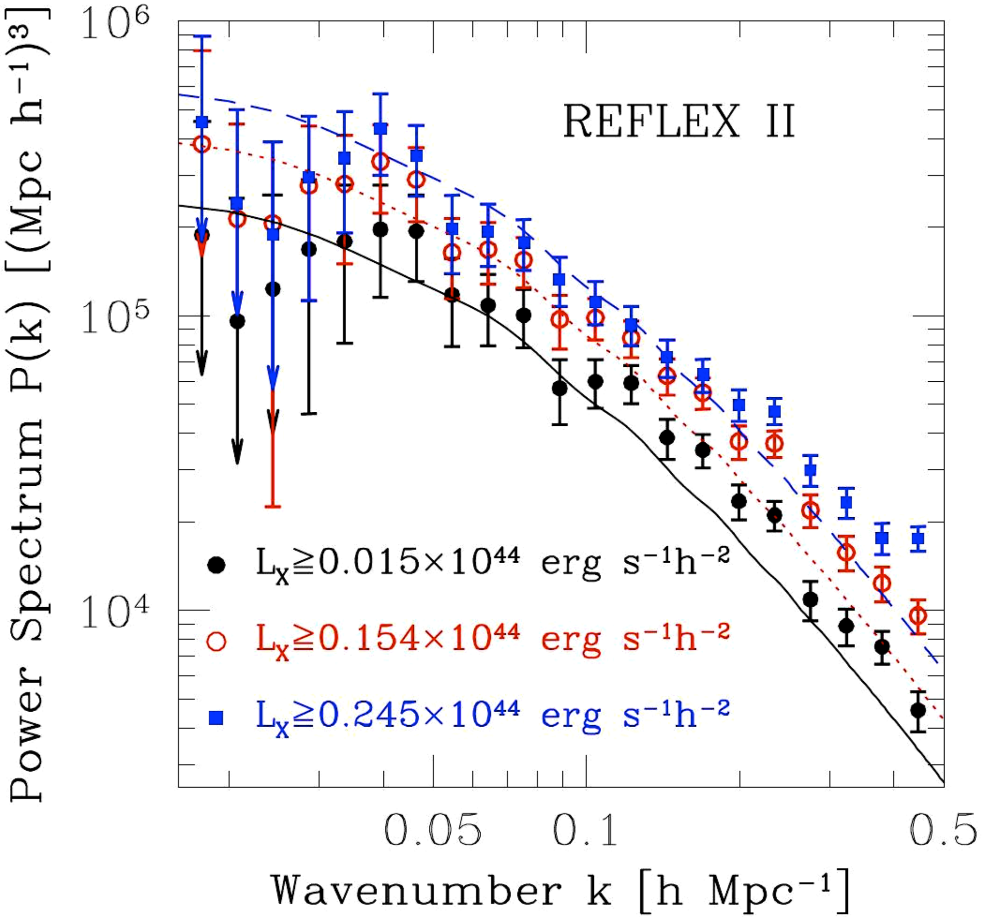


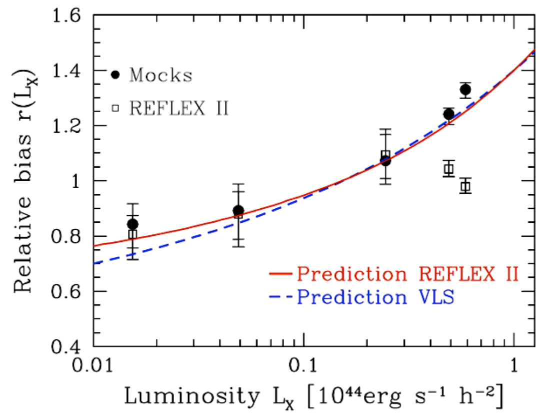
The lines give the prediction of the Concordance Cosmological Model with WMAP 5yr parameters

Balaguera-Antolinez et al. 2010

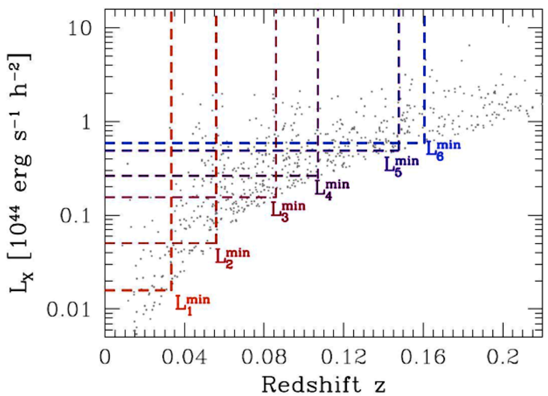
REFLEX II Power Spectrum (biasing)

The amplitude of the P(k) increases with increasing lower mass limit





Increase of the amplitude (above) for 6 volume limited subsamples

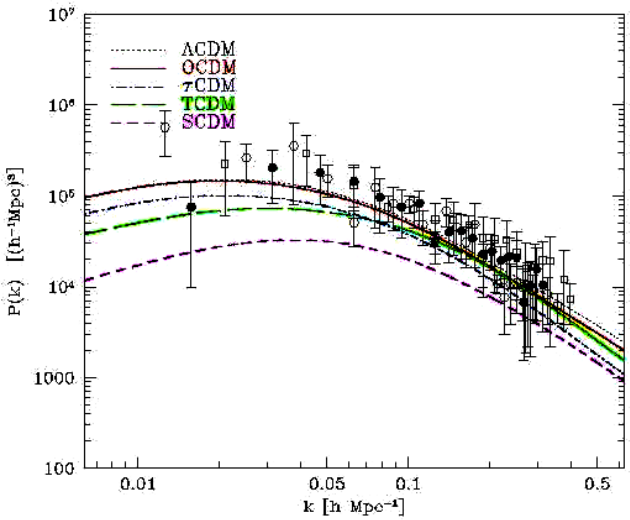


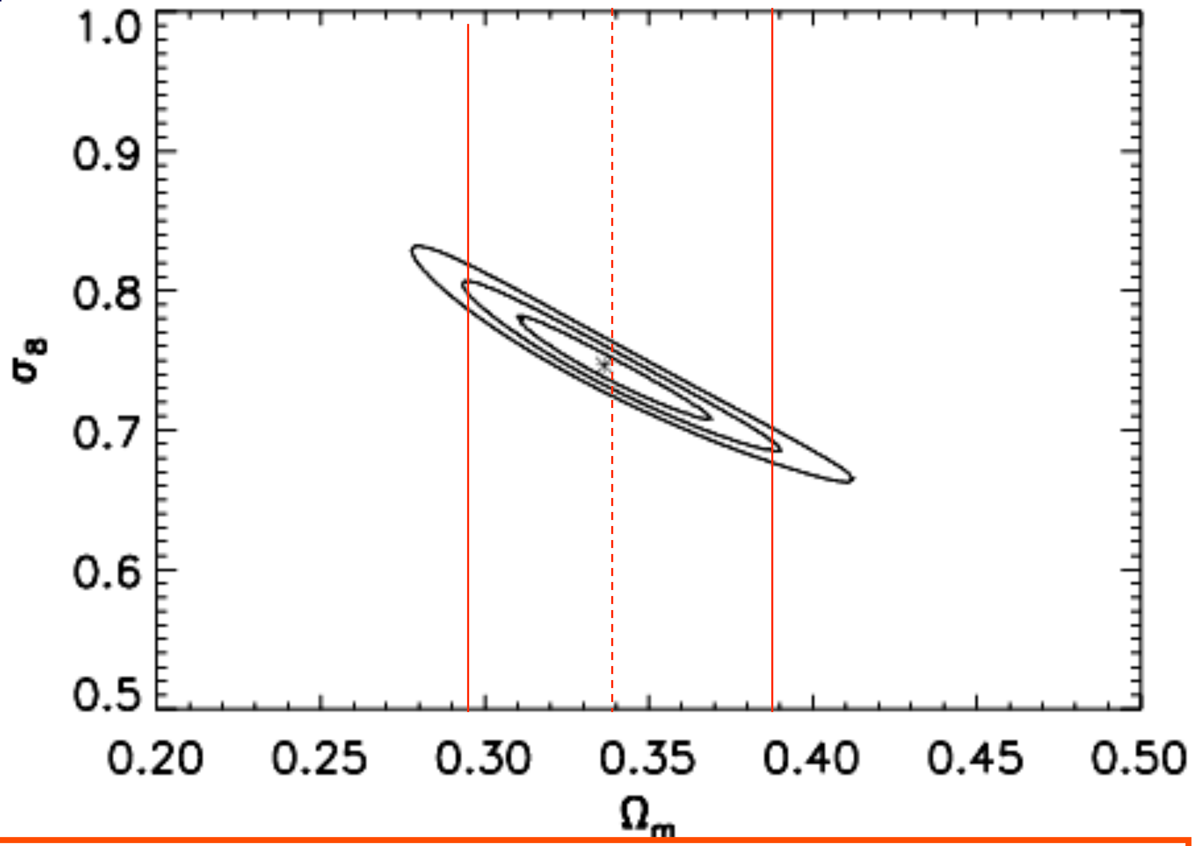
Constraints on Cosmological Models and Ω_m from the *REFLEX* Cluster Survey

[Schuecker et al. 2002, 03] (curves are 1,2,3 σ)

REFLEX power spectrum

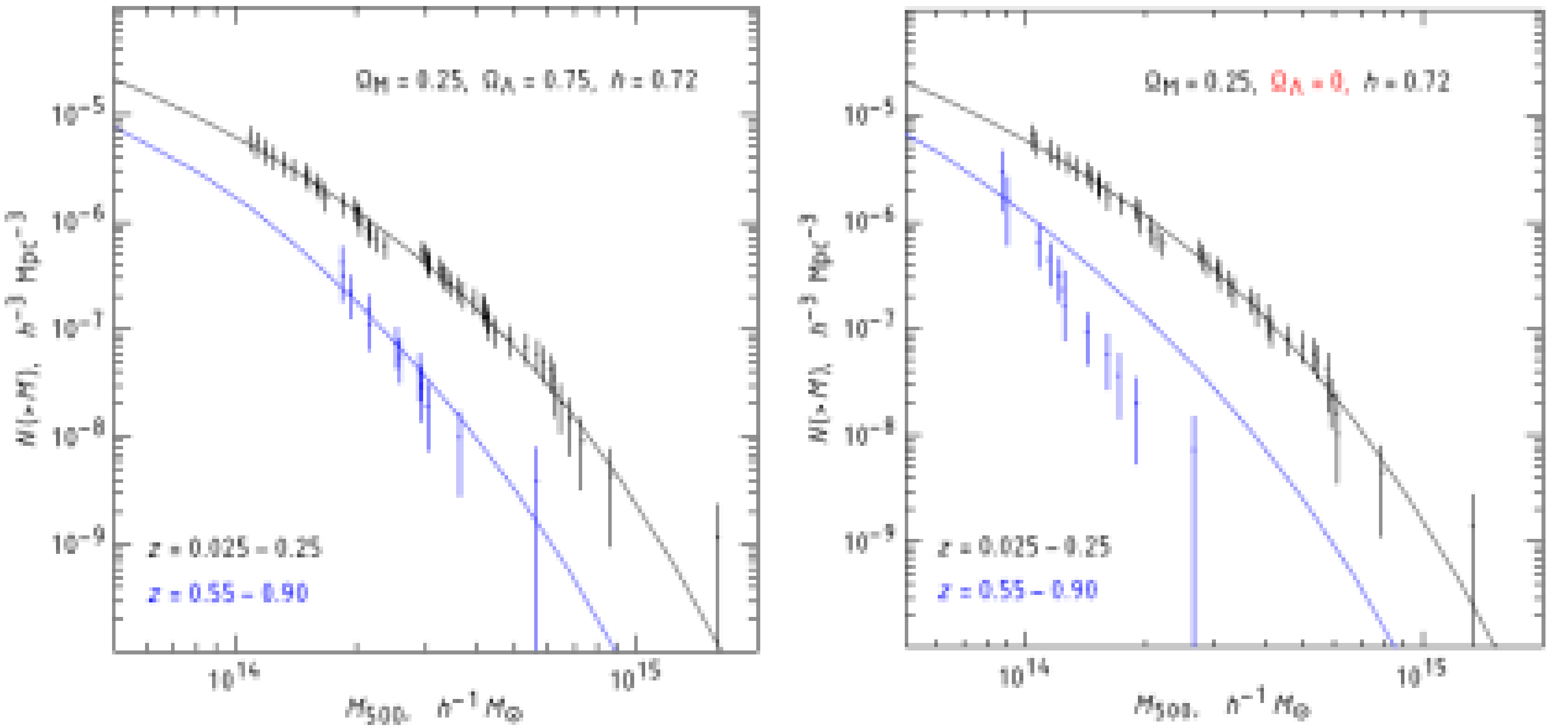
Volume-limited samples with boxlength of: 300, 400, 500 h^{-1} Mpc





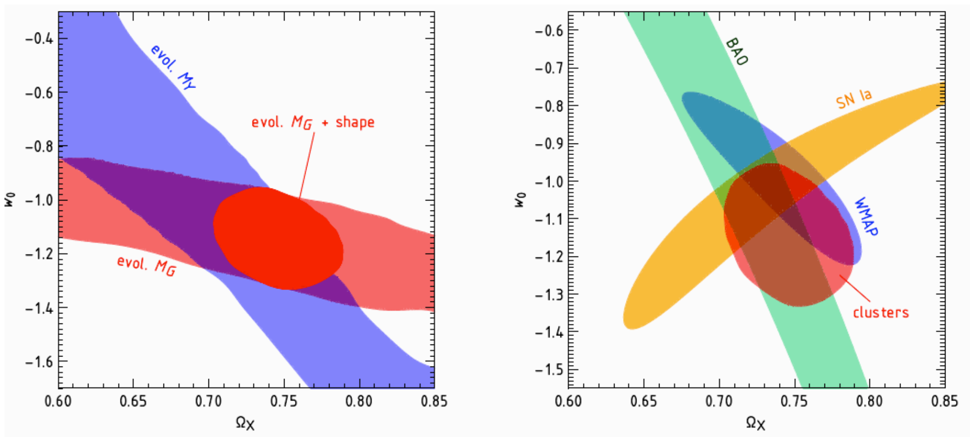
◊ $\Delta\Omega_m$ ~ 0.34 +-0.05 (+ syst. errors +-0.05) 2σ !

Evolution of the Cluster Mass Function



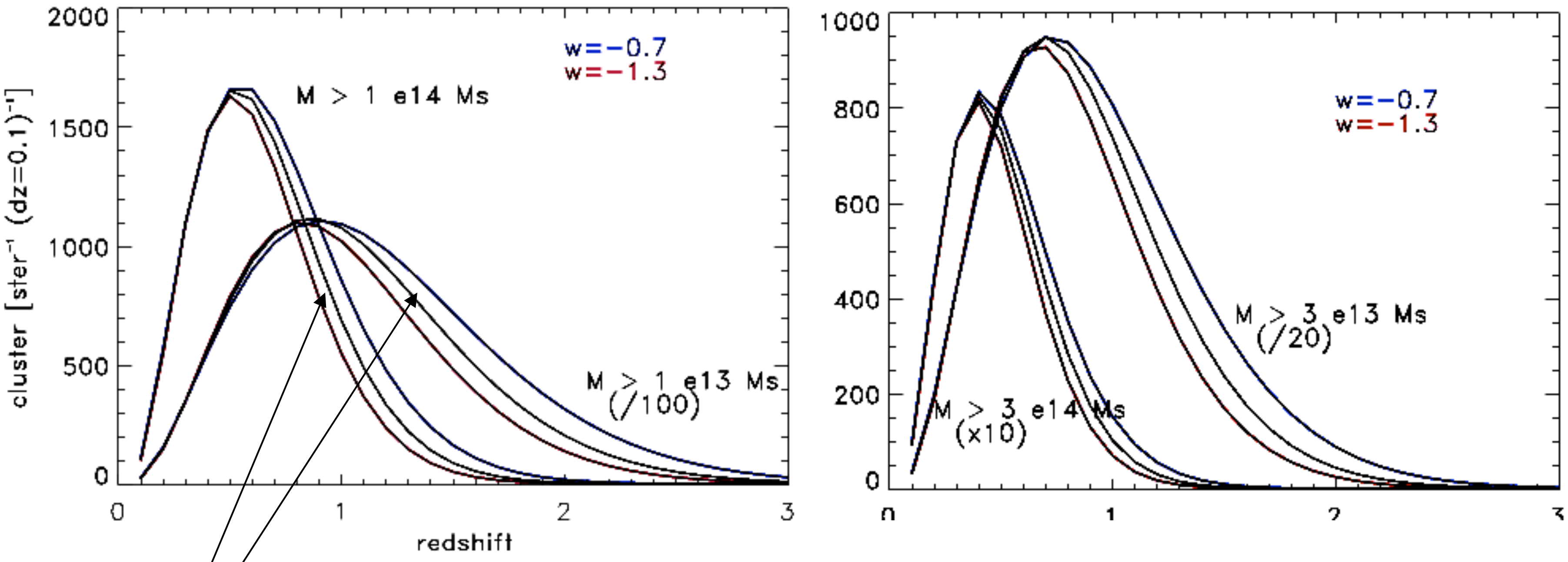
Model constraints from the observation of the cluster mass function evolution: gas mass and Y_X parameter as alternative observables (proxies)

Vikhlinin et al. , 2009



Evolution of the Cluster Mass Function

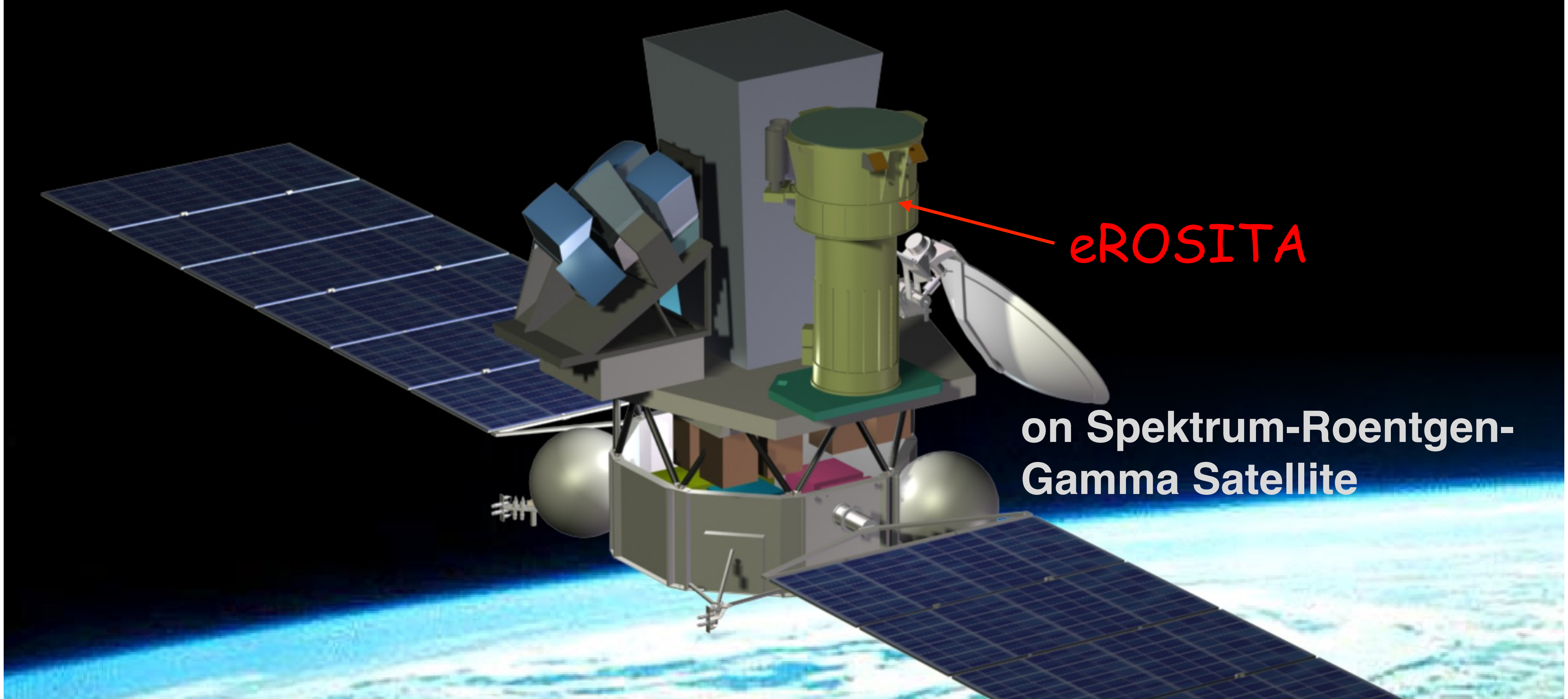
Differential comoving cluster abundance (> $Mass_{limit}$) $ster^{-1}$ $dz=0.1^{-1}$



→ There are more distant clusters for small -w !

Number count variation ~ 30%   dlogN/dlogM at this point ~ 3
→ the accuracy needed in the mass measurement is a few %

Prospects of the eROSITA Mission



- Detection of 50 000 – 100 000 galaxy clusters in X-rays
- Redshift evolution with several hundred clusters to $z \sim 1.5$
- Precise large-scale structure measure > 1 Gpc scale including baryonic oscillations

The eROSITA Instrument

Figure 2: Schematic view (CAD-model) of the eROSITA telescope. In front of the seven mirror modules are X-ray and thermal baffles (left figure). A carbon fiber structure combines these with cameras at the bottom (right figure). The telescope structure rests on the spacecraft truss via a hexapod. Two startrackers are used for correct boresighting. Cooling of the cameras require a complicated system of constant and variable conductance heatpipes and radiators. Also the heat of the electronics boxes is conducted by loop heatpipes to the thermal baffle on top of the telescope.

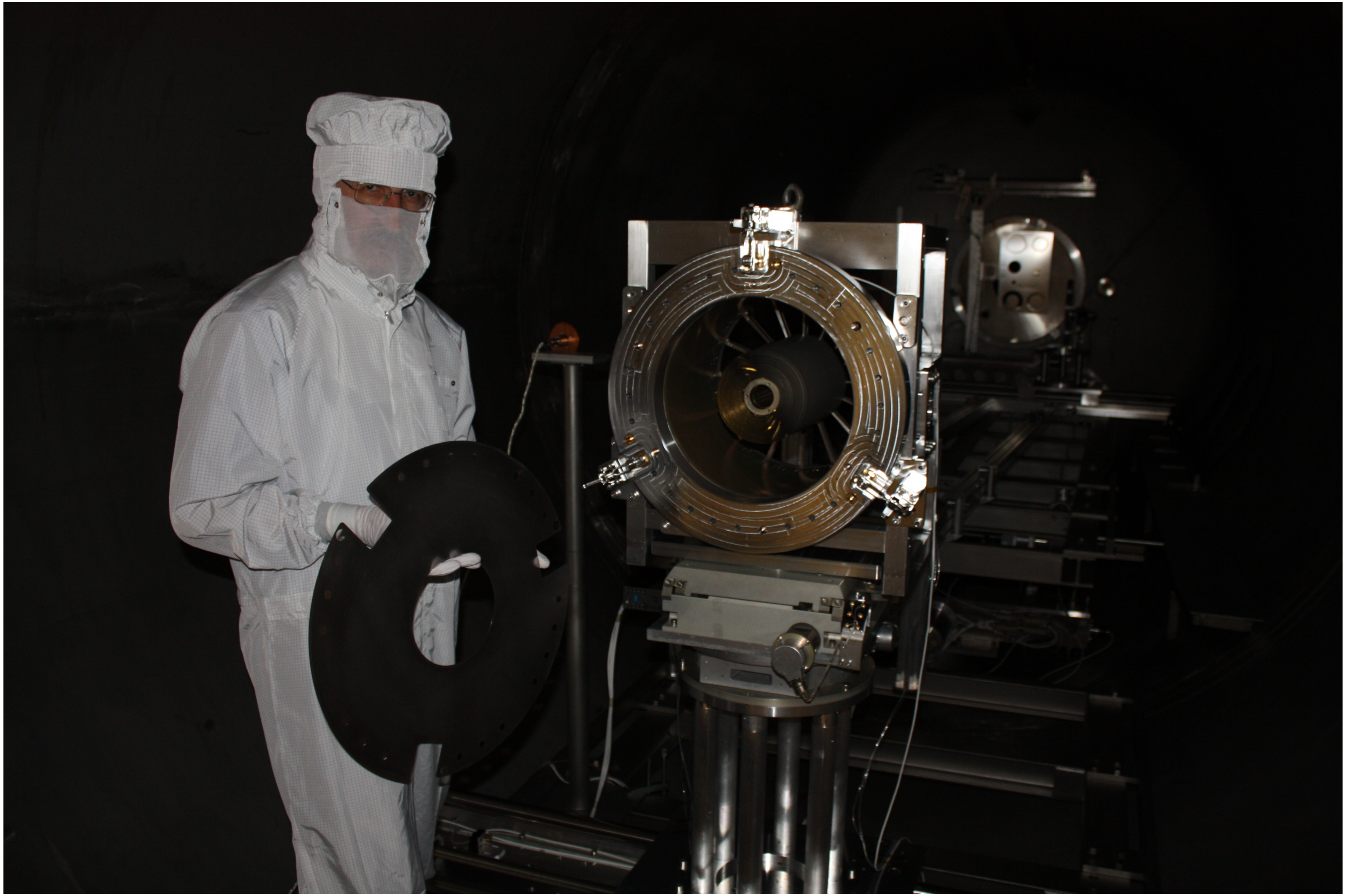
eROSITA Teleskop System

number of mirror systems	7
number of nested mirror shells	54
angular resolution	<15'' (1 KeV)
energy range	0.5 – 10 keV
diameter of 1 mirror system	358mm
focal length	1600 mm
material of mirror shells	nickel
mirror coating	gold
weight of 1 mirror system	< 50kg
detector principle	pn-CCD
size	19.2×19.2 mm^2
pixelsize	75µm × 75µm
read out speed	50msec
energy resolution	
weight of each detector	~14 kg

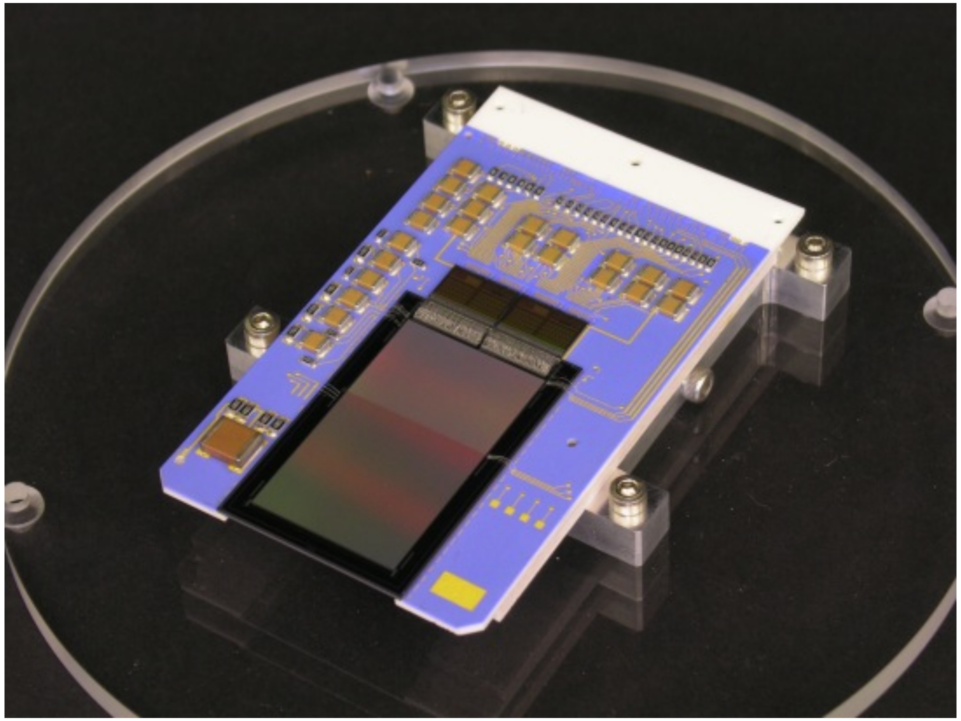
eROSITA Mirror Module

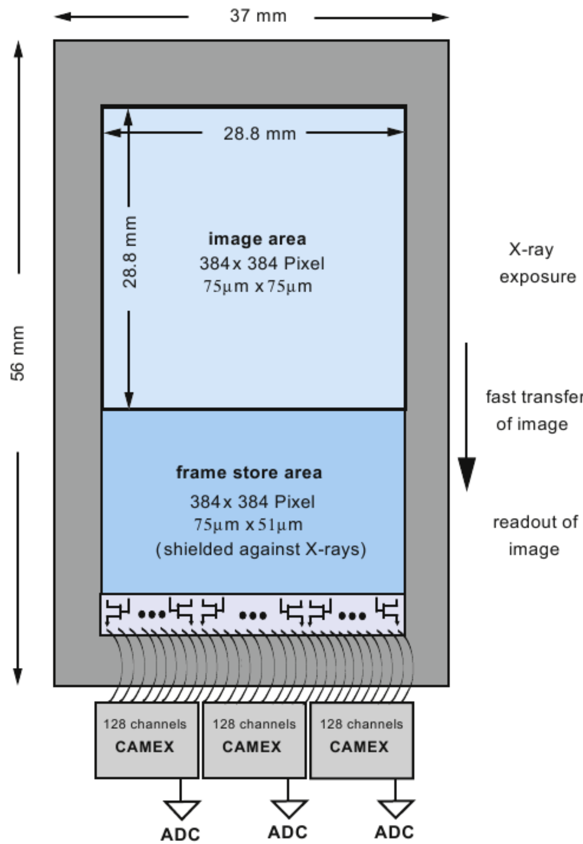
Photos credit: Vadim Burwitz

eROSITA Mirror Module



eROSITA Detector System





X-ray CCD with 384 x 384 pixels (FoV 1.03 deg)

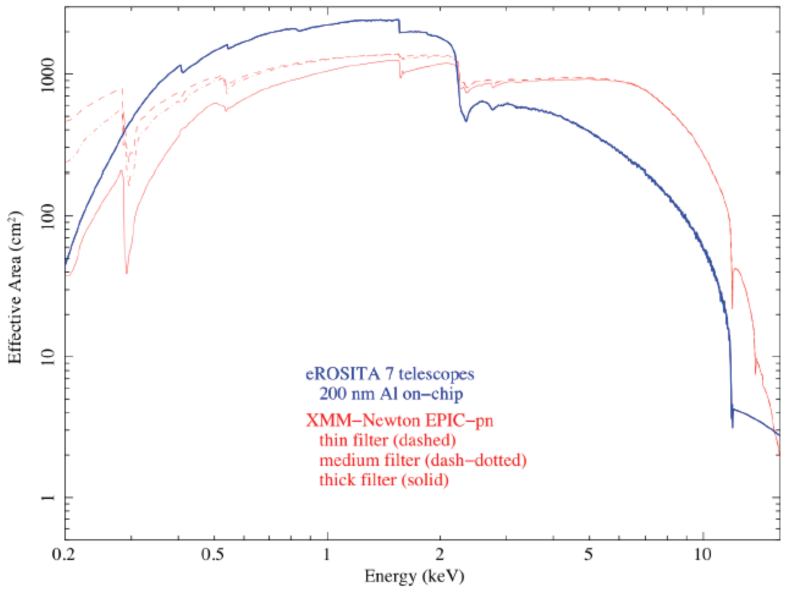
Pixelsize 75 μm x 75 μm (9.4'' x 9.4'')

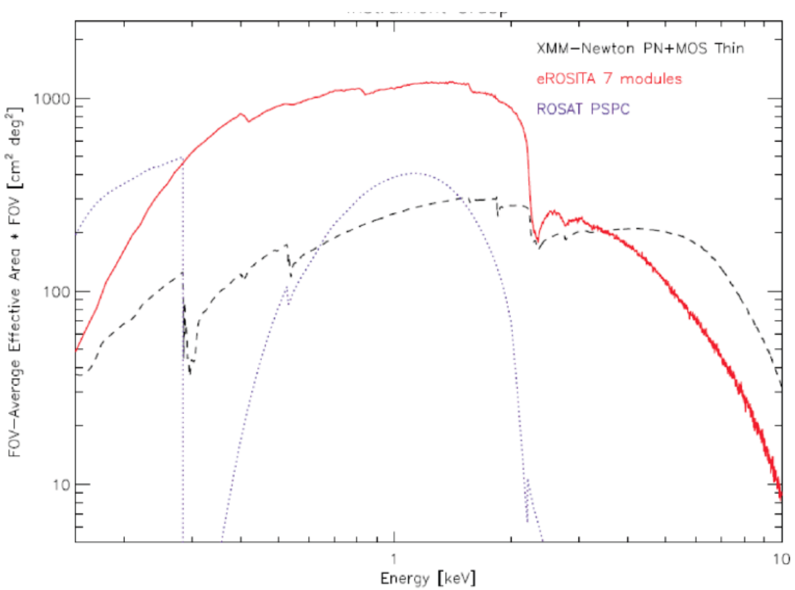
Integration time 50 msec (shift time to storage 100 μsec)

The eROSITA Survey

- SRG/eROSITA will fly to L2   (launch with Russian Zenit rocket)
- eROSITA will scan the sky in great ecliptic circles
- **In the 4 yr sky survey: 8 full scans of the sky**
- After the survey period, a pointed observation phase is foreseen
- The mission goal requirement is 7yr

Effective Area and Grasp of eROSITA

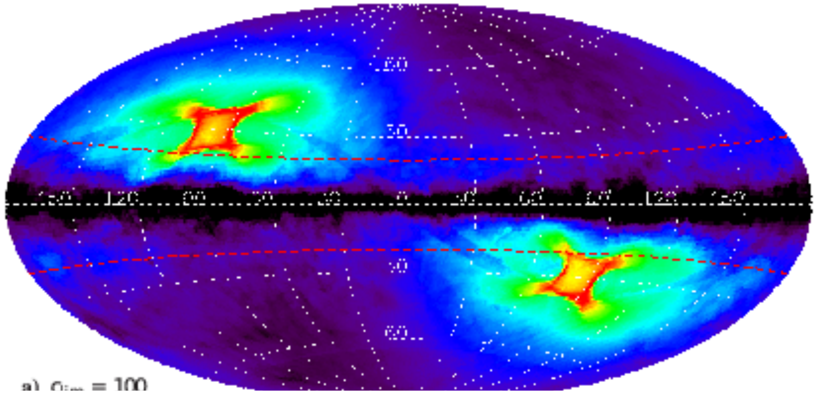




Effective area and grasp of eROSITA

compared to XMM-Newton

Galaxy Cluster Number Counts in the eROSITA Survey

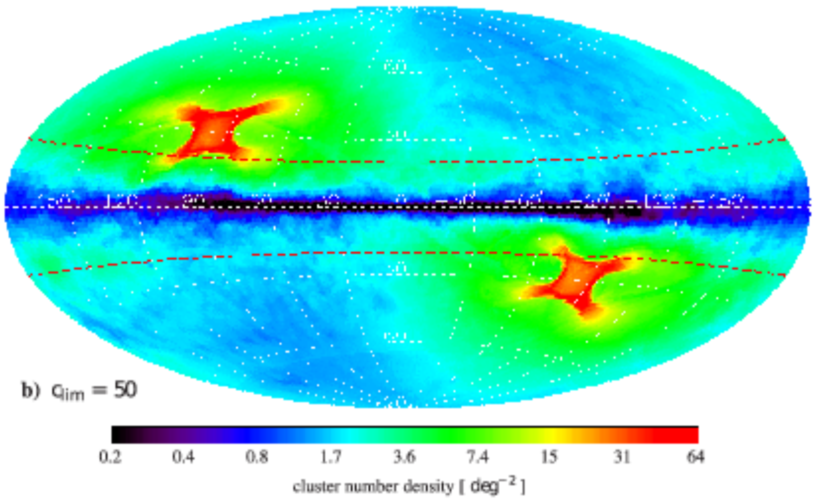


$N_{phot.}$	all sky	extragal. Sky
50	~300 000	~240 000
100	~140 000	~105 000
500	~ 20 000	~ 15 000
1000	~ 9 000	~ 6 700

M. Mühlegger Ph.D. Thesis

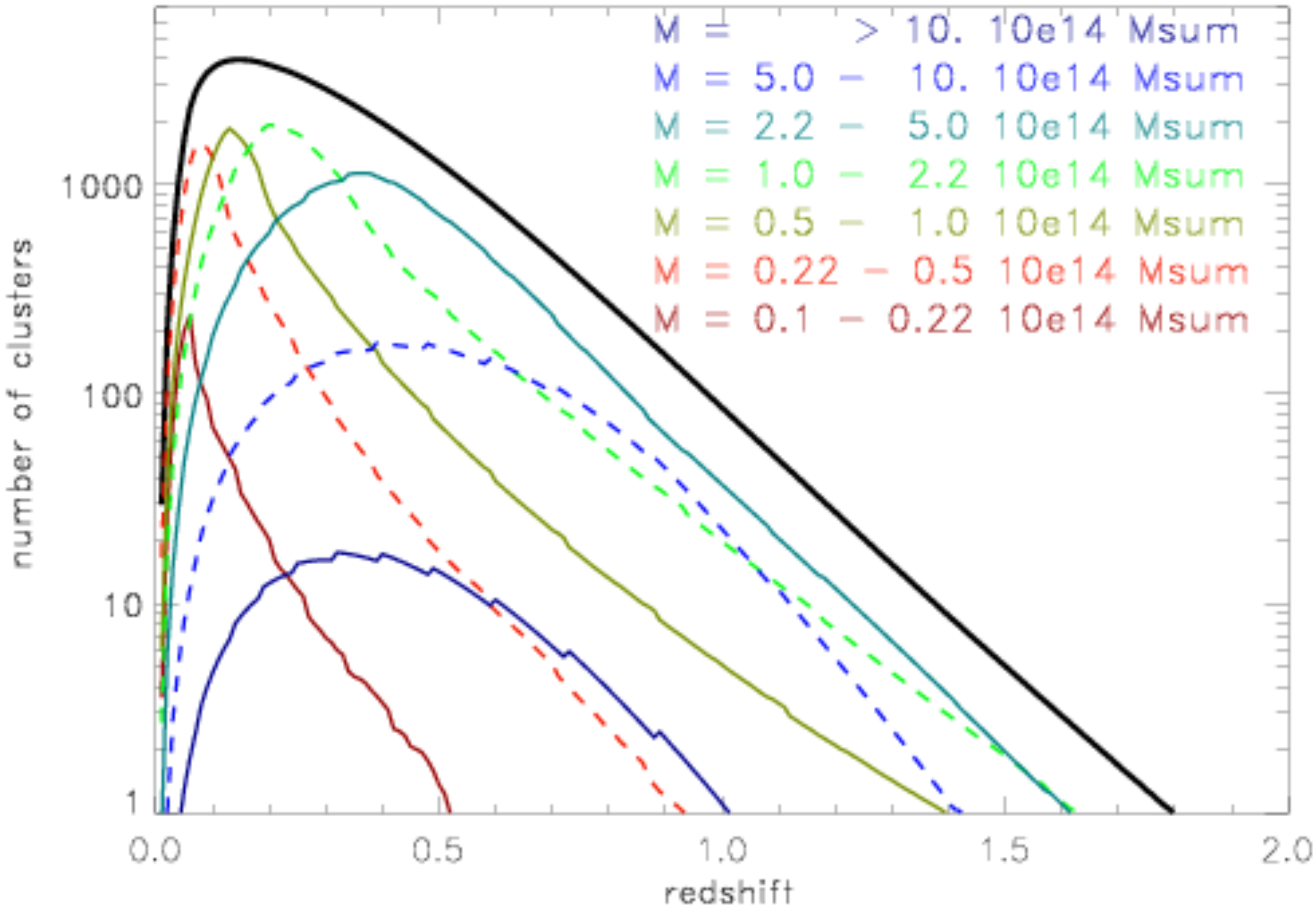
Redshift	extragal. Sky > 100 cts
> 0.3	~ 50 000
> 0.6	~ 10 000
> 0.8	~ 3 500
> 1.0	~ 900

M. Mühlegger, G. Chon,
H. Böhringer



Mass and Redshift Distribution of the Clusters

15 000 deg^2 4MOST region



Results of cluster number forecast for different cosmological models

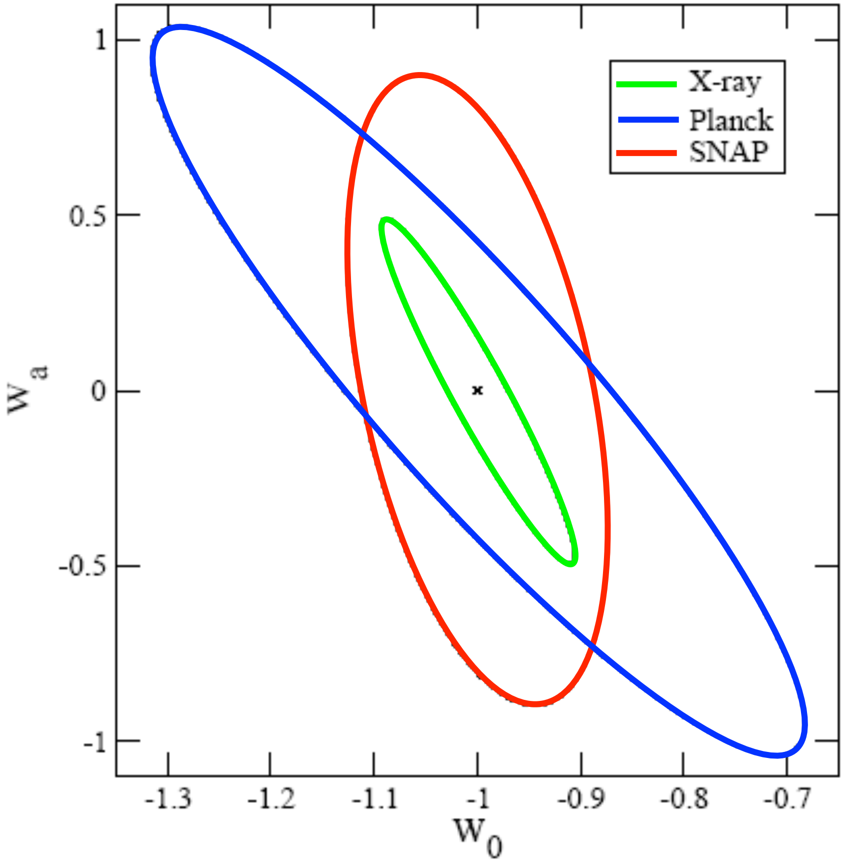
	refer.	σ_8=0.83	Ω_m=0.25	w = -1.3	w = -0.7
z > 0.4	41600	52600	27600	42300	43600
z > 0.8	4800	6900	3200	3900	6300
z > 1.2	490	760	315	327	830

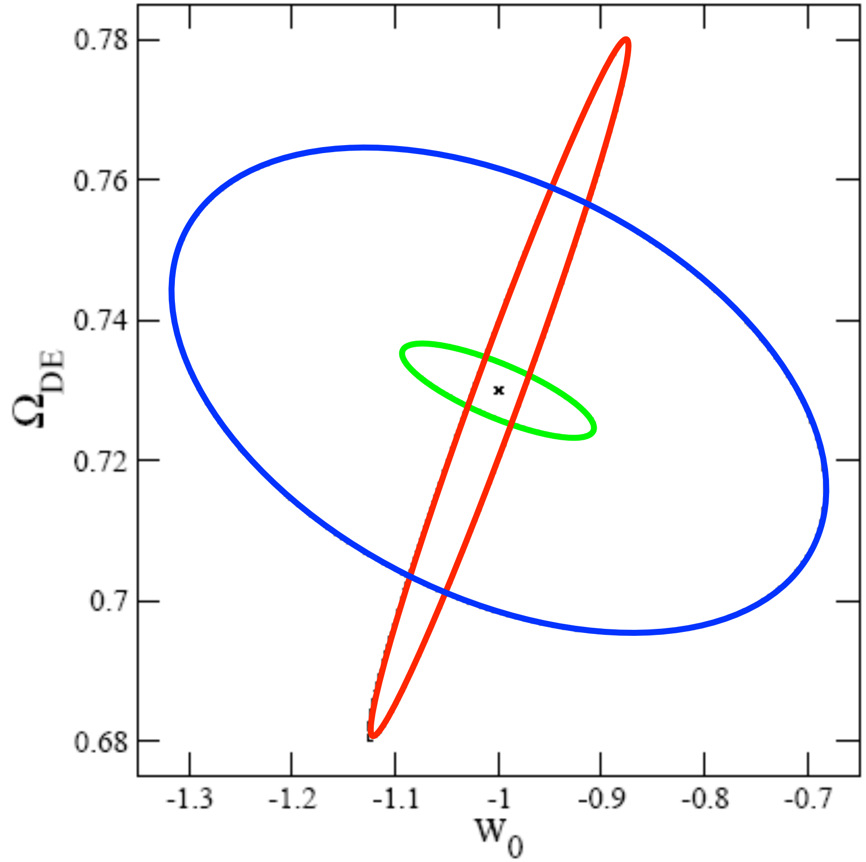
Constraints from 100K Cluster Survey

Time dependence of w_x

$w_{x(z)} = w_0 + w_a\, z$

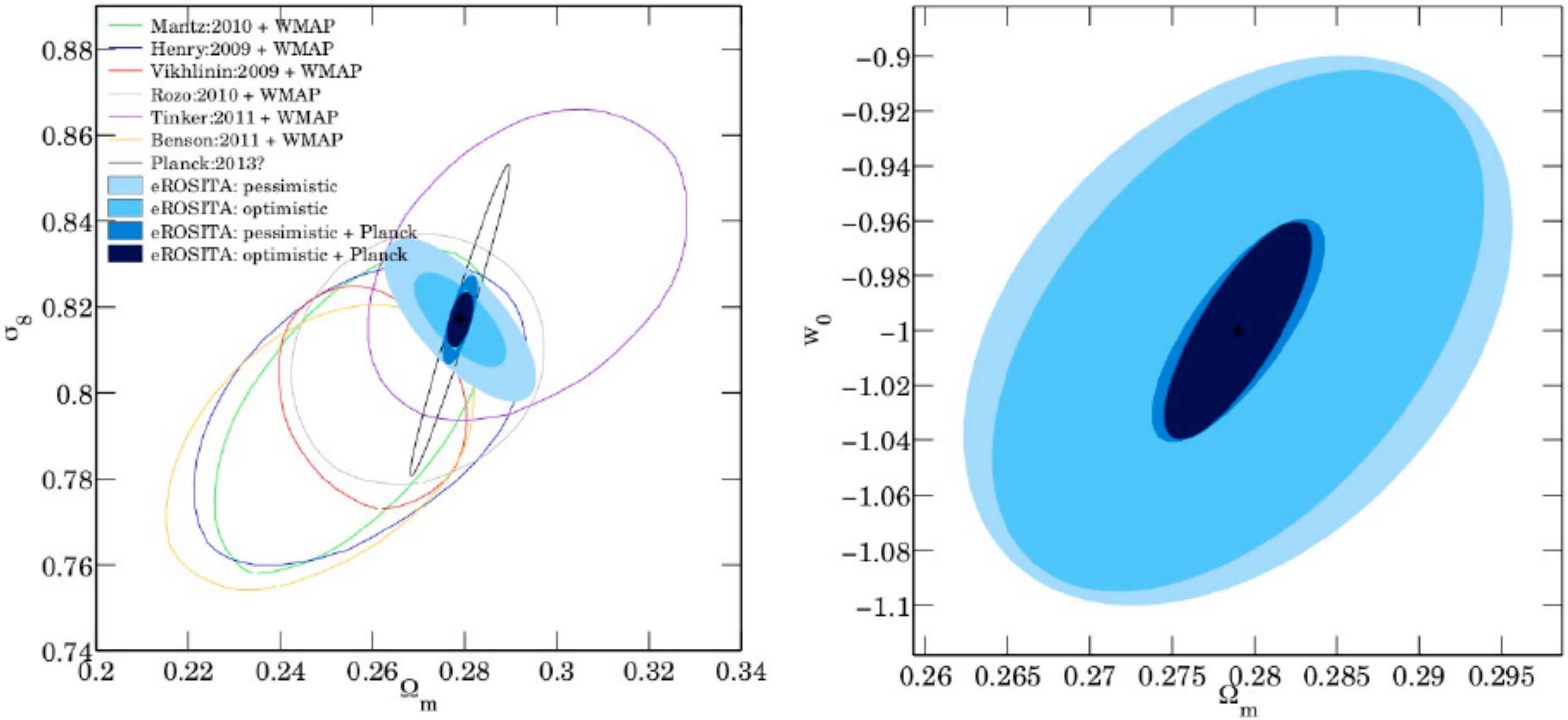
$p(z) = w_x(z) * \rho(z)$





Haiman, et al., 2005, astro-ph/0507013

Constraining Cosmological Models



Pillepich et al. 2012

Conclusions

- Galaxy clusters are important and useful probes to study the LSS and to test cosmological models.
These tests are complementary to other cosmological tests (consistency, breaking degeneracies).

- Progress in understanding scaling relations allows us now to calibrate observable-mass relations for galaxy clusters to about or better than 10% (for X-ray and SZE surveys)

- We have observationally confirmed (for the first time) that the statistical bias of the clustering of DM-halos (galaxy clusters) works as predicted.

•eROSITA is coming - official launch in Spring 2014 !