



Research Area E

# The Dark Universe

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Collaborators:

R. Bender, H. Böhringer, J. Dietrich, F.v. Feilitzsch, O. Gerhardt, A. Golovnev,  
**L.Guzzo (guest)**, W. Hillebrandt, B.Leibundgut, D. Lüst, B. Metcalfe, S. Phleps, W.  
Potzel, G. Pratt, F.K. Roepke, A. Riffeser, P. Rosati, R.P.Saglia, V. Springel, J.  
Thomas, S. Mukhanov, S.D.M. White  
+postdocs and students!

I acknowledge input from several of people above for the talk.

# Outline of talk:

1. Goals of Research Area E 'The Dark Universe'

2. Results of our work in 2007:

- Dark matter properties:
  - radial dark matter profile
  - dark matter substructure
  - central dark matter densities in elliptical galaxies
  - compact objects towards M31
- Dark Energy constraints:
  - Supernovae observations: chances and limitations
  - Supernova Ia explosion mechanisms
  - Clusters as cosmological probes

-not included here: BAO (Phleps), growth of LSS (Guzzo).

-not included here: Lab experiments: CRESST ...

# 1. Goals of Research Area E 'The Dark Universe'

- Refine simulations of present-day dark matter distribution (MPA)
- Constrain the nature of dark matter by gravitational lensing studies (USM, MPE, MPA, ESO)
- Develop WIMP detectors (TU, MPP) (CRESST: Talk of S. Bethke)
- Investigate astrophysics of type Ia supernovae (MPA)
- Investigate clusters and large-scale structure (BAOs) and calibrate them as cosmological tools (MPE, USM, ESO)
- Constrain the nature of dark energy from supernovae, galaxy clusters, large scale structure and lensing (MPE, USM, ESO), JRG!!
- Investigate the theoretical basis of dark energy (strings, branes...?) (LMU, RA-A)



## 2. Results of our work in 2007: Dark Matter Properties

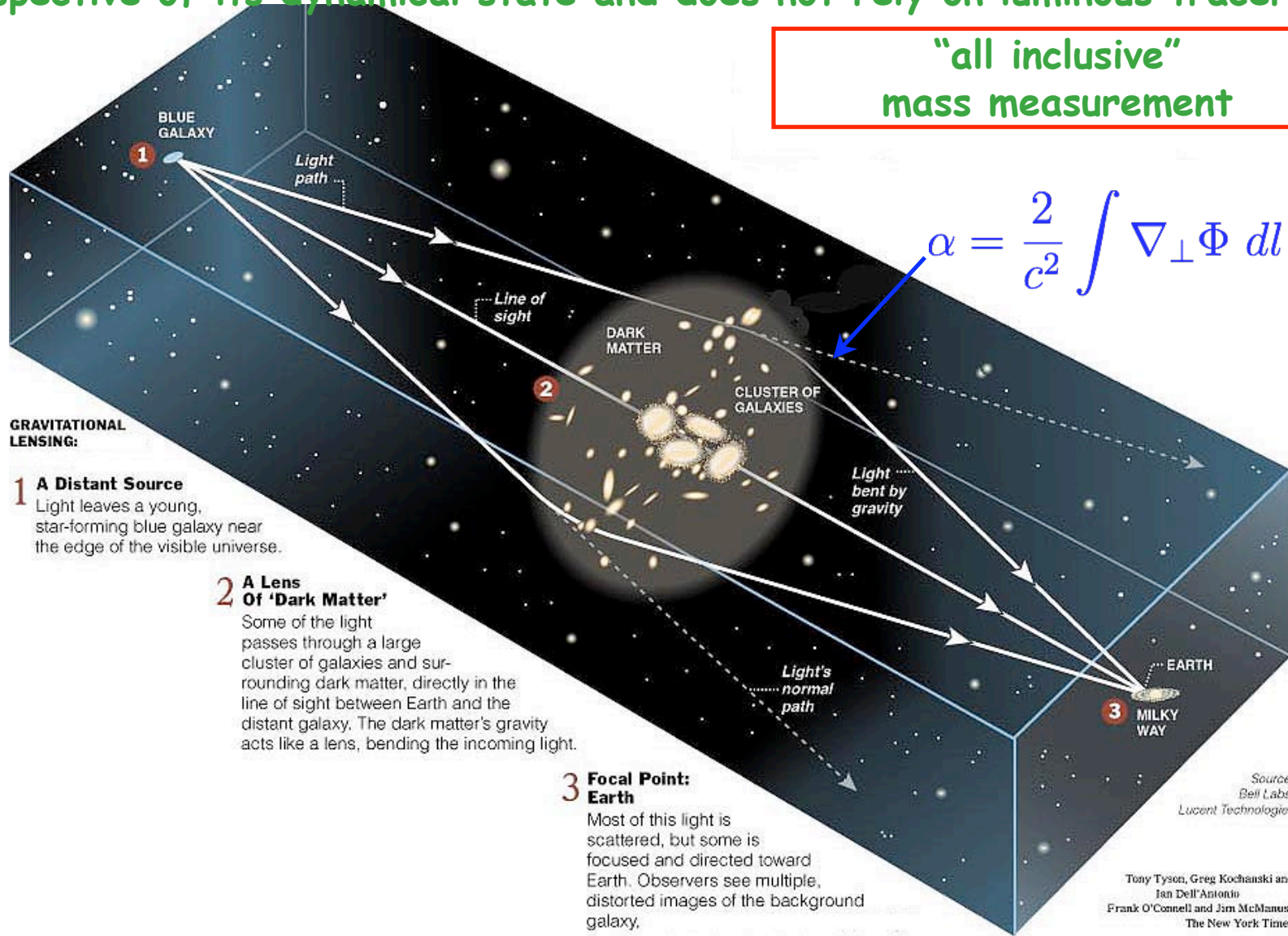
### Testing the CDM scenario:

- A) density profiles of CDM-halos (NFW-profile) should be fairly steep/cuspy in the centers, whereas e.g. for spiral galaxies and clusters of galaxies isothermal profiles with flat cores match observations better or at least equally well.
- B) The CDM scenario predicts a hierarchy of masses; every DM halo should contain DM substructures (subhalos) where the substructures are self-similar to the structures.
- C) The CDM simulations predict that DM-halos get truncated in dense environments by tidal forces. This can be tested by showing that galaxies `live' in smaller halos if they are close to the cluster center, than, if they are in the `field'.
- D) On average massive structures should form later than less massive ones.
- E) Does compact Dark Matter (MACHOs) exist?

# How making dark matter visible?

The Gravitational Lens effect measures the (projected) mass irrespective of its dynamical state and does not rely on luminous tracers

**“all inclusive”  
mass measurement**



### GRAVITATIONAL LENSING:

**1 A Distant Source**  
Light leaves a young, star-forming blue galaxy near the edge of the visible universe.

**2 A Lens Of 'Dark Matter'**  
Some of the light passes through a large cluster of galaxies and surrounding dark matter, directly in the line of sight between Earth and the distant galaxy. The dark matter's gravity acts like a lens, bending the incoming light.

**3 Focal Point: Earth**  
Most of this light is scattered, but some is focused and directed toward Earth. Observers see multiple, distorted images of the background galaxy.

Source: Bell Labs, Lucent Technologies

Tony Tyson, Greg Kochanski and Jan Dell'Antonio  
Frank O'Connell and Jim McManus/  
The New York Times

# Example

Gravitational Lens in Galaxy Cluster Abell 1689

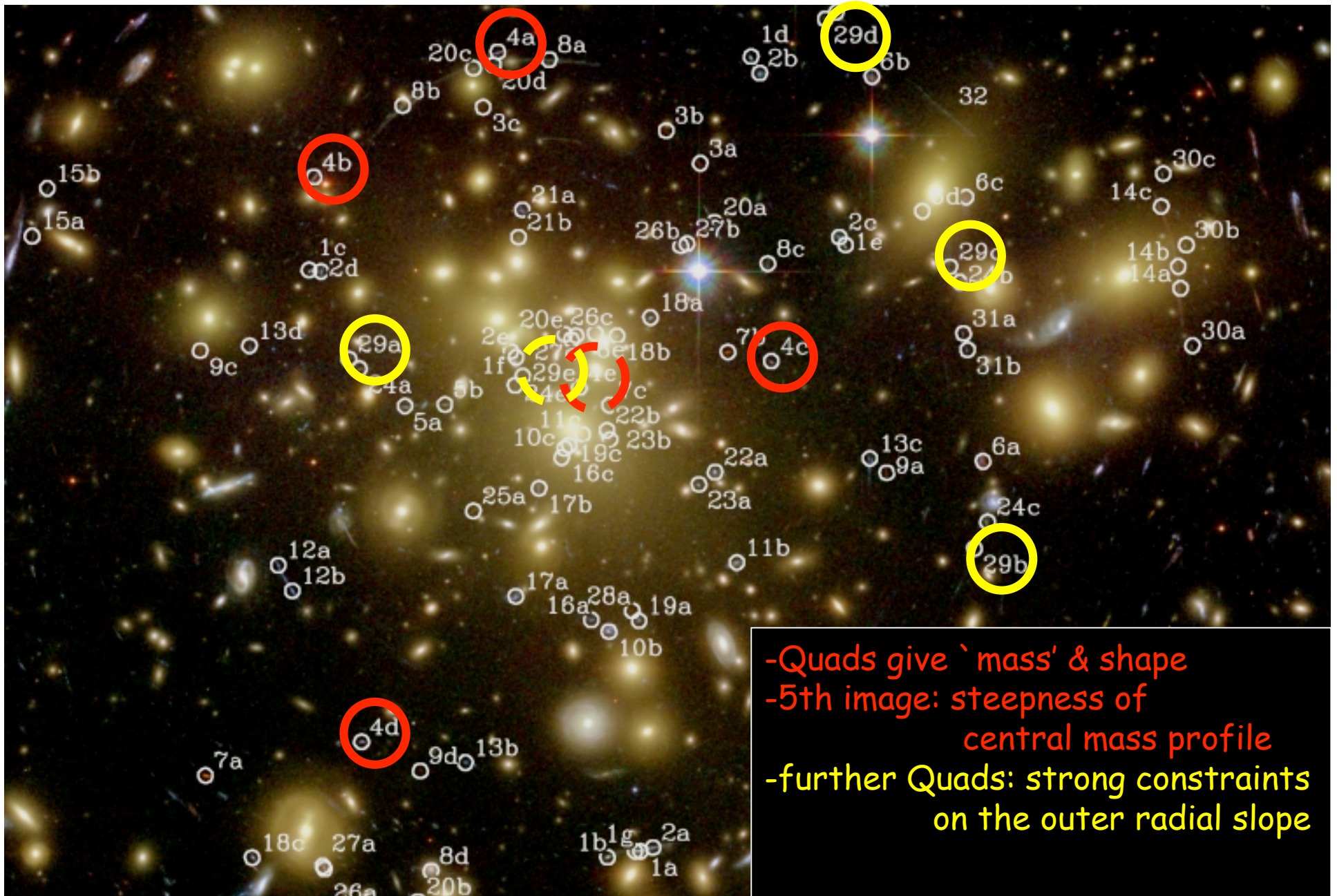


HUBBLESITE.org

# Dark Matter constraints from strong lensing in A1689: radial mass profile, galaxy DM haloes and 'dark' substructure:



## A1689: I. Determining the radial mass profile:



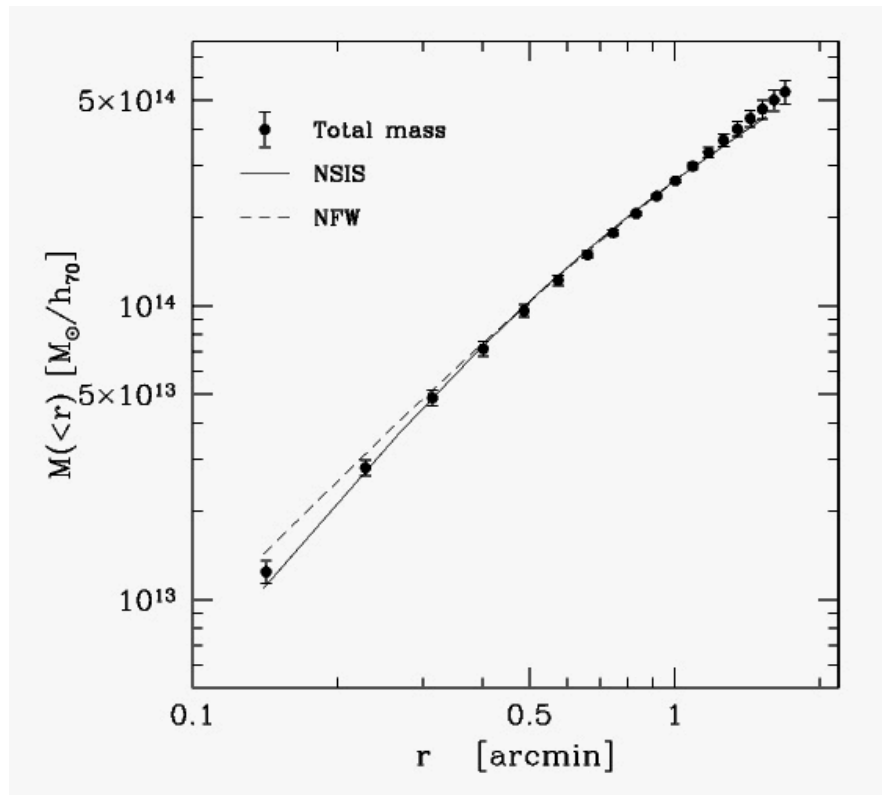
## A1689: II. Determining Galaxy DM Halo sizes



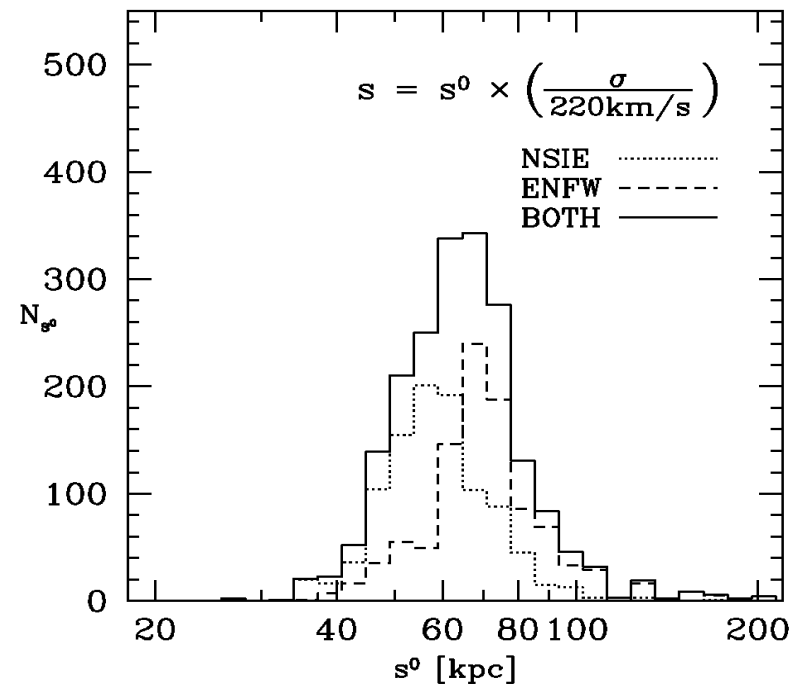
# Results on cluster mass profiles and galaxy halo sizes:

High precision mass profile for the cluster A1689 is well described by 'universal dark matter profile', but shallower core: Baryonic physics or 'warm' dark matter? (or a N-body resolution problem???)

A galaxy with velocity dispersion of  $\sigma=220\text{km/s}$  has a halo size of only 60-70kpc in the cluster (Halkola, Seitz, Panella, 2007) whereas the same galaxy would have a size of about 400kpc in the field (Hoekstra et al. 2004)



Halkola, Seitz, Pannella 2006

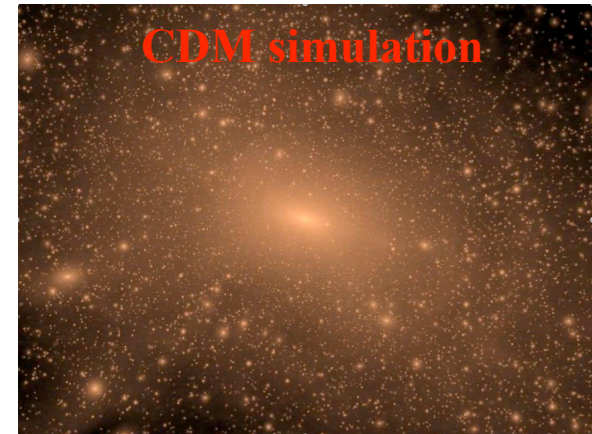


Halkola, Seitz, Pannella 2007

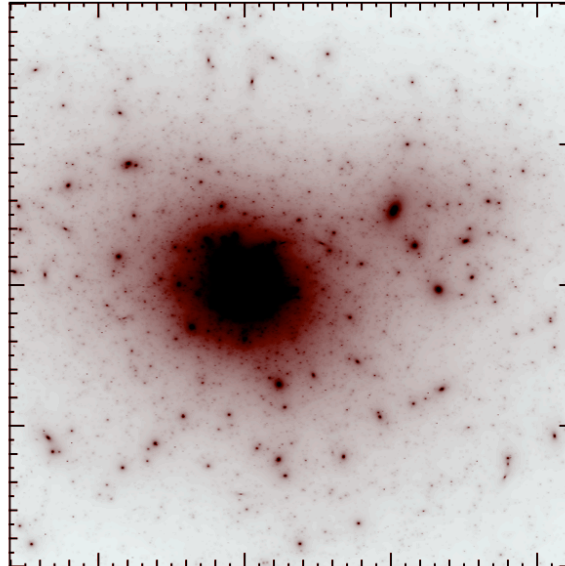
# A1689: III. Limits on Dark Matter subhalos NOT traced by light. Can we make them visible?

$$N(M_{\text{DM-halo}}) \propto M_{\text{DM-halo}}^{-2}$$

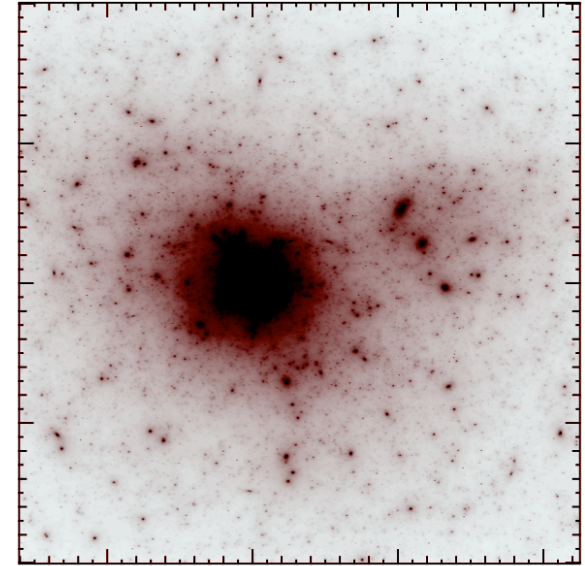
COLD dark matter substructure in a MW-halo as simulated by Diemand et al 2006 (right): 'subclumps on all scales'. WARM dark matter would form relatively fewer low mass halos.



DM traced by light only



additional 20% DM substructure

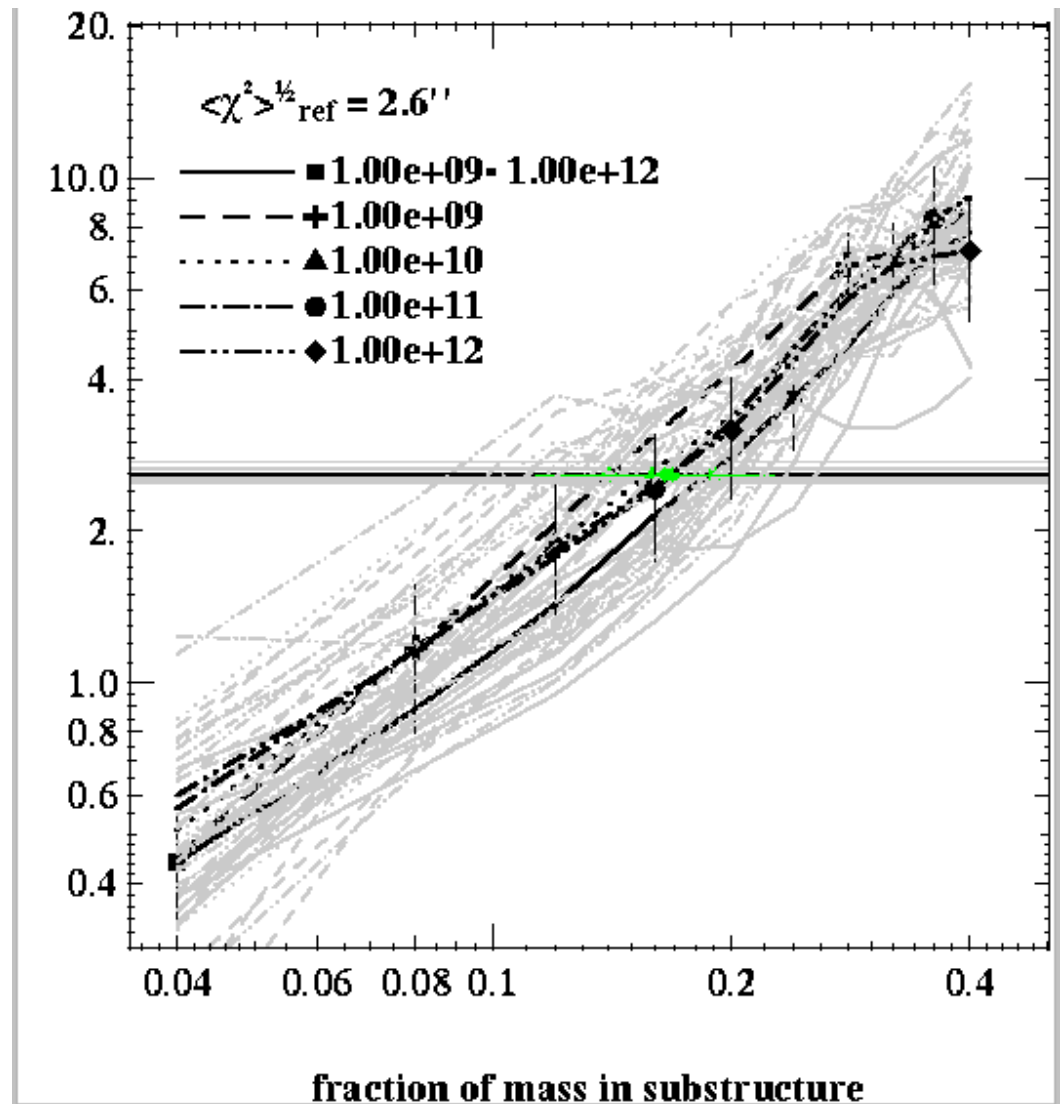


additional 40% DM substructure

Results:

We can indeed give an **upper limit of 25%** (at 2sigma) on the **fraction of mass in sub-halos not traced** by galaxies using the lensing effect.

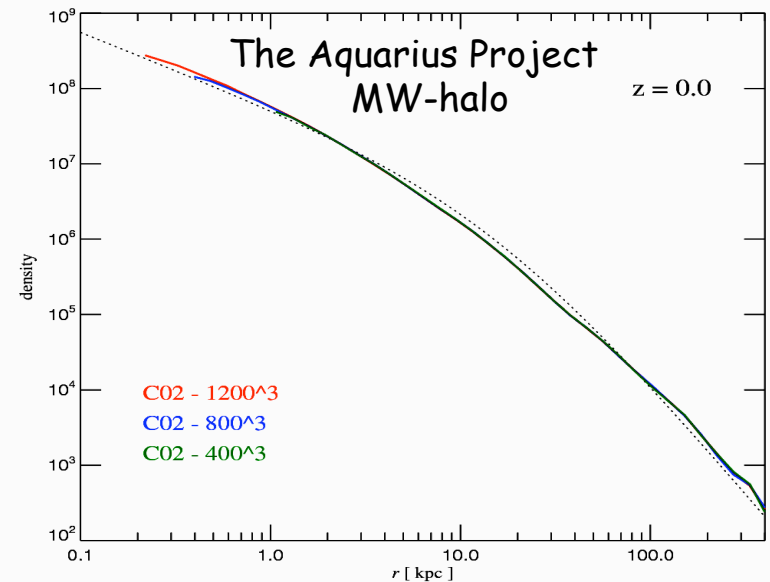
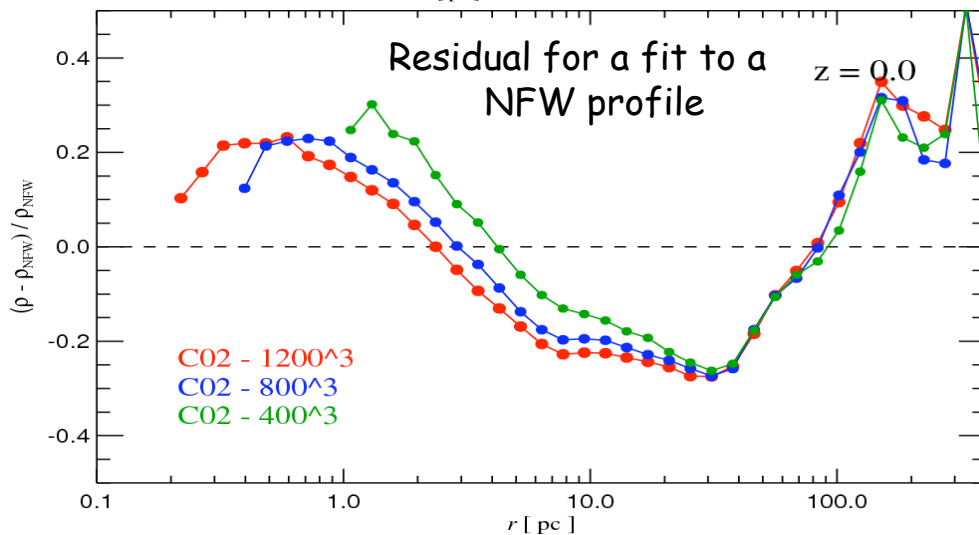
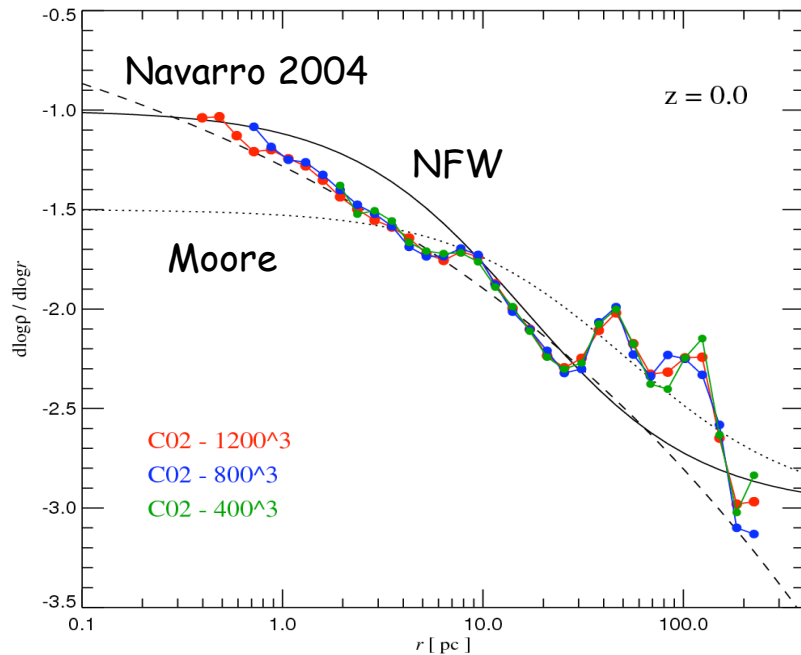
This value is independent of the mass-spectrum of the subhalos, as long as they have masses between  $10^9$  and  $10^{12} M_{\text{sun}}$ .



# The radial mass profile: new results from the Aquarius high resolution numerical DM-simulations

Springel, White et al., in prep

- density profile is not particular well fit by a NFW profile,
- density profiles becomes gradually shallower in the center
- fractional mass in subhalos is 12% or less



# Dark matter in Coma early-type galaxies

(J. Thomas, R. Saglia, R. Bender et al. 2007, MNRAS, 382,657)

dynamical analysis of stellar kinematics in 17 early-types in Coma

$M_B = -18.8 \dots -22.56$

long-slit spectra out to  $1-4 r_{\text{eff}}$  (major, minor, diagonal ...)

axisymmetric 3Integral Schwarzschild fits to kinematics/photometry

determine --  $\rho = \rho_{\text{DM}} + \Upsilon \times v$

-- orbital structure

orbital structure  $\rightarrow$  formation mechanism

(J. Thomas et al. 2008a)

dark matter distribution  $\rightarrow$  assembly epoch

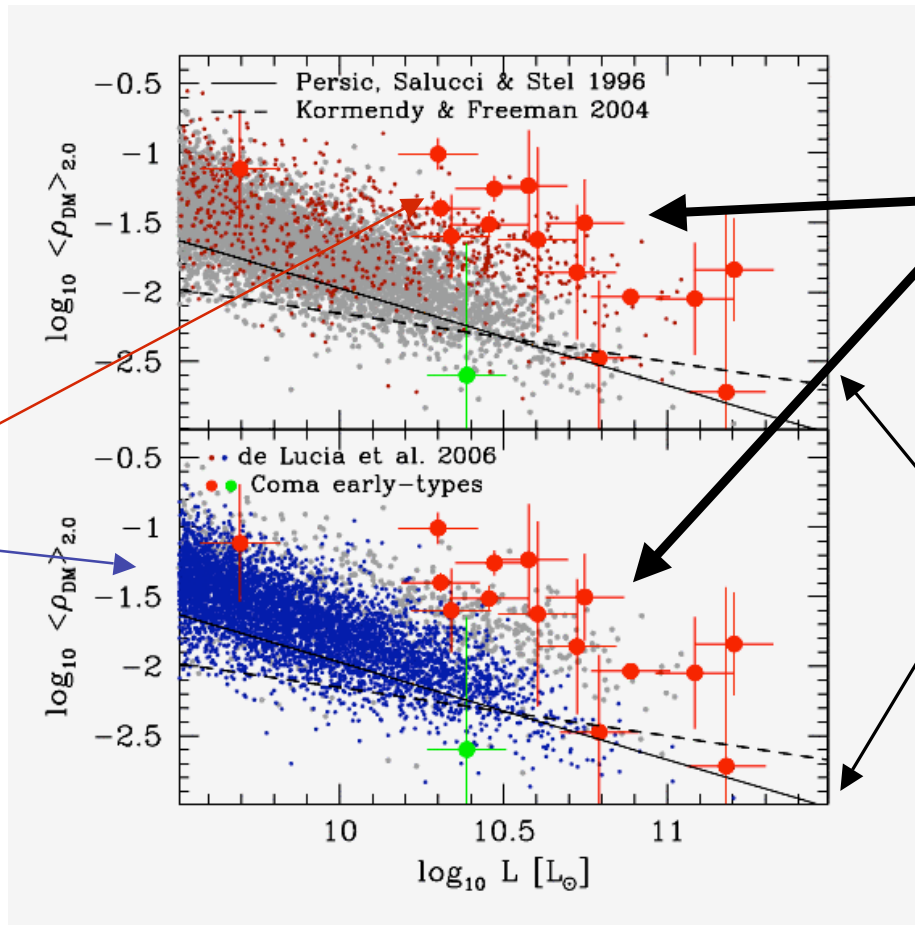
(J. Thomas et al. 2008b)



predictions  
from semi-  
analytic galaxy  
formation  
models:

ellipticals

spirals

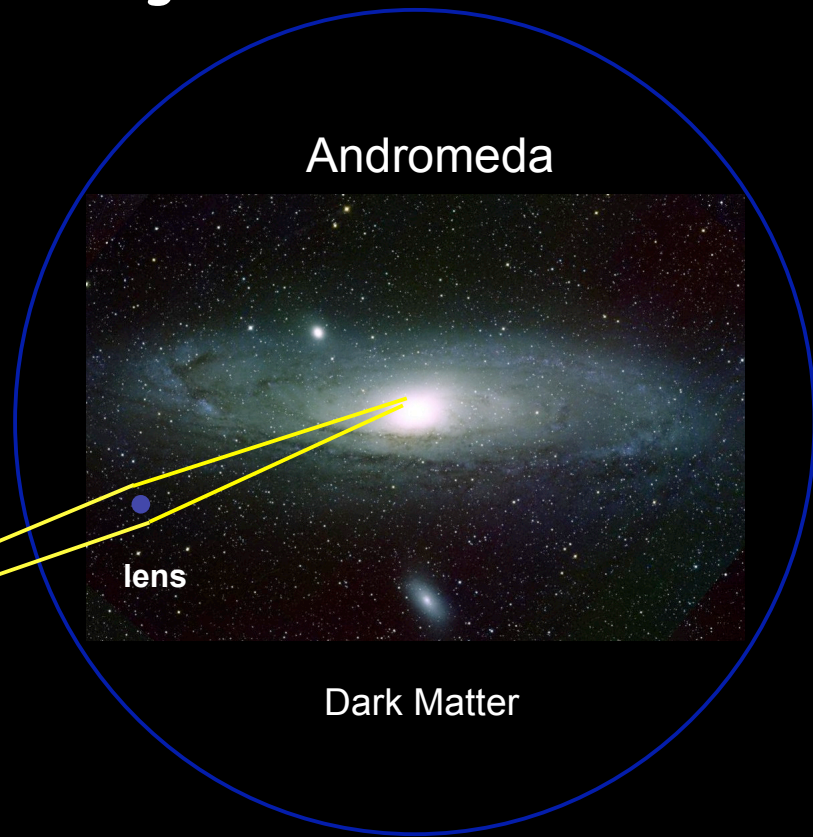
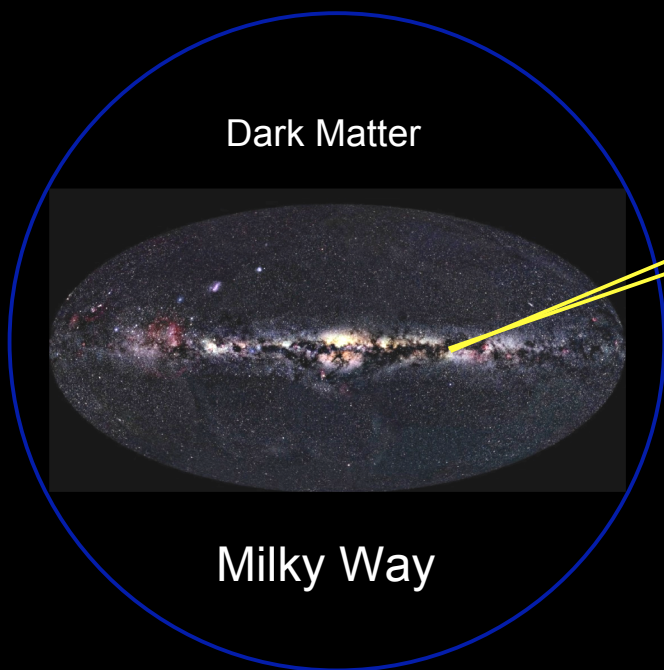


central dark matter  
densities from  
dynamical models of  
Coma early-types  
(averaged inside  $2 r_{\text{eff}}$ )

observed scaling  
relations for spiral  
galaxies

- ellipticals in Coma have higher central dark matter densities than spirals of same L
- overdensity matches with predictions from semi-analytic galaxy formation models
- dark matter density is a tracer of the assembly epoch
- dark matter halos of Coma ellipticals assembled earlier than halos of local spirals

# Compact DM fraction in the M31 and MW halo & the Mass Function in the M31 bulge with Microlensing (Seitz, Riffeser, Bender)



770 kpc

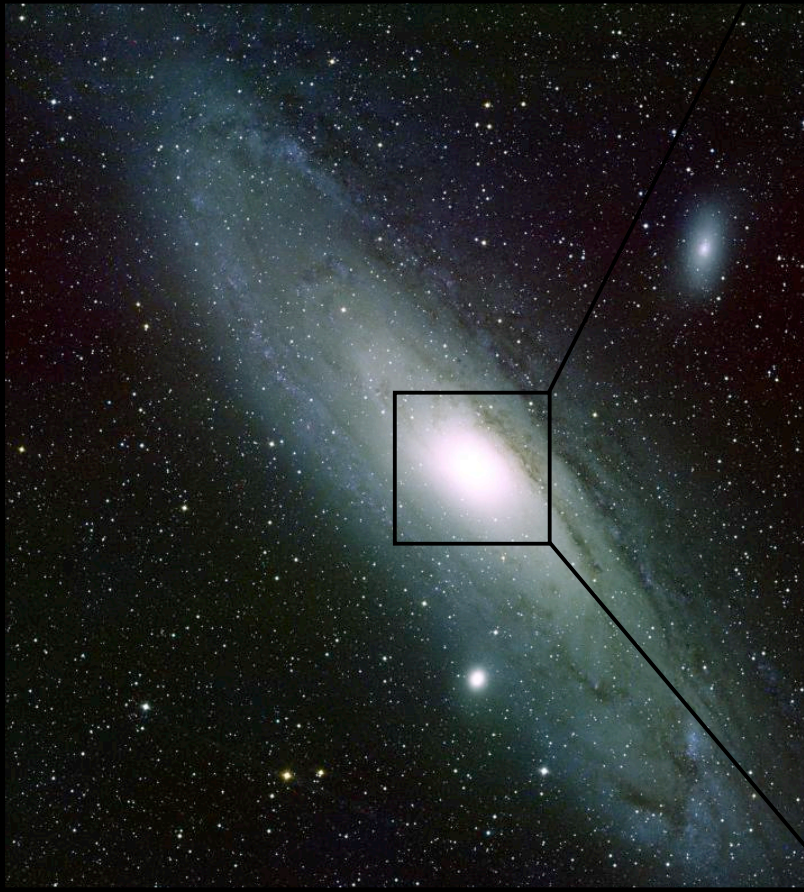
- compact dark masses can be detected with the gravitational lens effect.
- since events are rare ( $\ll 1/10^6$ ) and short, one needs long term, continuous monitoring on large fields
- large field also helps discriminating self- vs halo-lensing

We MONITORED the central 4kpc of the bulge in R(650nm) & I-band(850nm) for several years.

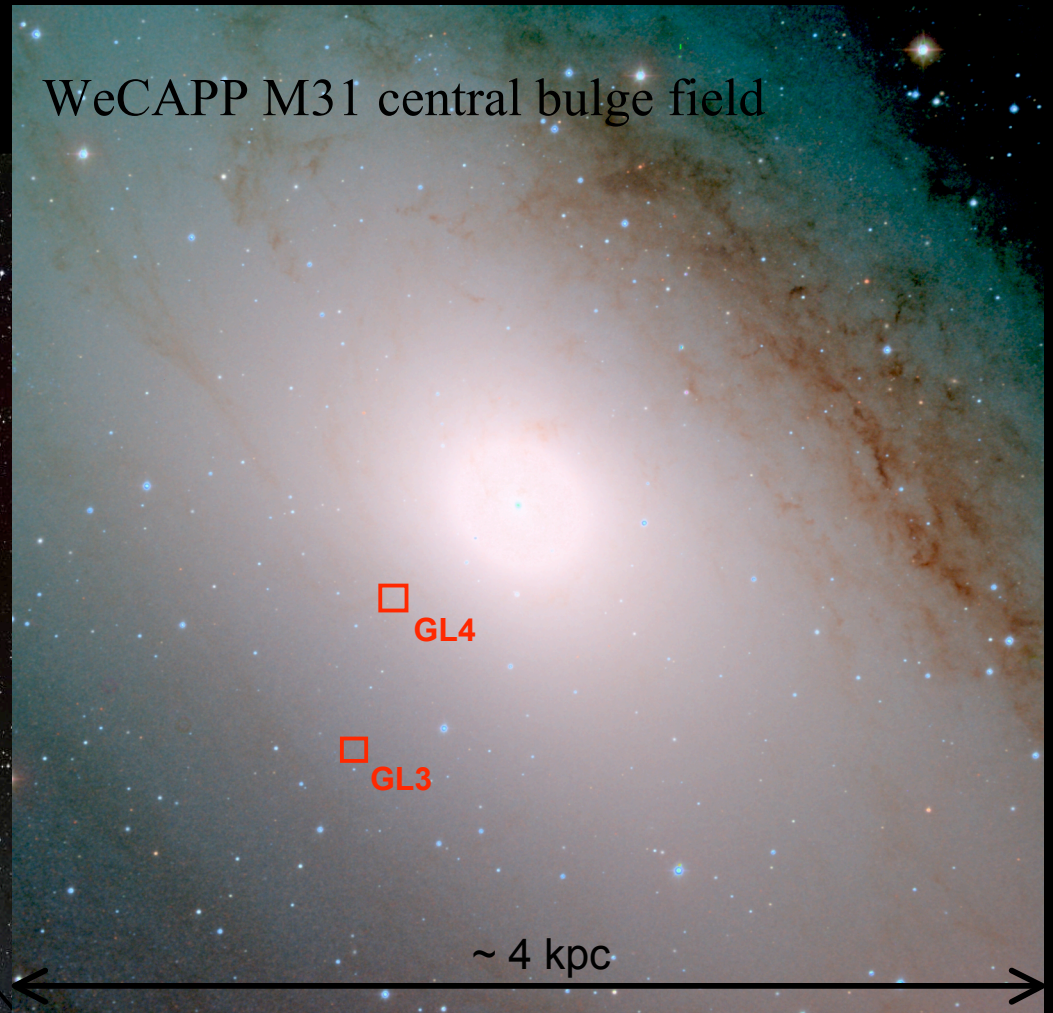
NOTE: individual stars located in M31 can not be resolved since they are blended with 100s of stars within the Point-Spread Function (PSF).

VARIABLES have been identified with difference images

Andromeda, M31

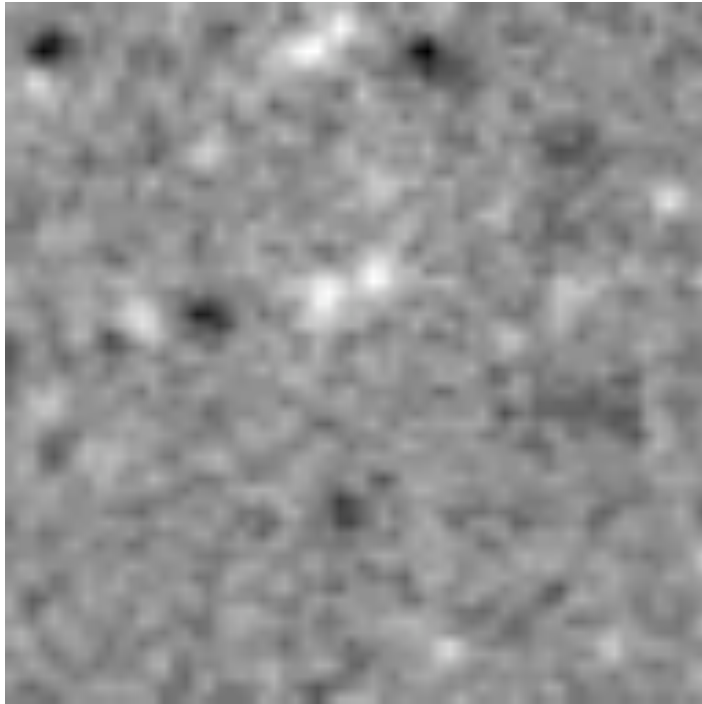


WeCAPP M31 central bulge field



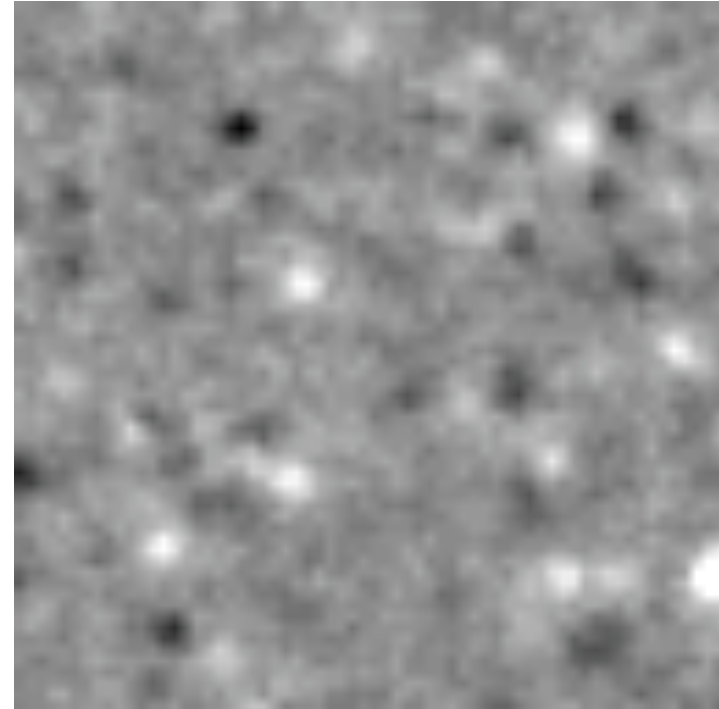
**Needle in the haystack:** Microlensing events have to be discriminated against tens of thousands of intrinsically variable sources !!!!

2 examples for lower signal-to-noise short time-scale events: *GL3* & *GL4*



**GL3**

32"x32", 8.8' SE from center,  
8 months in 1999/2000 season



**GL4**

32"x32", 5.6' SE from center,  
8 months in 2001/2002 season

large density of variables decreases effective area for lensing search

(Riffeser et al. 2008b, in preparation)

## Interpretation of WeCAPP-GL1:

This event (Riffeser et al 2003) is so bright, that it can hardly be caused by self-lensing once the finite source sizes of stars are taken into account (Riffeser, Seitz & Bender 2008a).

Numbers:

-At the location of WeCAPP-GL1 it is 80 times more easy to produce this event with halo lensing (by MACHOS) than with self-lensing (lensing by a bulge or disk star), if one assumes a full MACHO halo and masses of order solar.

-An event with a S/N of 50 or larger than GL1 is expected once every 140 years from self-lensing within the total WeCAPP field, or once every 6 years from halo lensing (for a full MACHO halo)

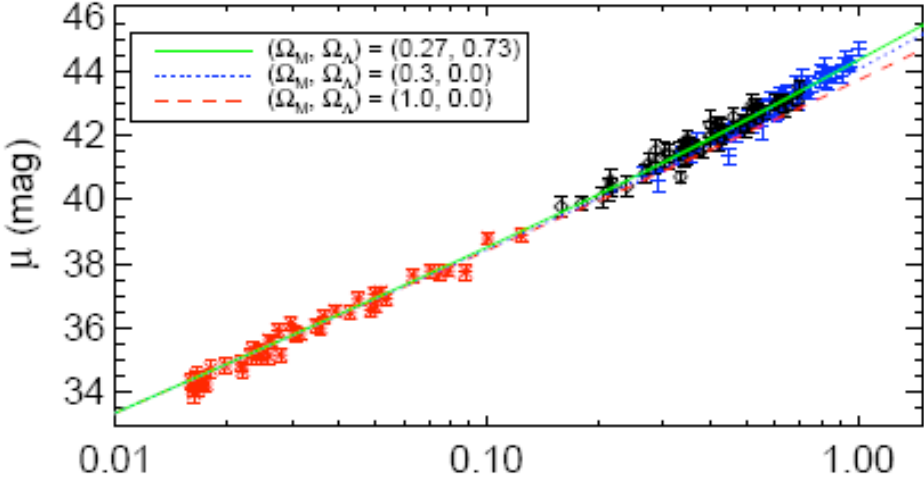
## 2. Results of our work in 2007:

### Constraining Dark Energy with Supernovae and Galaxy Clusters\*

\* For constraints from LSS and BAOs see talks by  
Luigi Guzzo and Stefanie Phleps

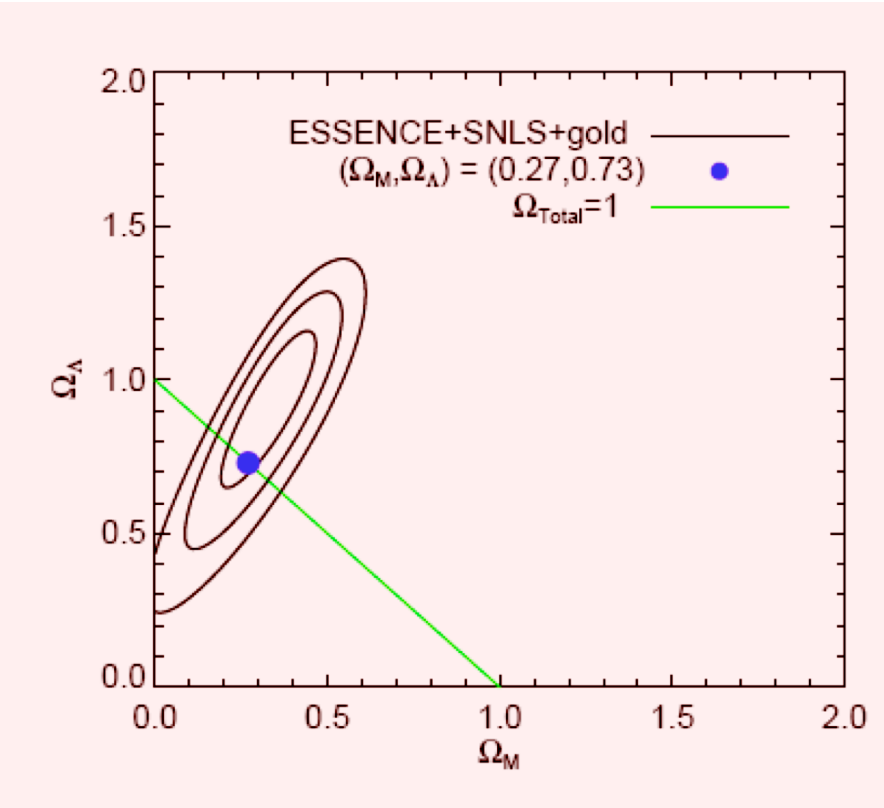
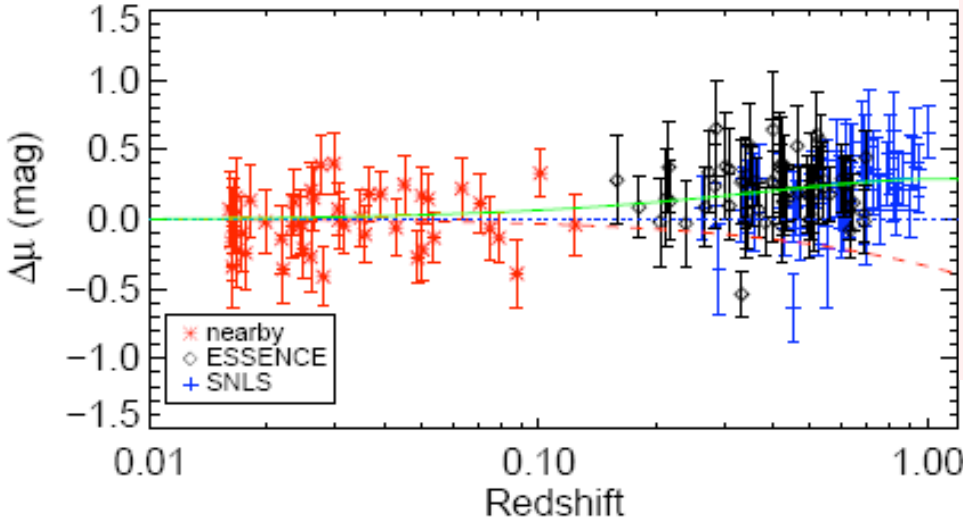
# The SN Ia Hubble Diagram

Bruno Leibundgut et al.



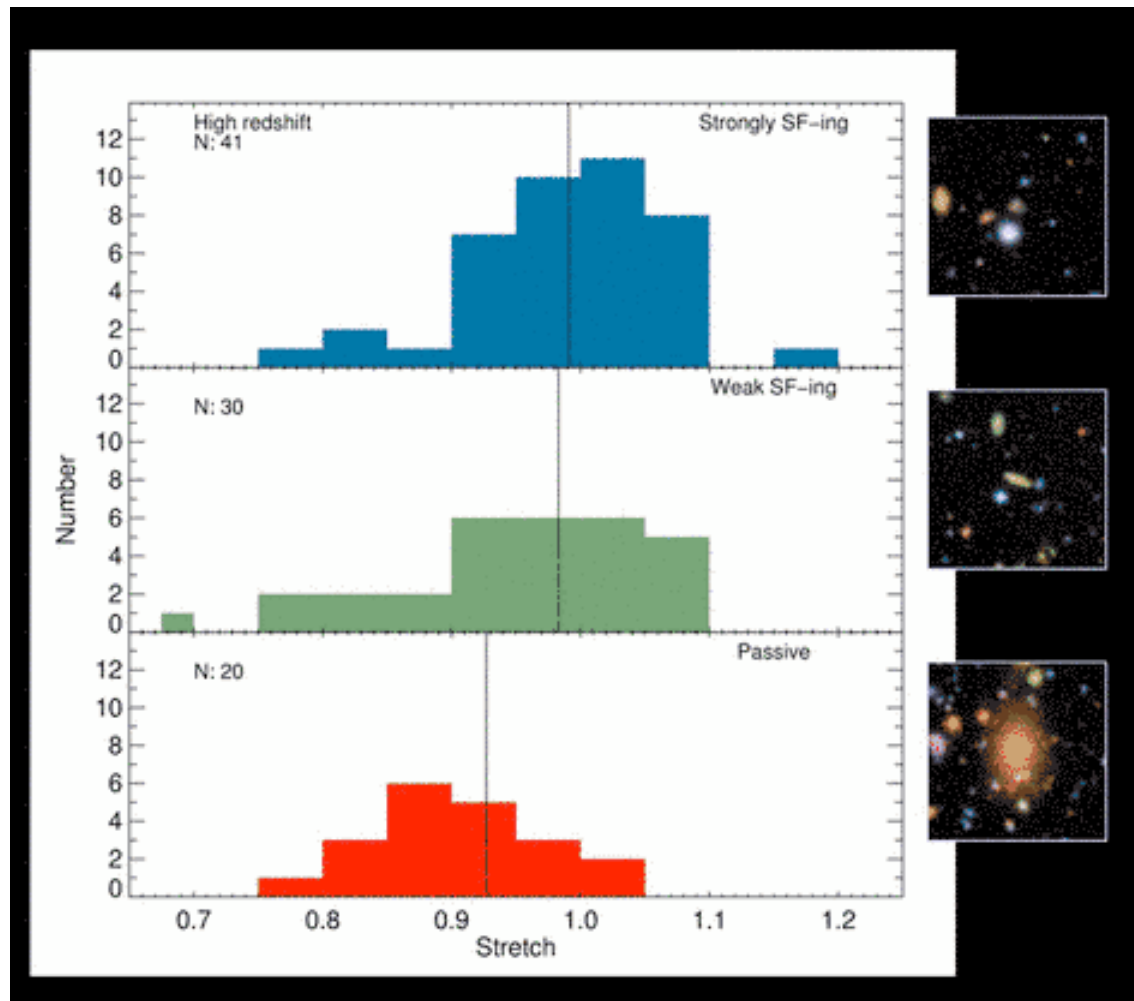
from ESSENCE, SNLS  
and nearby SNe Ia

## Wood-Vasey et al. 2007



# Requirements to measure $w(z)$ with SN

Bruno Leibundgut, ESO



Limit uncertainties  
to  $< 2\%$

- solve the local field problem
- solve reddening problem
- understand evolution (e.g. metallicity effects)
- understand SN Ia physics
  - Progenitors -> MPA
  - explosion mechanism(s) -> MPA
  - 3-dimensional -> MPA

Sullivan et al. 2006

# Understanding the SN explosion mechanisms:

W. Hillebrandt et al.

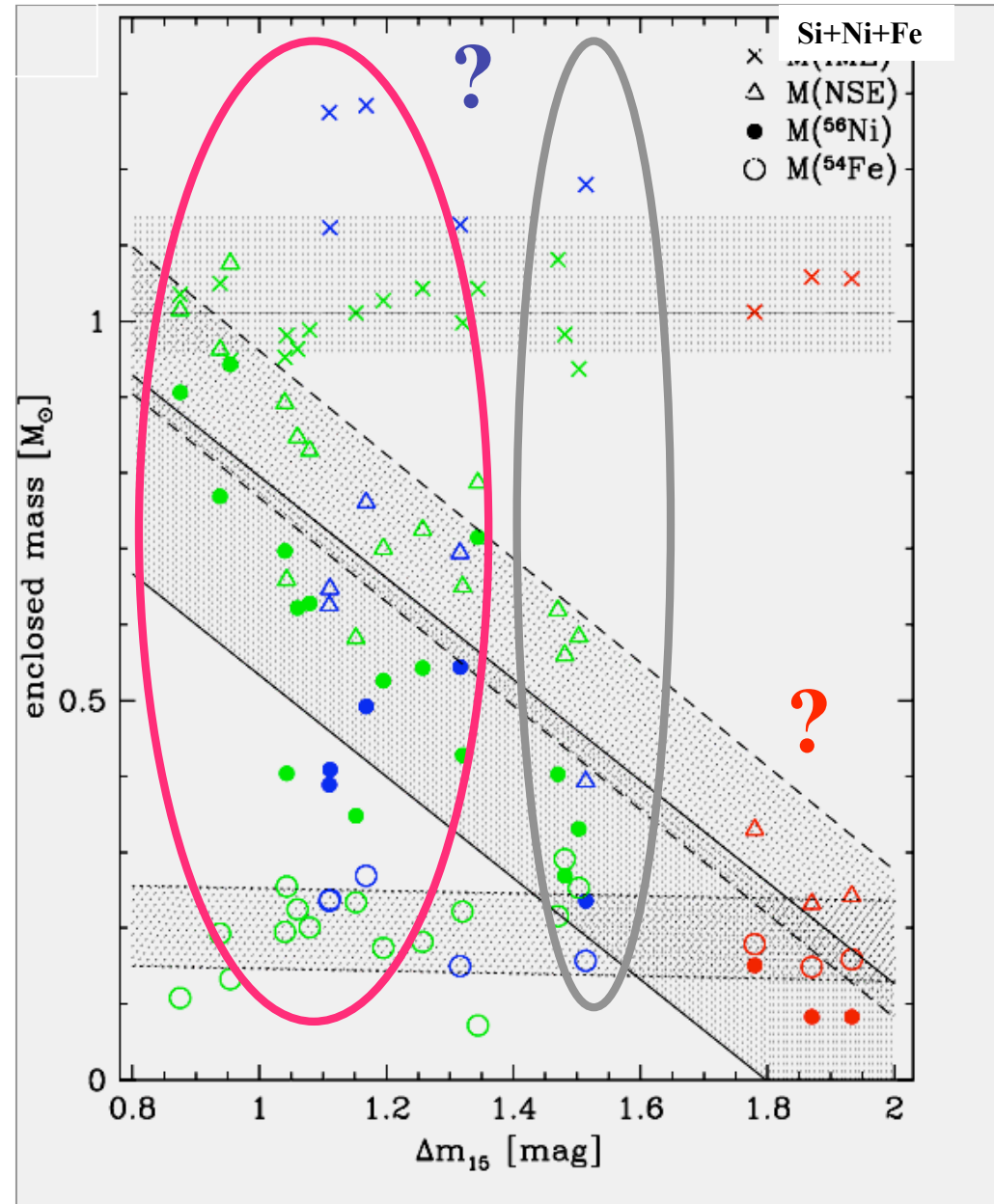
## The "Zorro" diagram

P. Mazzali, F. K. Röpke,  
S. Benetti, W. Hillebrandt, 2007

*grey*: Deflagrations (subsonic  
burning zone, 'flame')

*purple*: Transition from  
Deflagration to Detonation  
(supersonically propagating shock),  
bright SNe

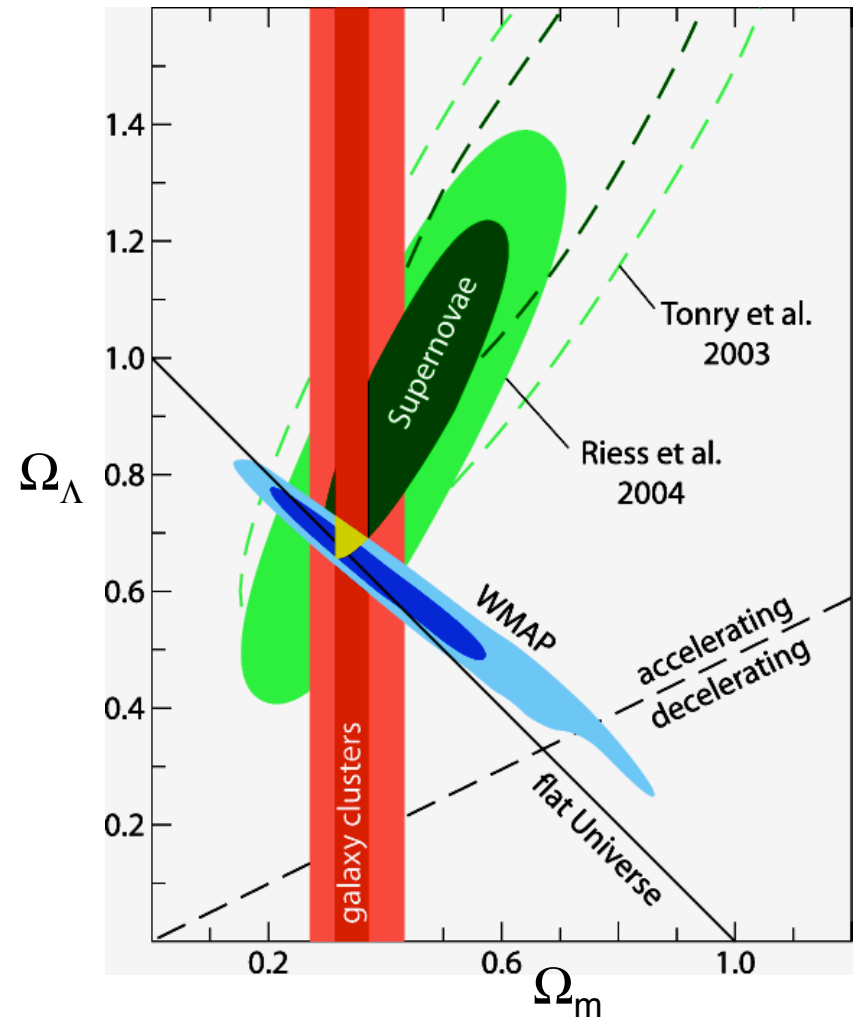
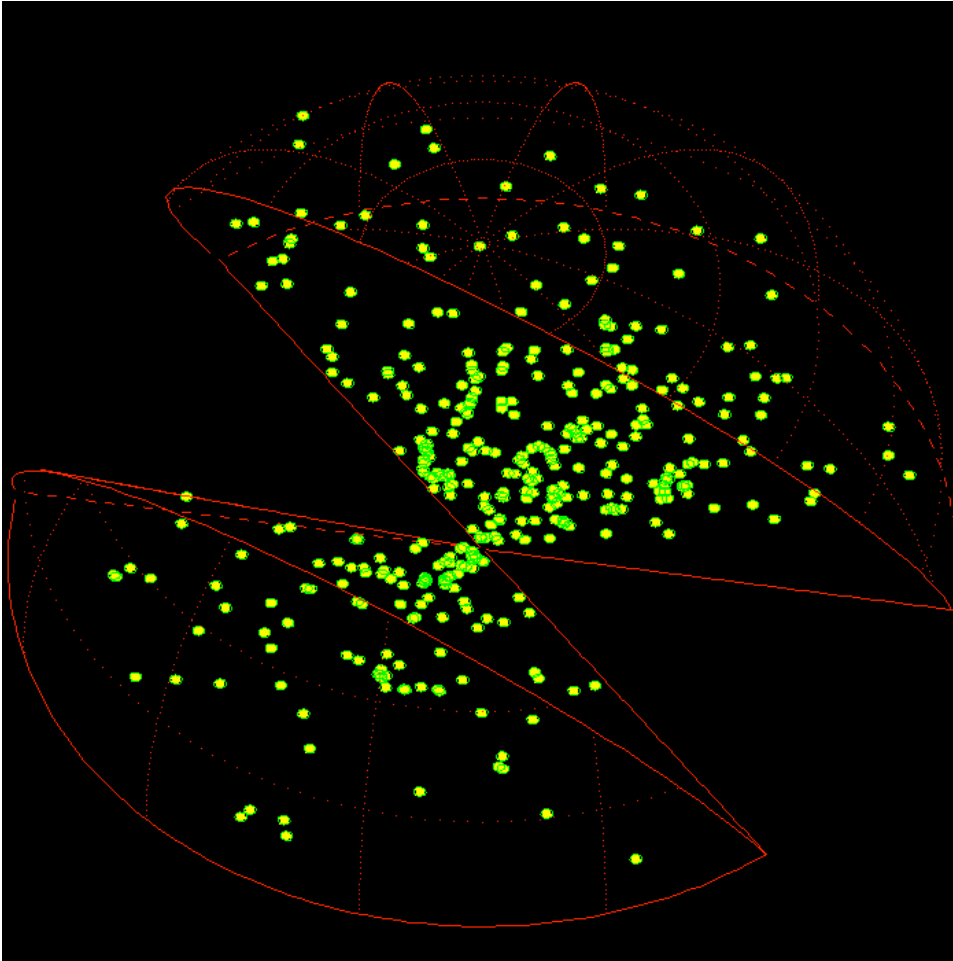
*red*: unknown mechanism



# Constraints on cosmological parameters with REFLEX Clusters

Hans Böhringer et al.

3 dimensional representation of  
REFLEX cluster distribution

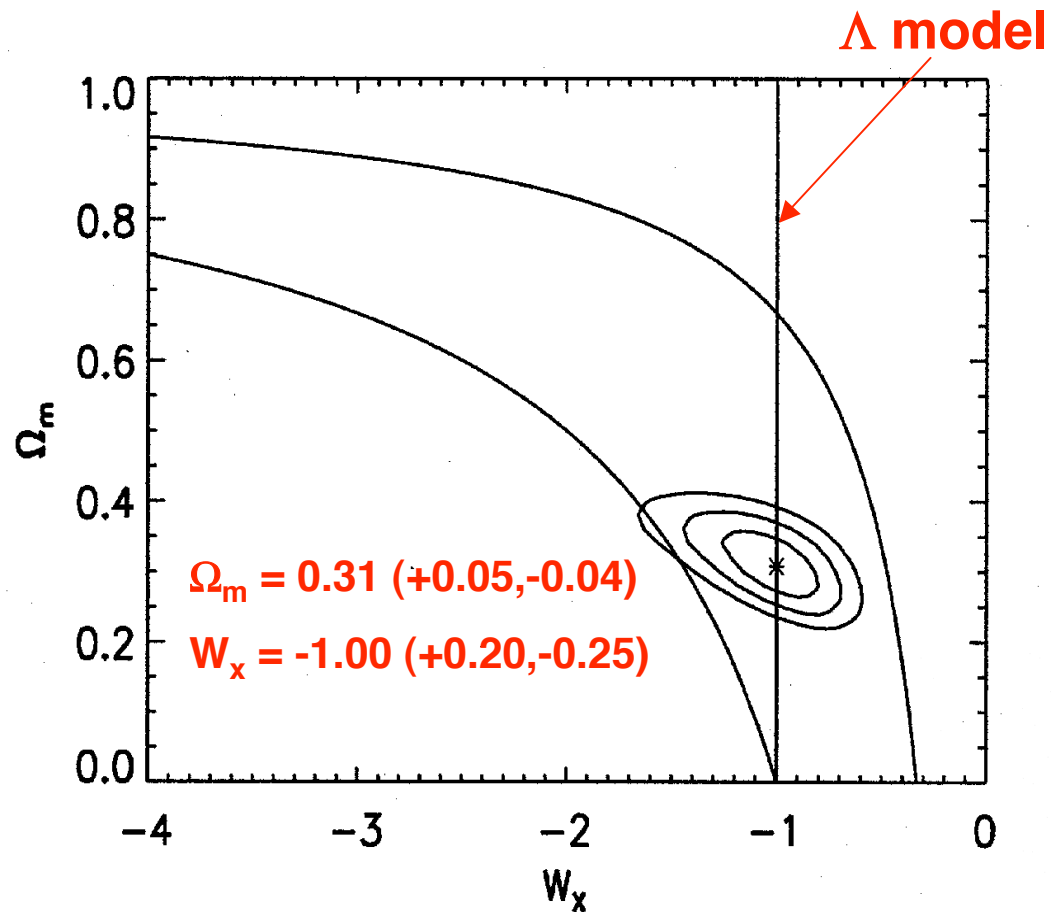
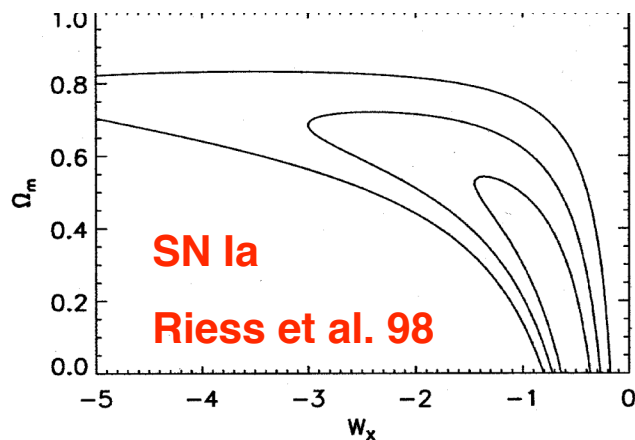
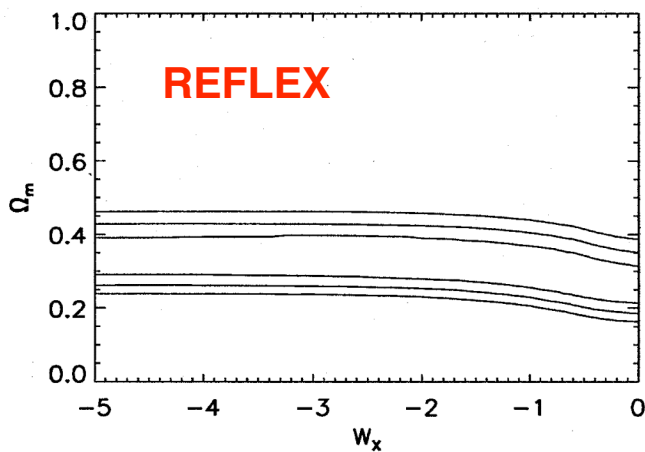


The galaxy cluster data reinforce the Concordance Cosmology (with low  $\sigma_8$ )

# Combined Constraints REFLEX & SN Ia on $\Omega_m$ and $w_x$

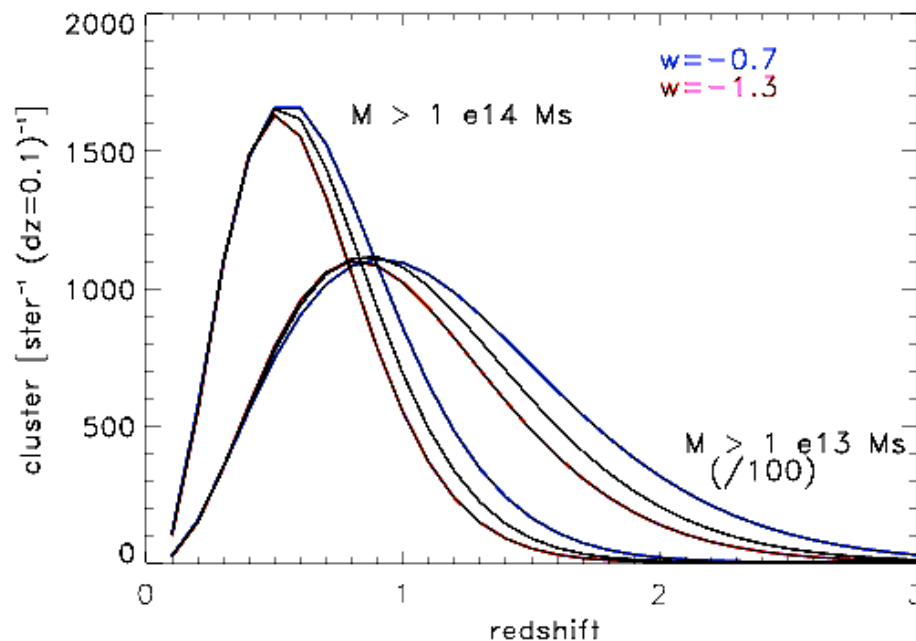
Data from REFLEX and SN observations of  
Riess et al. 1998 and Perlmutter et al. 1999  
[Schuecker et al. 2003]

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



# Evolution of the Cluster Mass Function

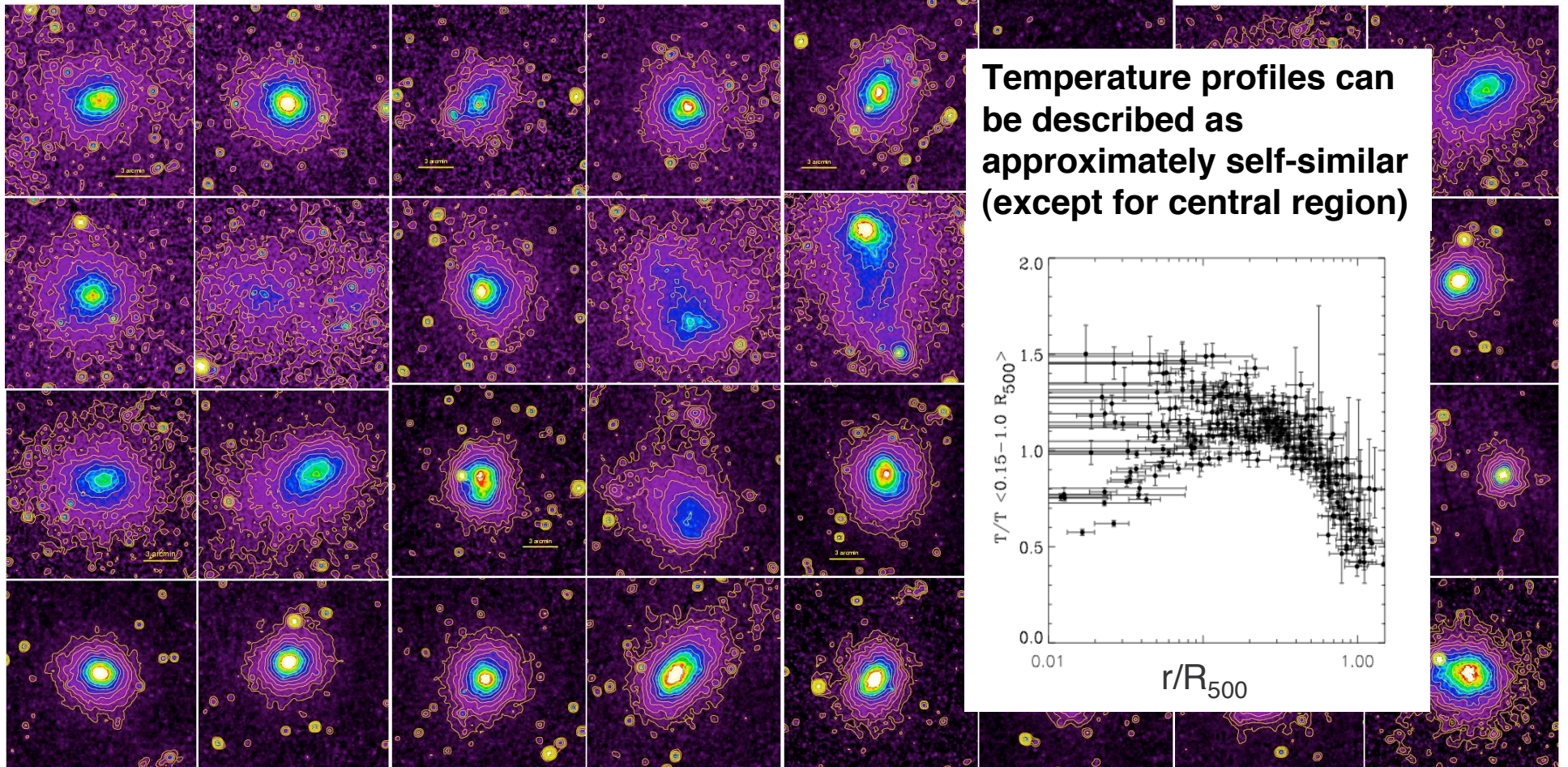
Differential comoving cluster abundance ( $> \text{Mass}_{\text{limit}}$ )  $\text{ster}^{-1} dz=0.1^{-1}$



→ There are more distant clusters for small  $-w$  !

Number count variation  $\sim 30\%$   $d\log N/d\log M$  at this point  $\sim 3$   
→ the accuracy needed in the mass measurement is a few %

For the cosmological studies the knowledge of cluster structure statistics is important → Galaxy Cluster Structure Survey: 33 XMM-Newton Obs.

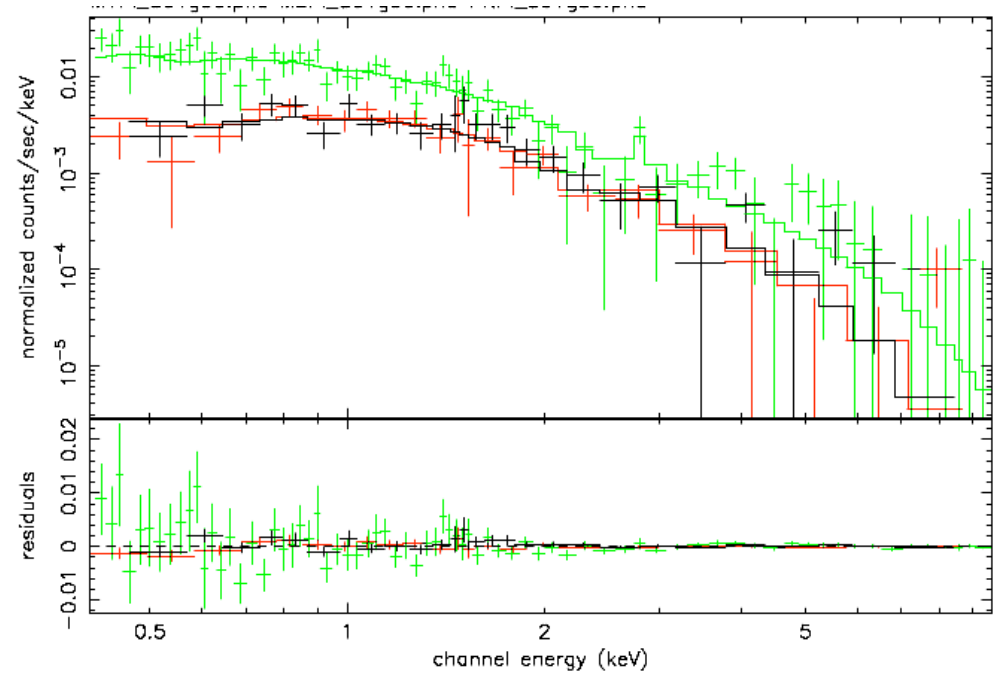
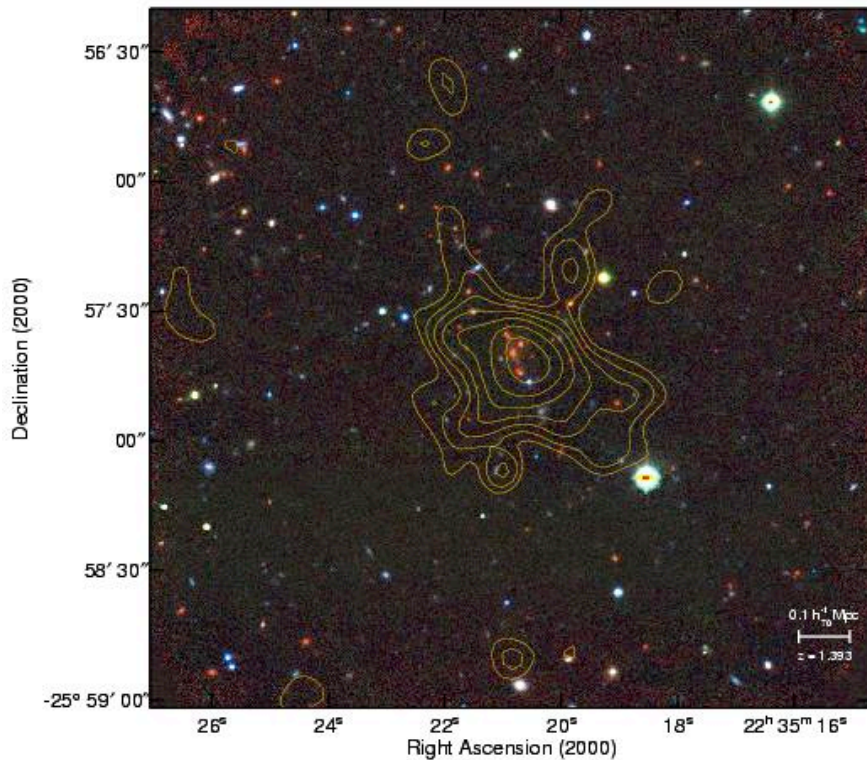


Temperature profiles can be described as approximately self-similar (except for central region)

The selected clusters form a representative sample of cluster morphologies! We find a high degree of self-similarity in their outer temperature profiles.

Böhringer et al., *A&A*, 2007, 469, 363.

# Large Project to Search for Distant Clusters to Understand Cosmic Evolution Example of a cluster discovered @ $z=1.39$



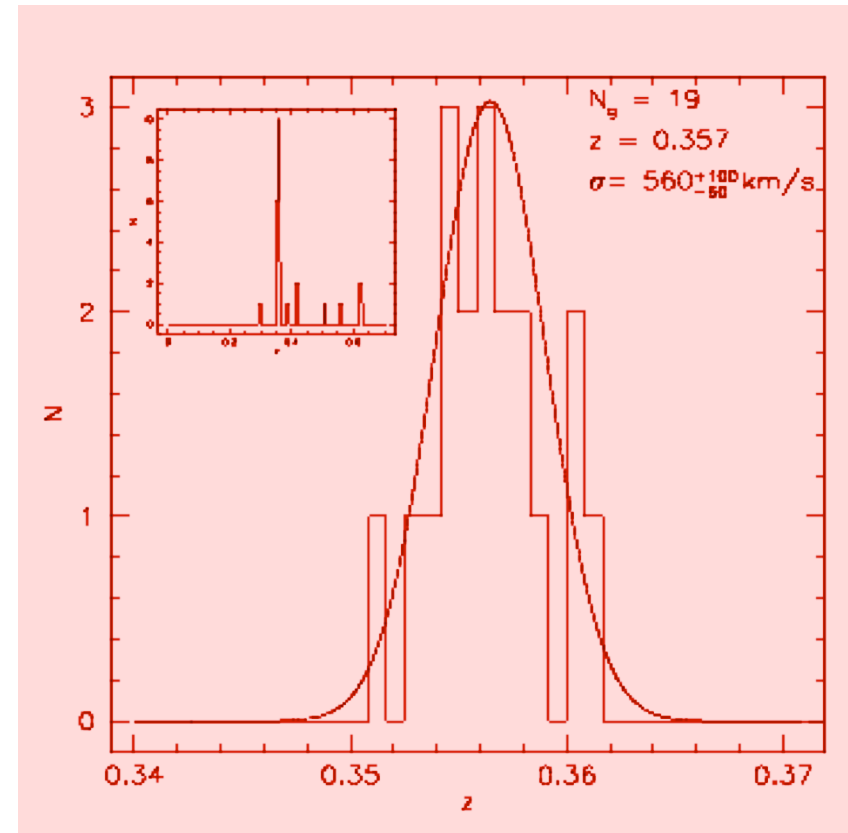
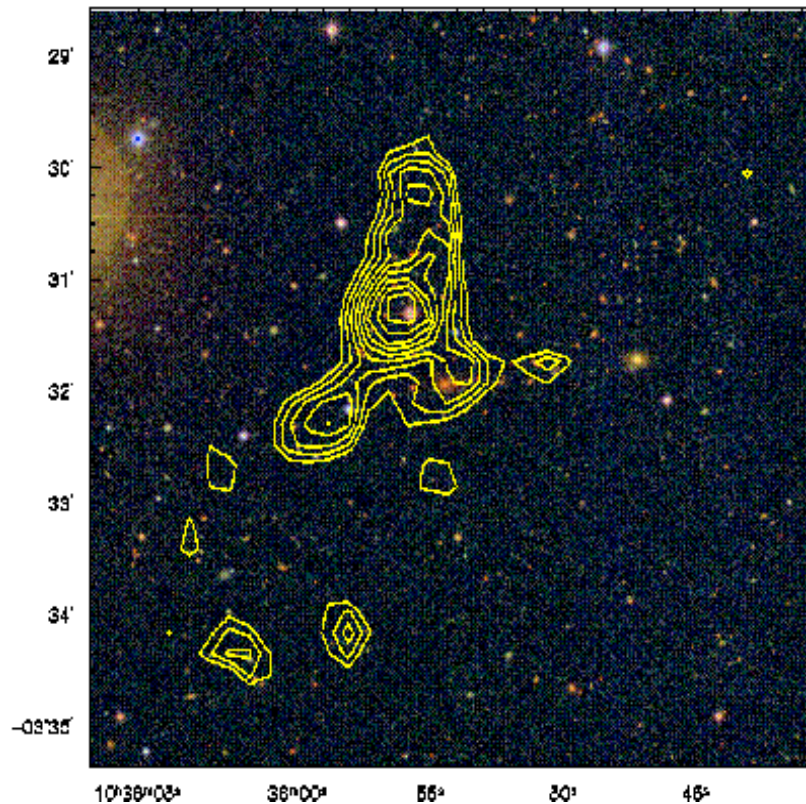
Highest redshift at which enrichment by Iron has been observed in the intergalactic medium in clusters

**Result:  $T = 5.5 \pm 0.9 \text{ keV}$**

**Metal. =  $0.41 \pm 0.21$**

# Weak Lensing Selected Clusters

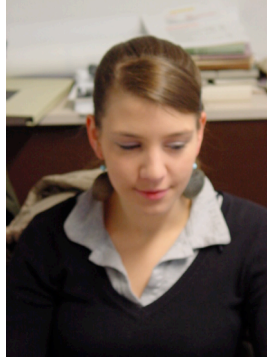
Jörg Dietrich



31 cluster candidates selected by their shear signal. First spectroscopic confirmation made. More data under investigation and more observations coming. Detailed comparison of lensing, X-ray, and optical properties.

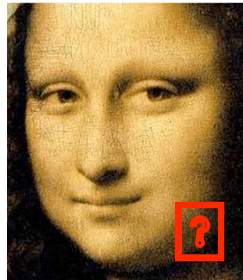
## New students to work with us on the `dark universe` (funded by Excellence Cluster):

S. Roth, PhD student, TU  
with W. Potzel  
"CRESST/EURECA cryogenic  
detectors"  
Talk on Monday



A. Golovnev, Postdoc, ASC, LMU  
with S. Mukhanov  
"Quantization of motion  
in curved manifolds"  
Talk on Wednesday

NN,  
PhD student, MPA  
with V. Springel  
"Simulations of DM-  
structure formation"



Chien-Hsiu (Sherman)  
Lee, PhD student, USM  
with S. Seitz, A. Riffeser  
"Limits on compact dark  
matter from  
Microlensing surveys  
towards M31"  
see poster

Payel Das,  
PhD student, MPE  
with O. Gerhardt, R.P.  
Saglia, H. Boehringer  
"Dark matter and  
orbital structure in  
elliptical galaxies"  
see poster



Stefania Giodini,  
PhD student, MPE  
with H. Boehringer  
"Detection of  
clusters of  
galaxies in optical  
data"  
see poster



