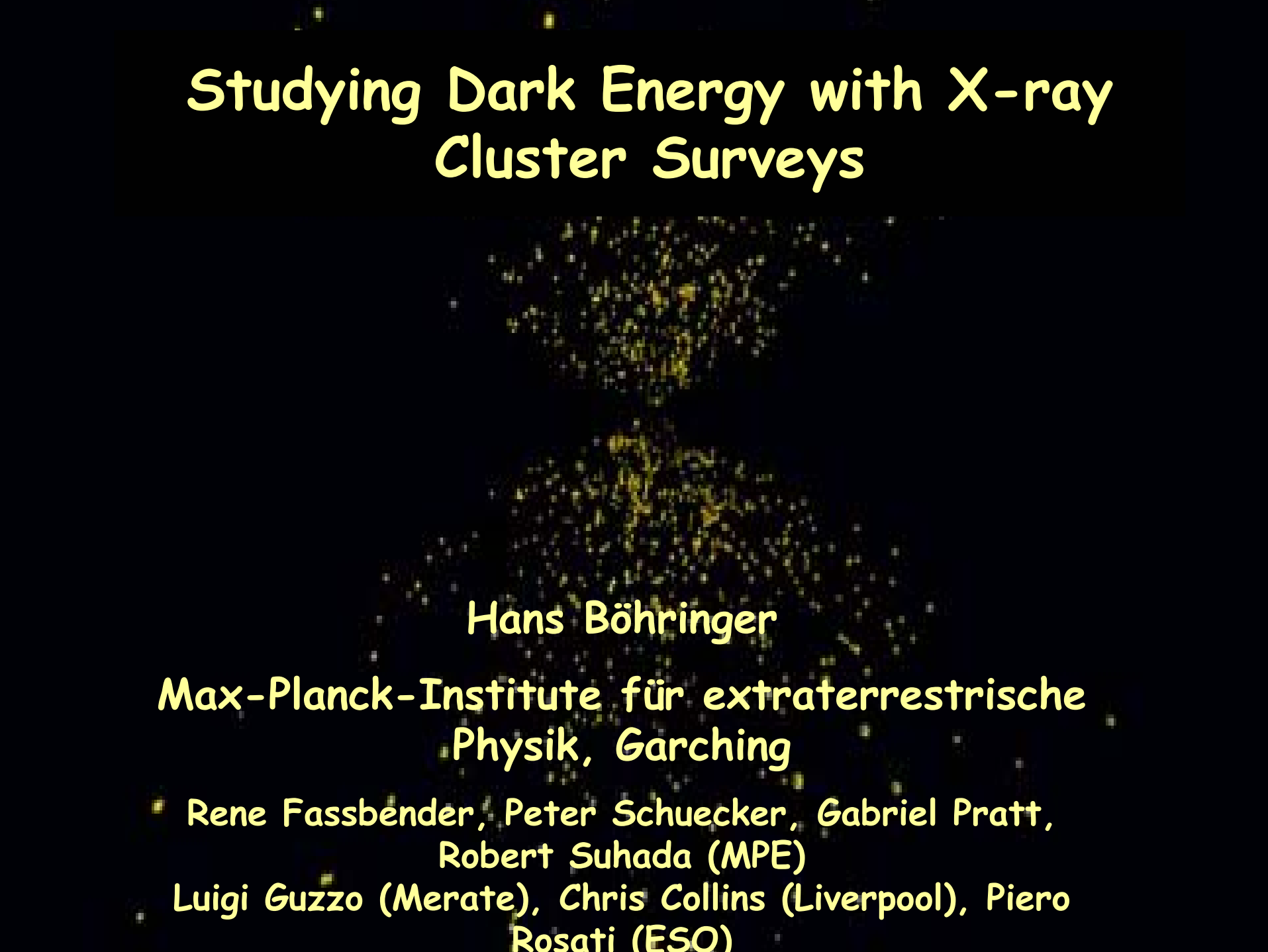
Studying Dark Energy with X-ray Cluster Surveys



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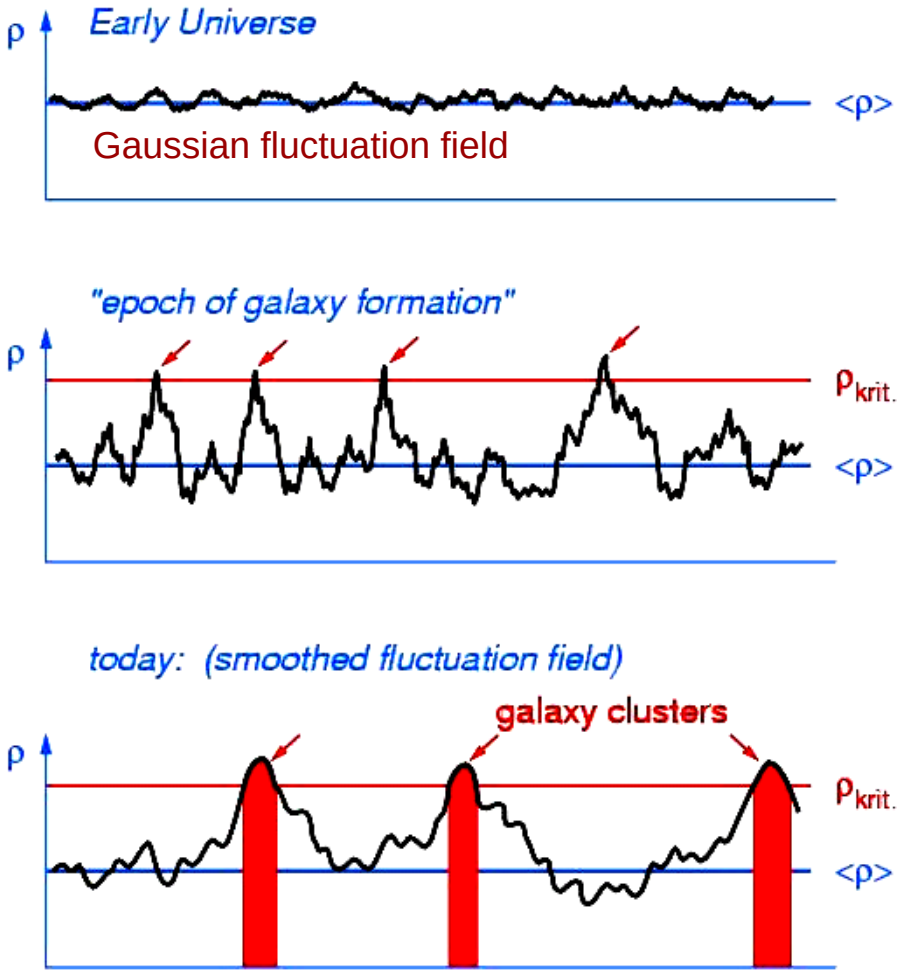
Overview

- **Cosmology with Galaxy Clusters**
- **The Cluster Power Spectrum from the ROSAT Survey**
- **Outlook : the eROSITA Mission**

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



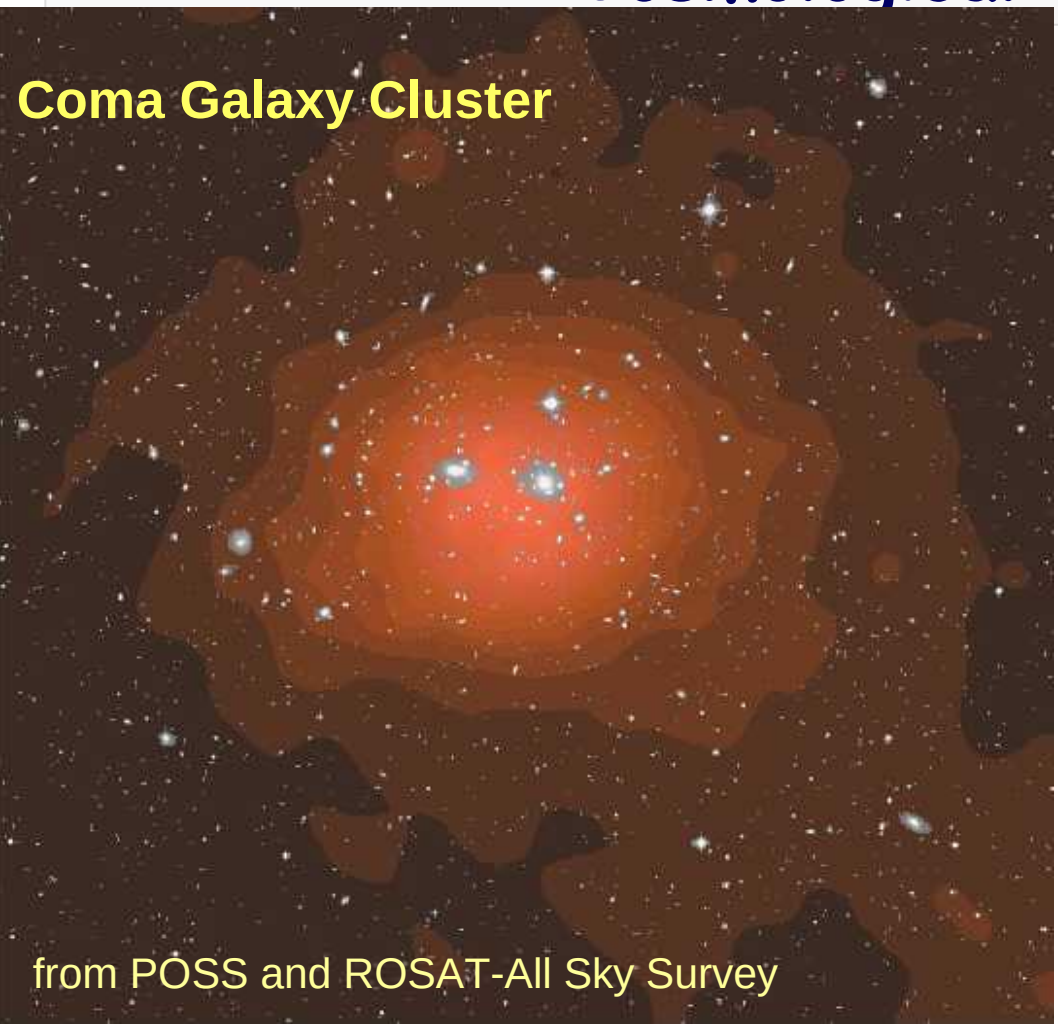
Statistics of the peaks (Cluster Population) determined from the statistical properties of the fluctuation field, P(k)

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

Cosmological Tests with Galaxy Clusters

- **Cluster Abundance (Mass function)**
- **Large-Scale Clustering Statistics**
- **Cluster Evolution**
- **„Standard Candles“ = e.g. Baryon Fraction; SZE-X-rays**
- **Cluster Structure (DM halo shape)**

The Role of X-ray Galaxy Clusters in Cosmological Studies



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

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.

Three fundamental astronomical building blocks of the Universe:

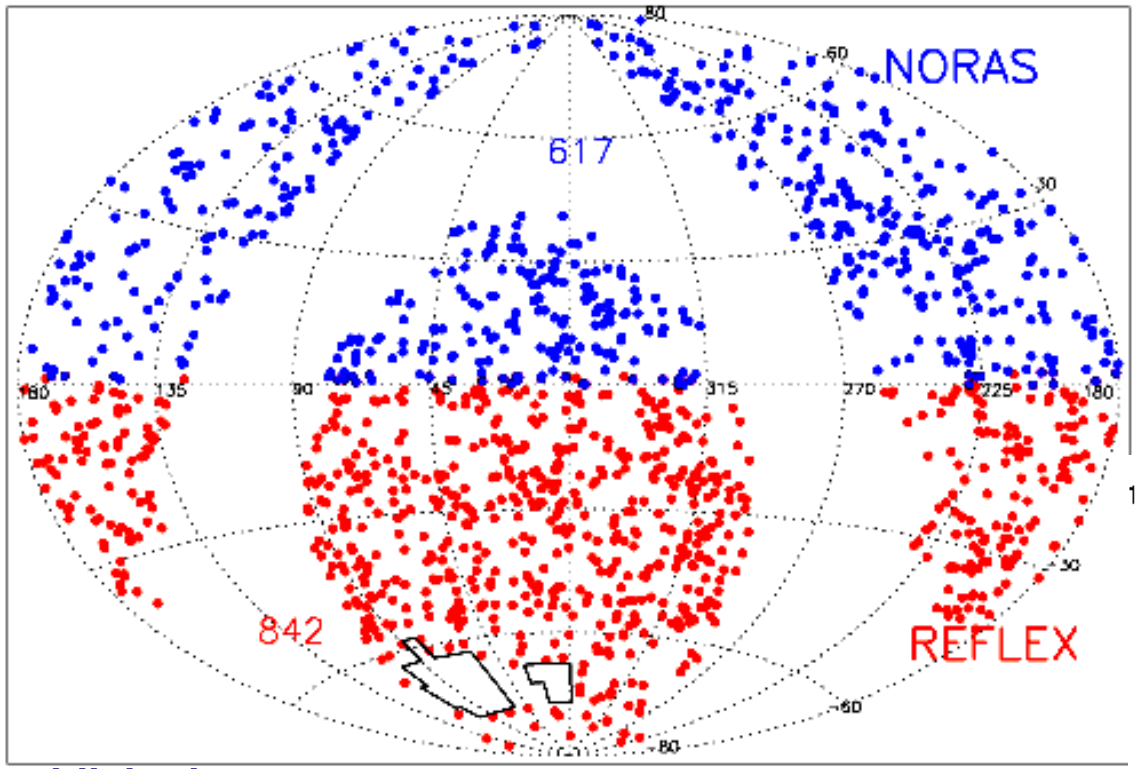
Stars

Galaxies

Clusters of Galaxies

Combined REFLEX & NORAS Survey

Extragal. ALL-SKY RASS Survey



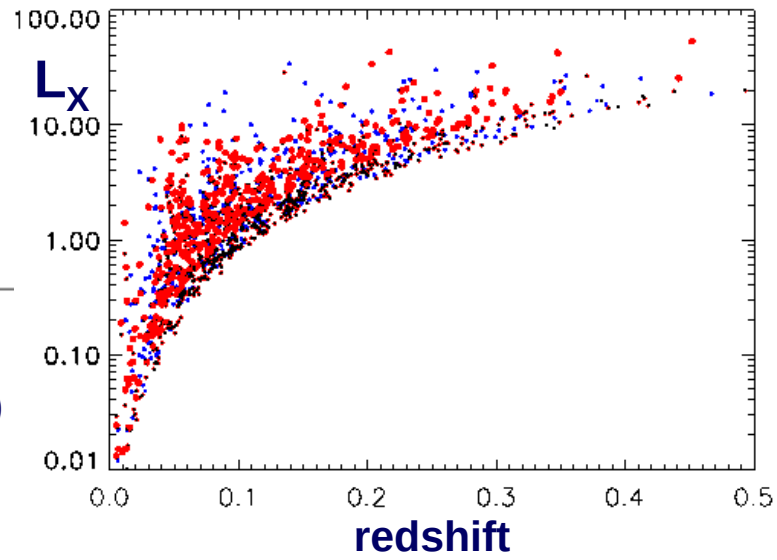
REFLEX 2 + NORAS 2

~ 1600 clusters

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

REFLEX 2: 6 runs ESO 3.6m

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



Published:

REFLEX = 447 (SOUTH) (F > 3 10^{-12} erg s^{-1} cm^{-2})

NORAS 1 = 378 + 141, incompl.;(eBCS =299)

Status of NORAS II + REFLEX II

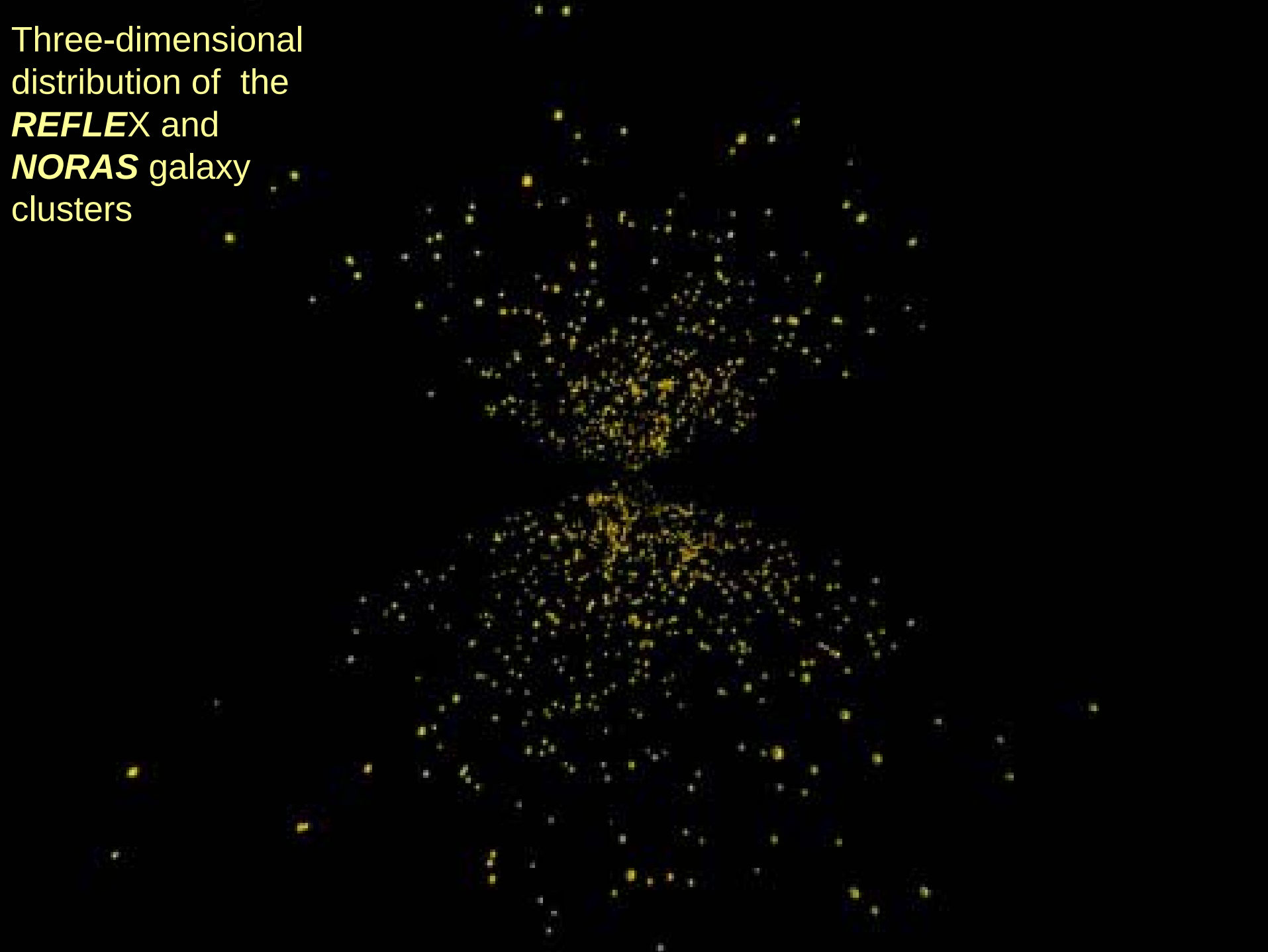
REFLEX I & II = 447 + 457 clusters

- **flux limit 1.8 10^{-12} erg s^{-1} cm^{-2} (0.1 – 2.4 keV)**

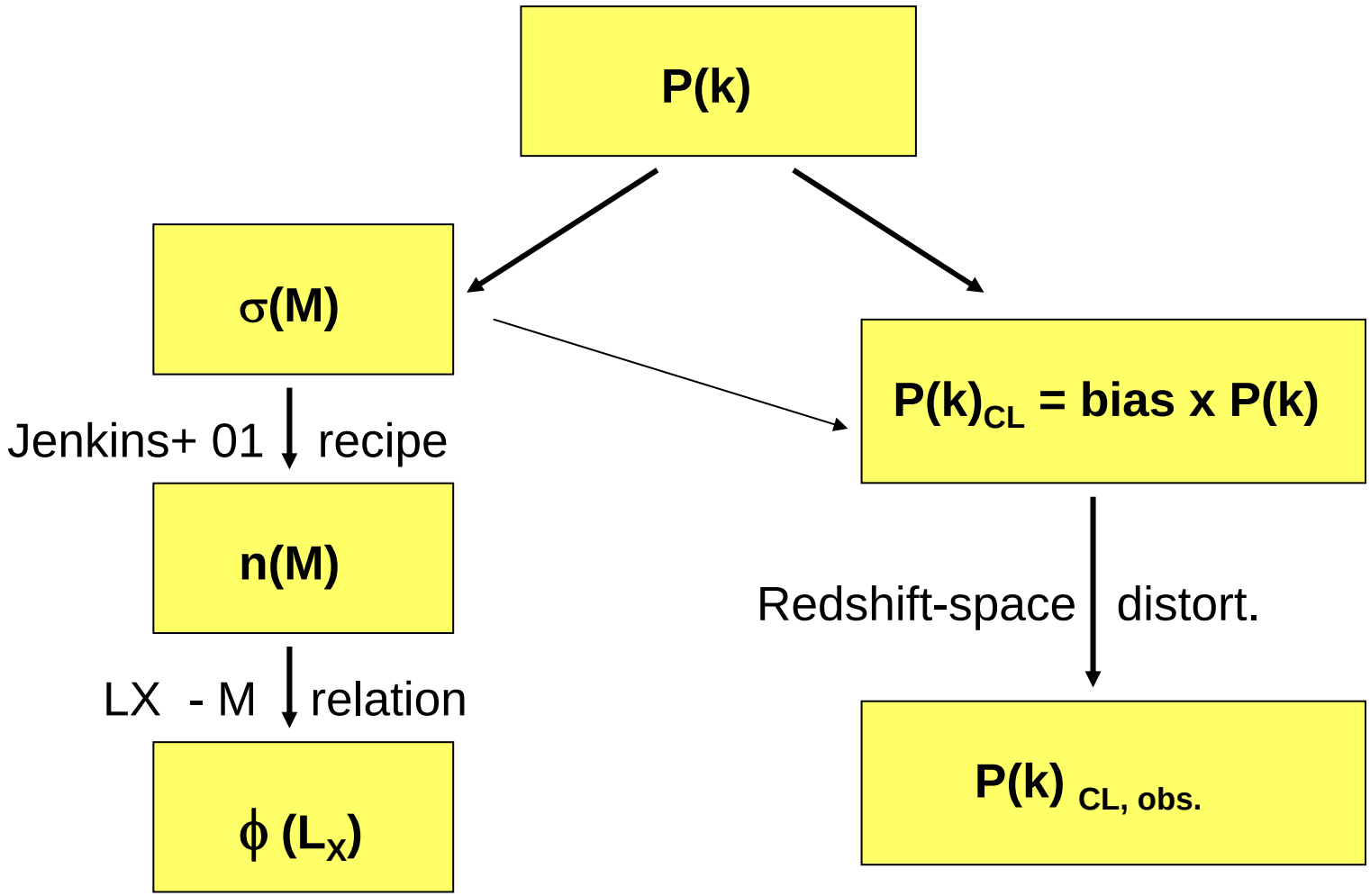
NORAS I & II >= 800 clusters

- **flux limit 2.0 10^{-12} erg s^{-1} cm^{-2} (0.1 – 2.4 keV)**

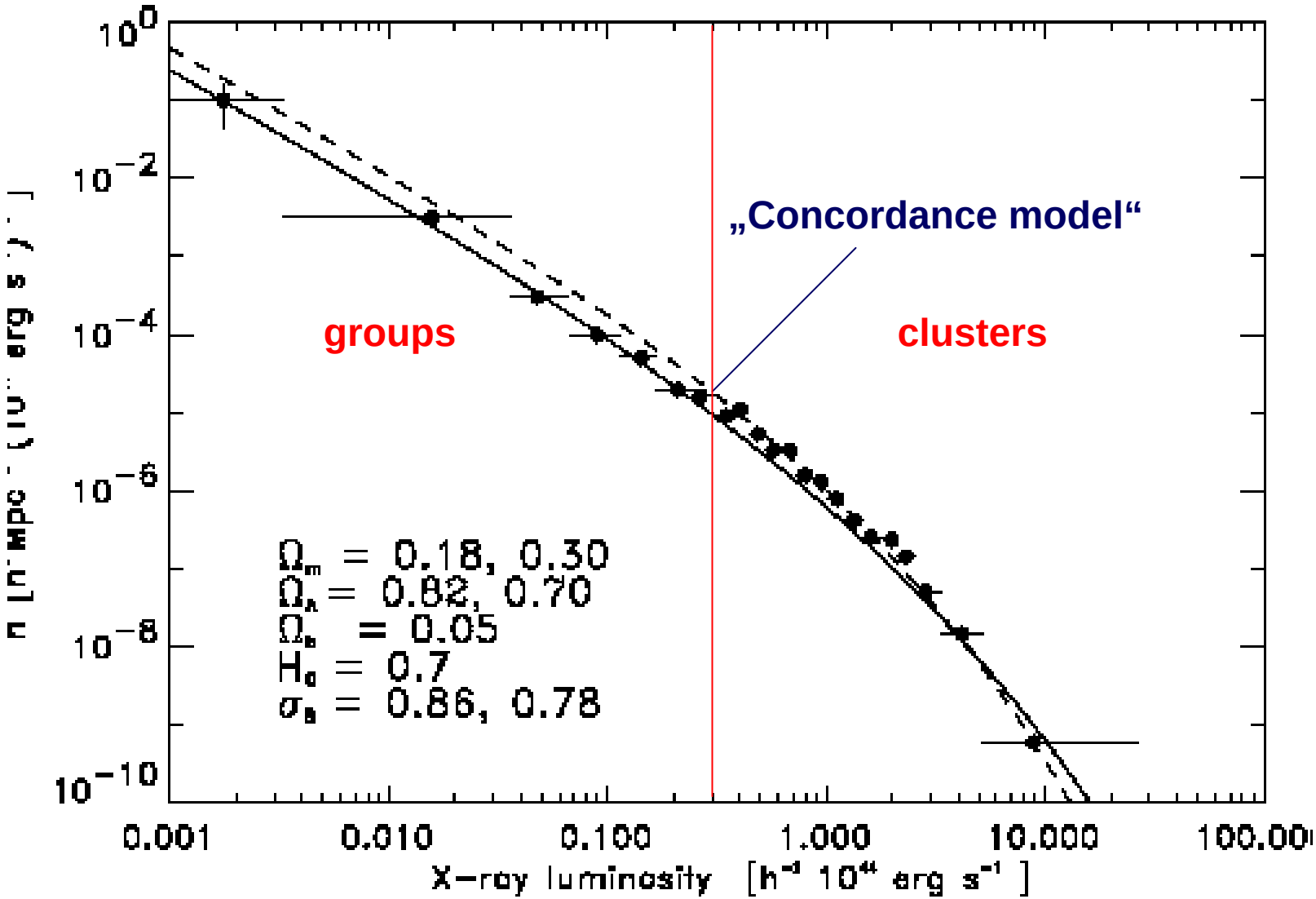
Three-dimensional distribution of the ***REFLE***X and ***NORAS*** galaxy clusters



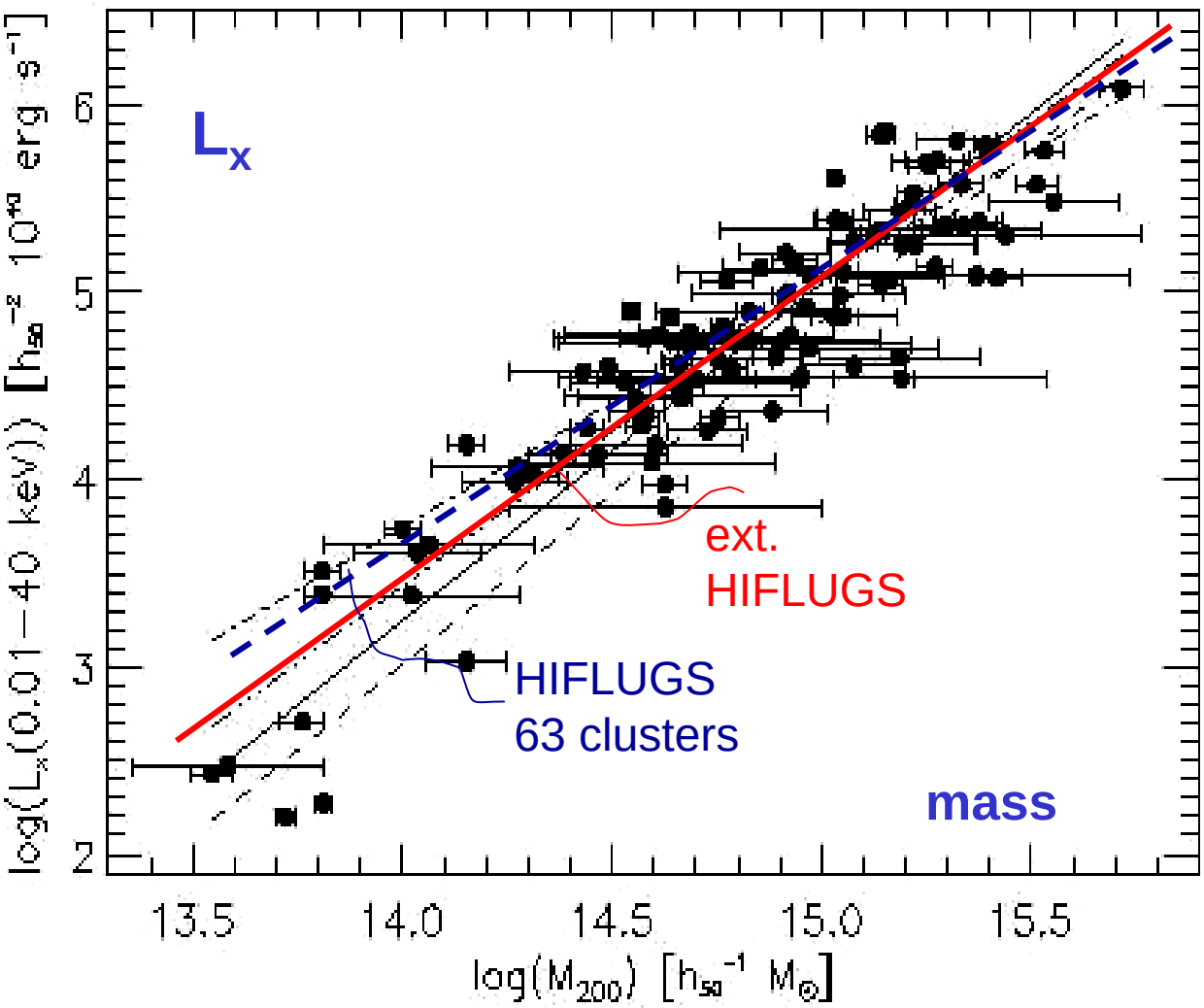
Prediction of the Lx-function and $P_{cl}(k)$



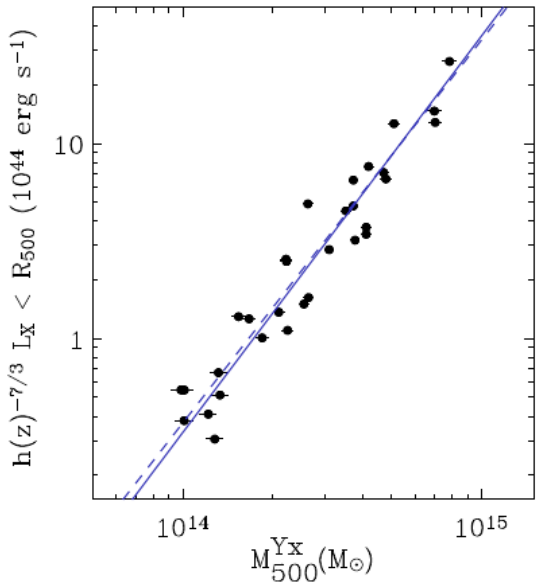
Fitting the REFLEX X-ray Luminosity Function with Cosmological Model Predictions

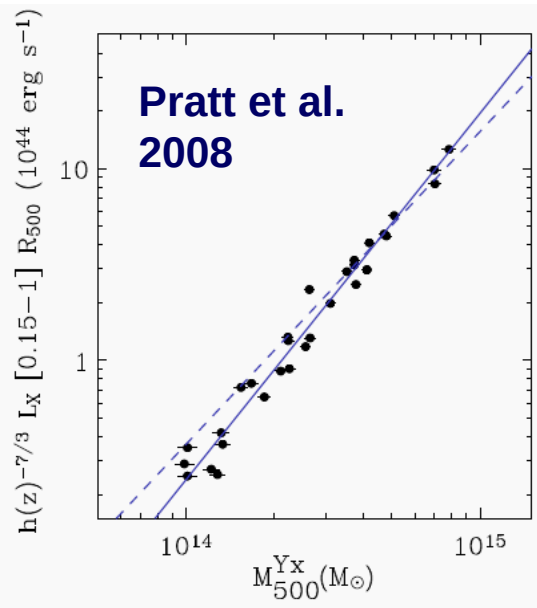


Empirical L_X – Mass Relation



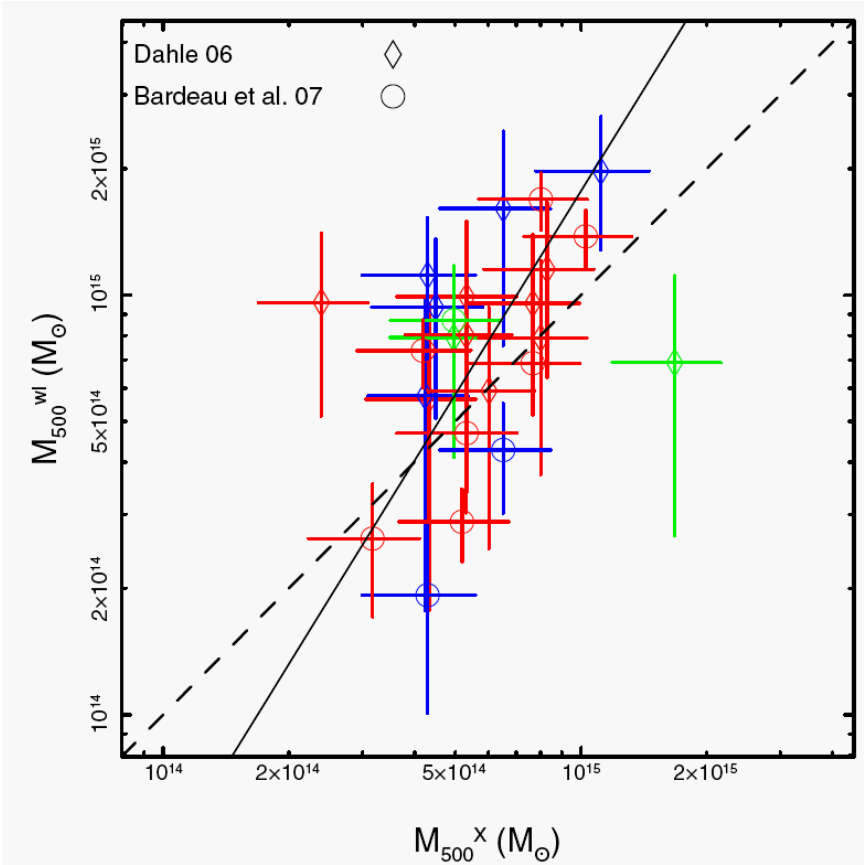
Reiprich & Böhringer 2002





X-ray vs Weak Lensing Mass Calibration

LoCuSS Project (G. Smith et al.) **Zhang et al. 2007**



Mass bias for X-rays :

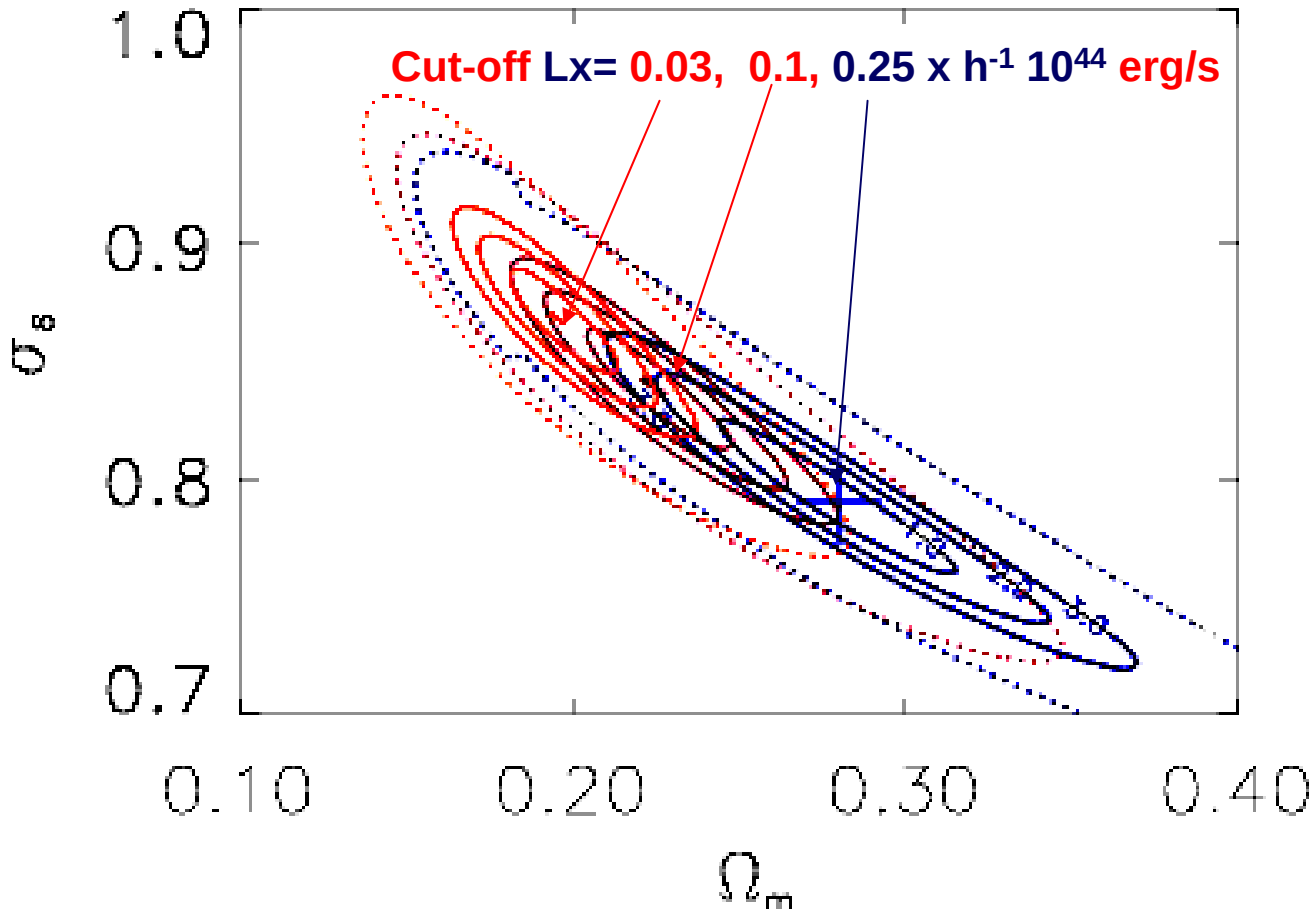
~ - 15% +- 15%

Errors in previous modeling:

- **RB02 isothermality +20-25%**
- **HE assumption, multiT - 10-20%**
- **optimistics scatter - 10-20%**

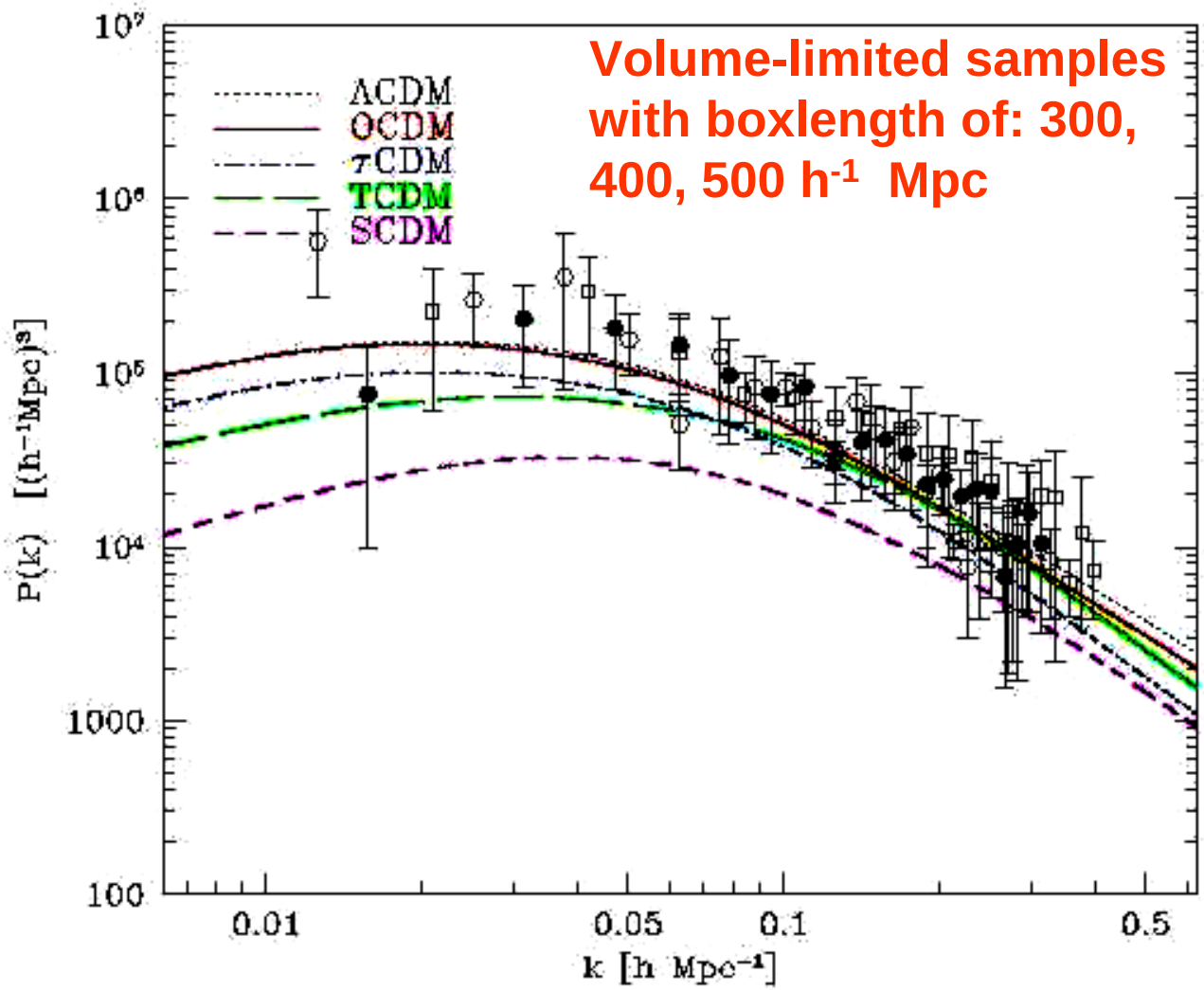
→ rough compensation of up to 30% uncertainties !

Cosmological Constraints from Nearby Cluster X-ray Luminosity Function



Perfect prediction of the Concordance Cosmological Model for the Luminous Clusters from the REFLEX Sample

Spatial Distribution Characterized by P(K)

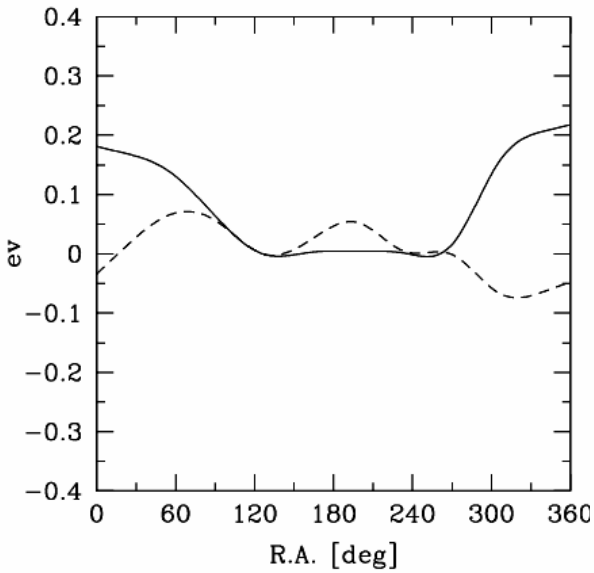


Schuecker et al. 2001

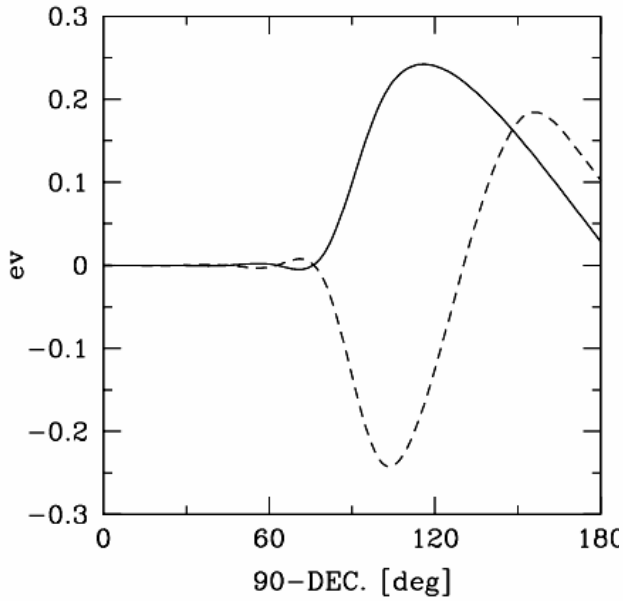
Karhunen-Loeve Eigenmode Decomposition of the Distribution of the REFLEX G.C.

Examples of KL modes : introduced by Vogeley & Szalay 1996

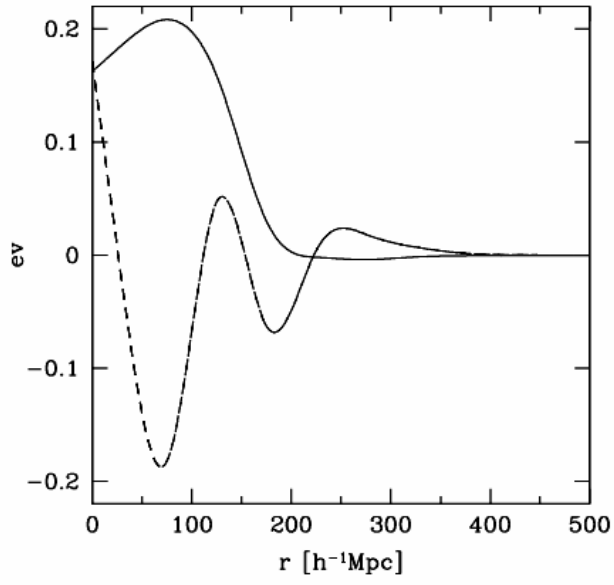
In R.A. direction



in declination



in radial direction



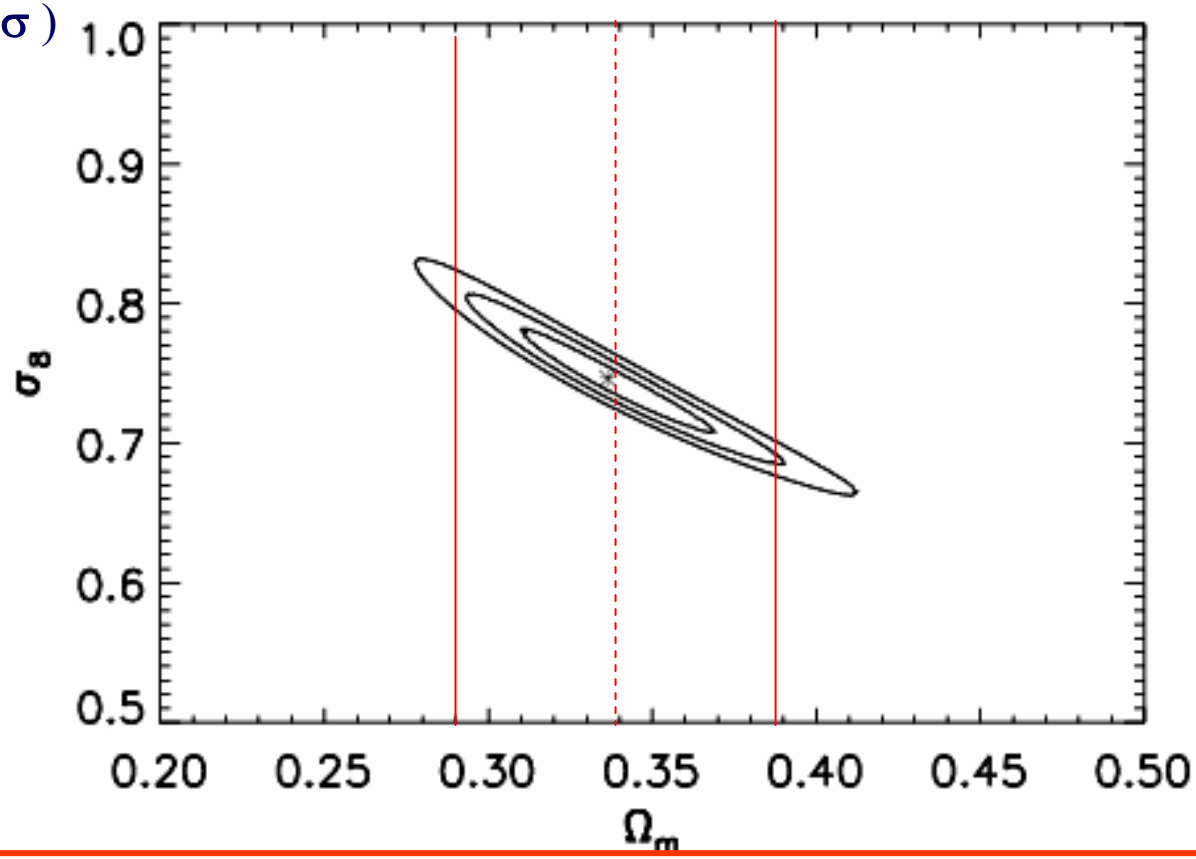
[Schuecker et al. 2002]

This analysis allows us to simultaneously assess the form of the power spectrum and the cluster abundance !

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

[Schuecker et al. 2002a,b]

(curves are 1,2,3 σ)

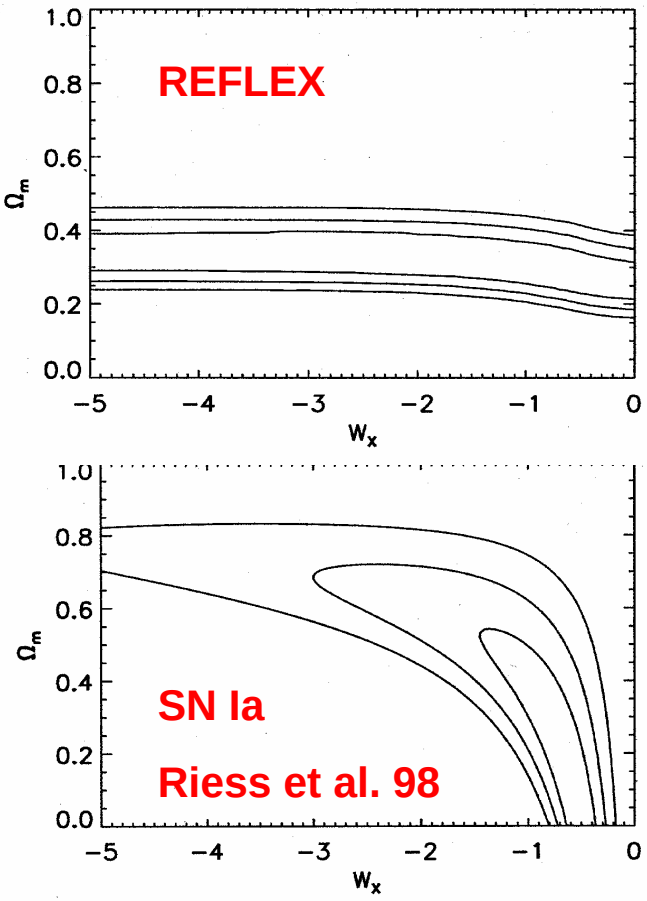


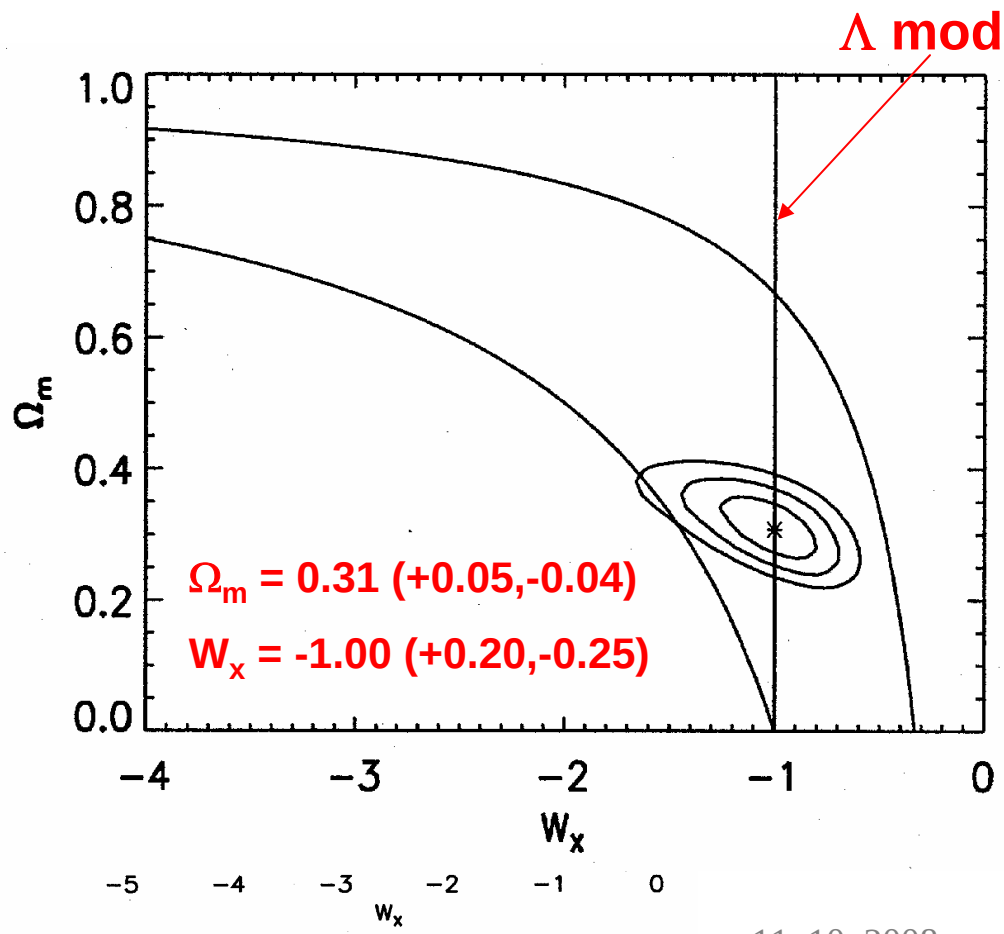
→ $\Delta\Omega_m$ ~ 0.34 +-0.05 (+ syst. errors +-0.05) 2σ !

Combined Constraints REFLEX & SN Ia on Ω_m and W_x

Data from REFLEX and SN observations of Riess et al. 1998 and Perlmutter et al. 1999 [Schuecker et al. 2003]

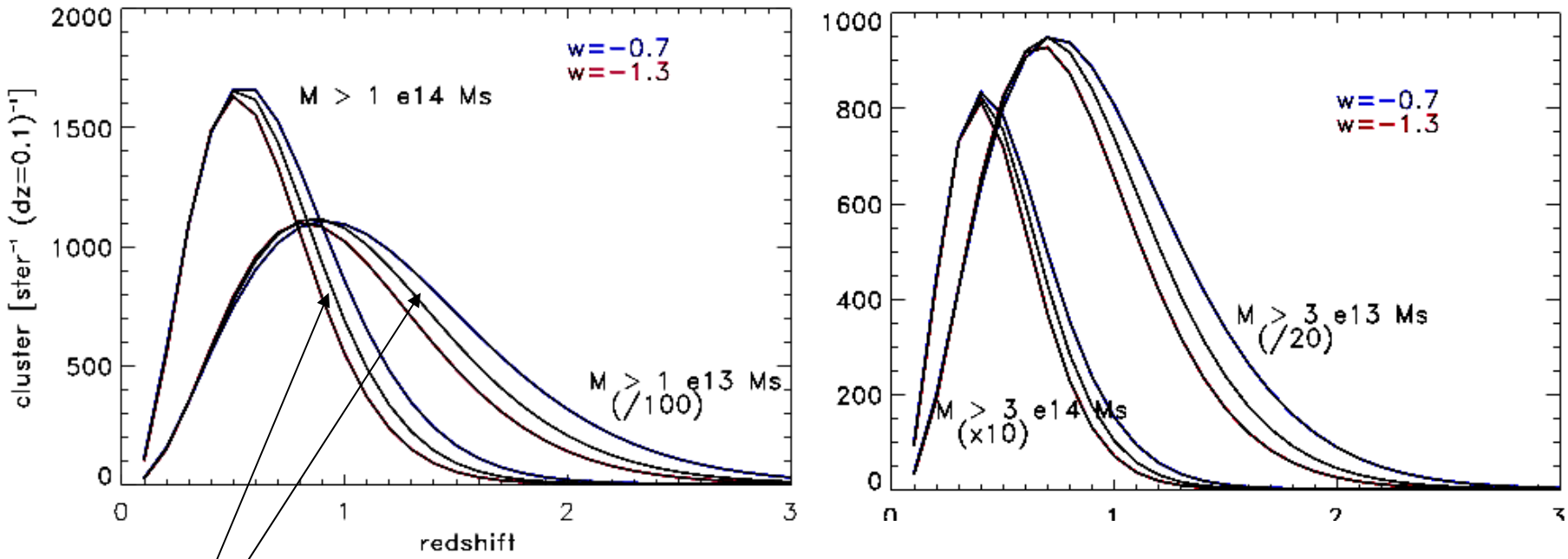
$$\Lambda \Rightarrow \rho_x(z) \quad ; \quad w = \frac{P_x}{\rho_x}$$





Evolution of the Cluster Mass Function

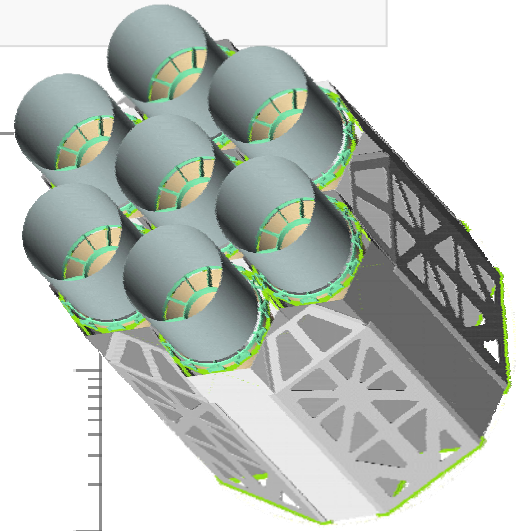
Differential comoving cluster abundance (> $Mass_{limit}$) $ster^{-1}$ $dz=0.1^{-1}$



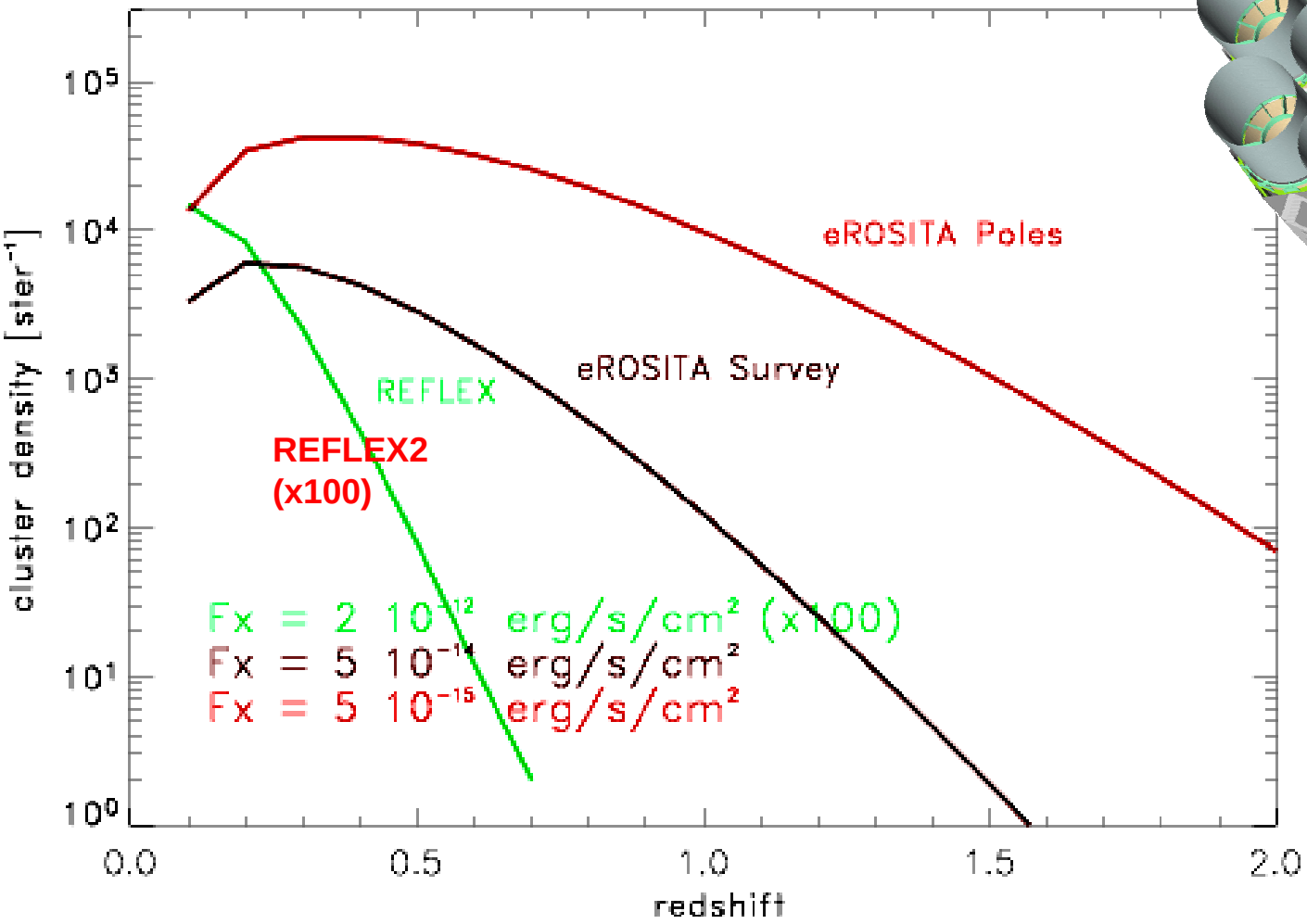
→ There are more distant clusters for small -w !

Number count variation ~ 30-50% dlogN/dlogM at this point ~ 3
→ the accuracy needed in the mass measurement is a few %

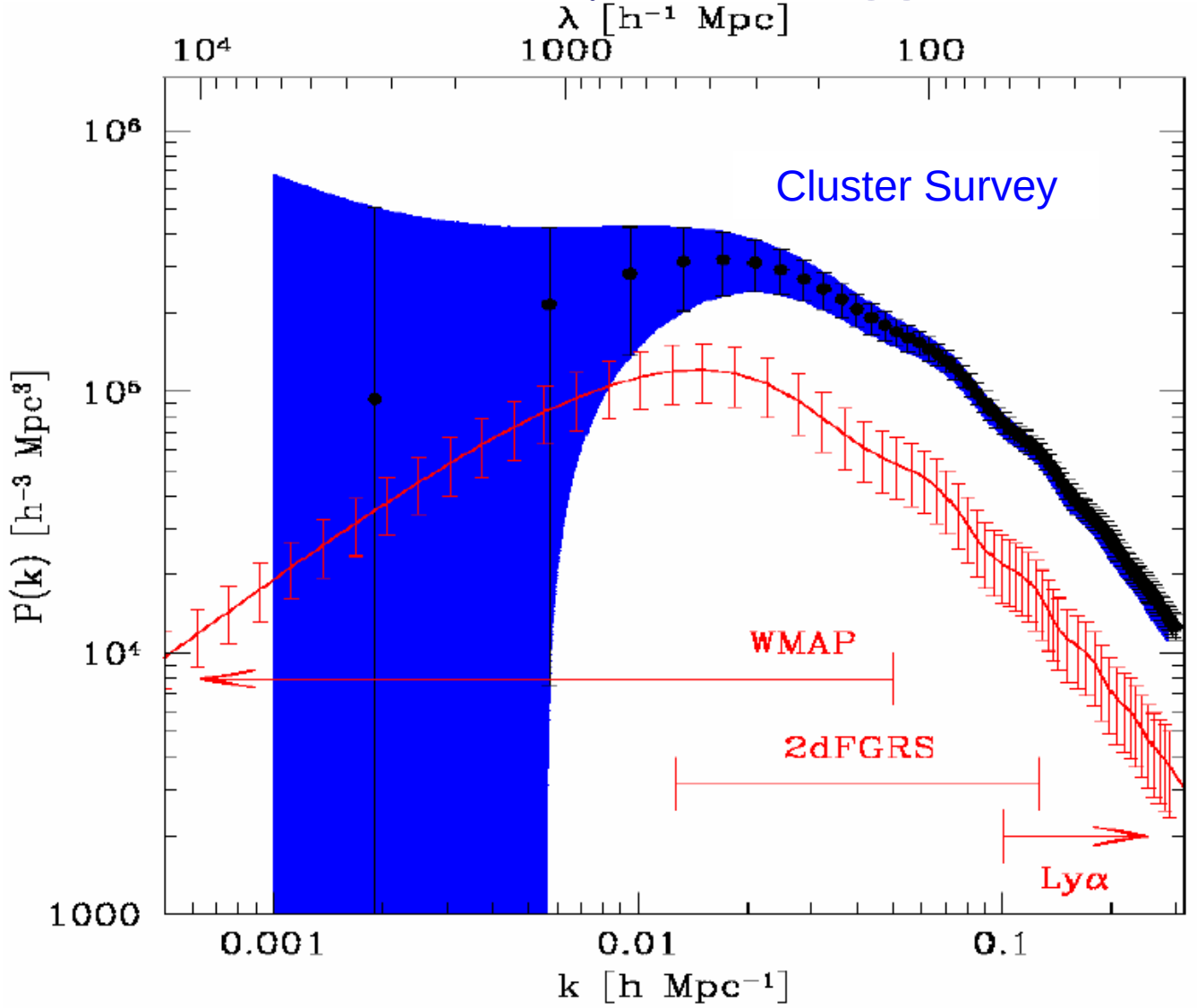
Prospects of the eROSITA Survey



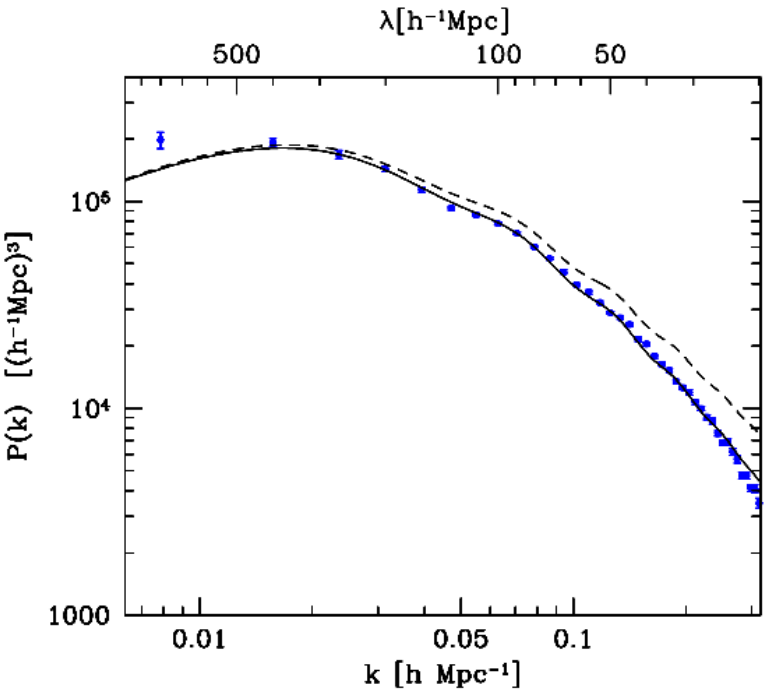
eROSITA

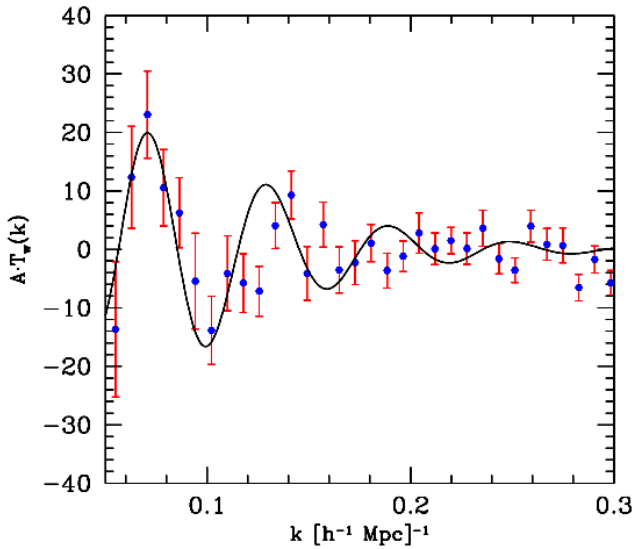


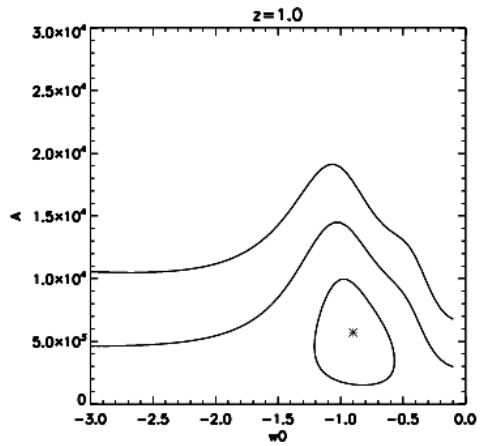
P(k) and Baryonic Wiggles



Cosmological Constraints with Baryon Oscillations measured in the cluster power spectrum







>= 100 000 clusters in survey required !

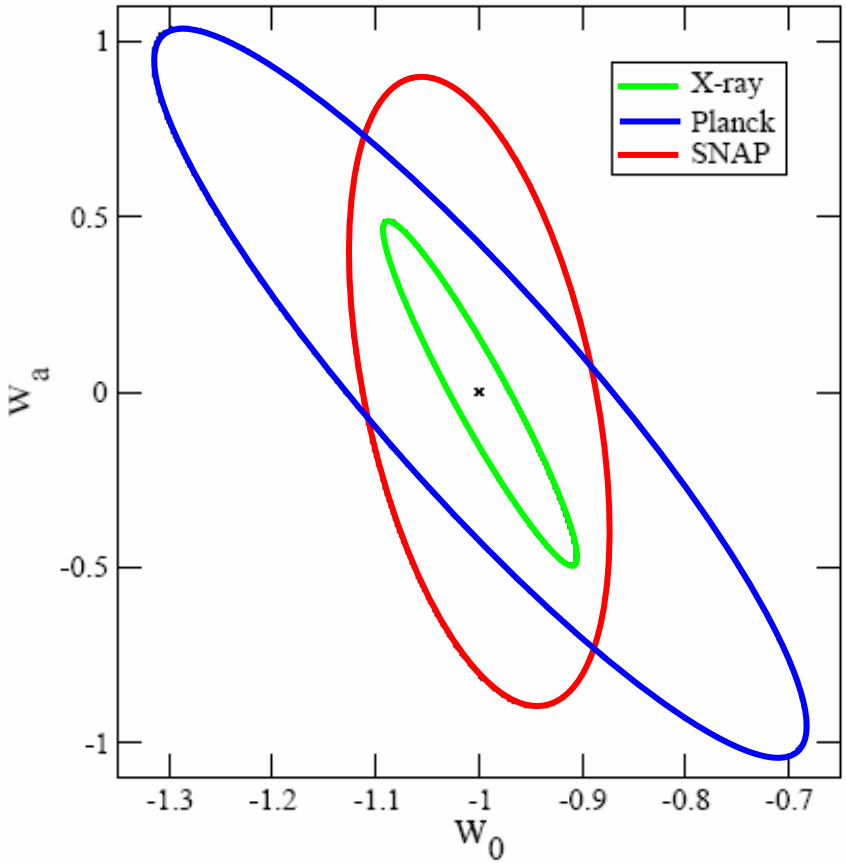
Peter Schuecker Talk

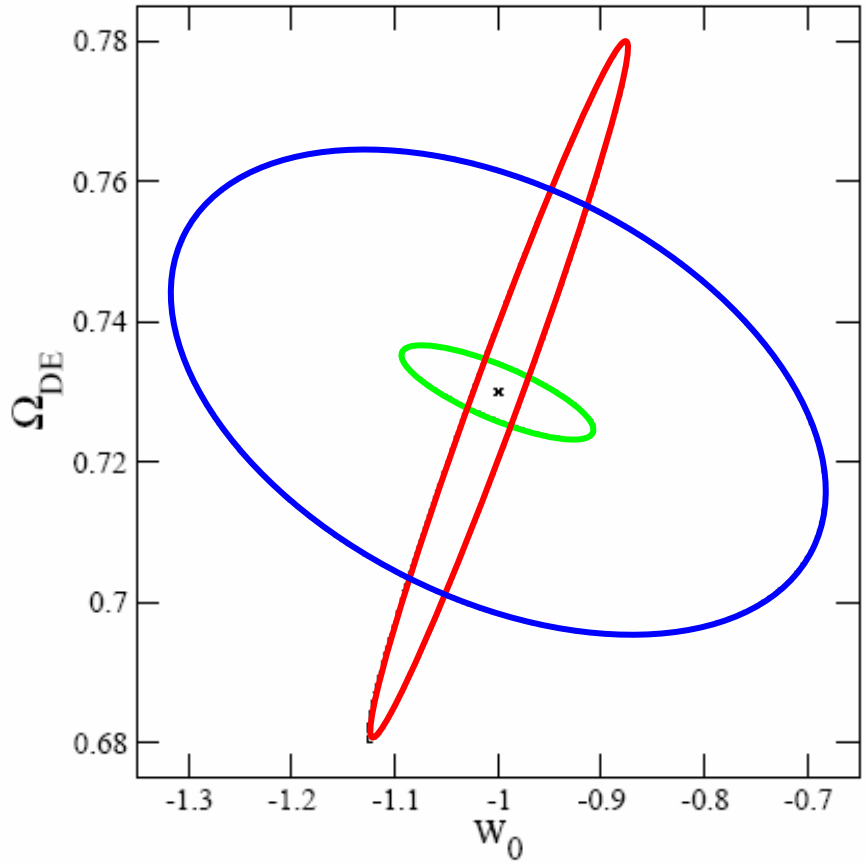
Constraints from 100K Cluster Survey

Time dependence of w_x

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

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





Results from the White Paper submitted to the NASA/DOE Dark Energy Task Force: Haiman, et al., 2005, astro-ph/0507013

Conclusions

Galaxy Clusters are important cosmological probes :

- **We get a consistent description of the present day cluster population (abundance & clustering) within the concordance model (based on ROSAT cluster surveys)**

  → **robust predictions of σ_8 and Ω_m**

- **Large and Deep X-ray and SZ cluster surveys offer great potential (with order 10000 clusters → constraints of w to few%)**

  -- **requires tight control of systematics** (mass to few % !)

  (future survey analysis will involve multiple parameters and require detailed comparison to simulations)