THE UNIVERSITY OF BRITISH COLUMBIA

CIFAR
CANADIAN INSTITUTE for ADVANCED RESEARCH

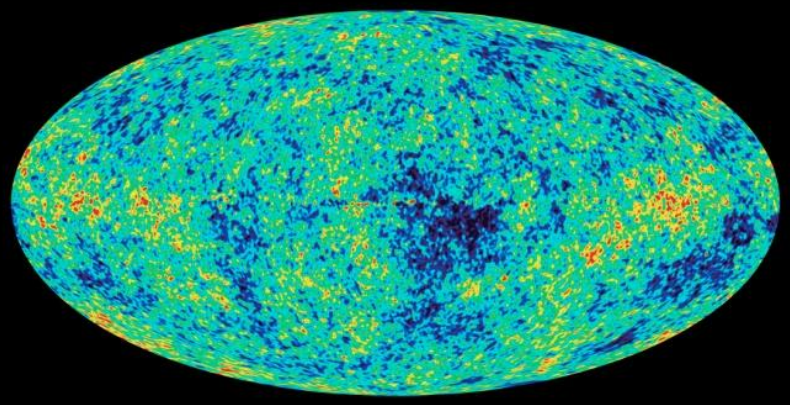
Gravitational Lensing: The beginning of a new era for the study of the dark universe?

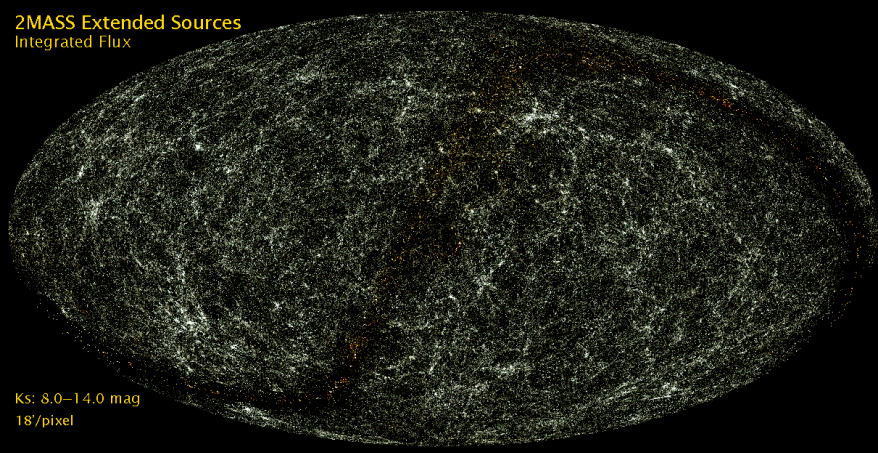
L. Van Waerbeke

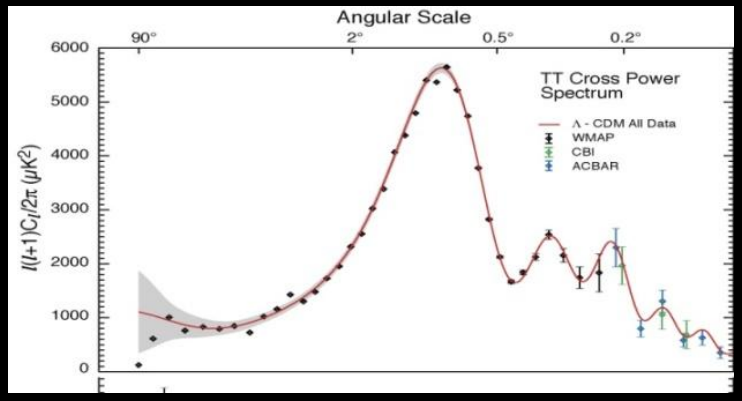
TEXAS symposium
Sao Paulo dec 2012

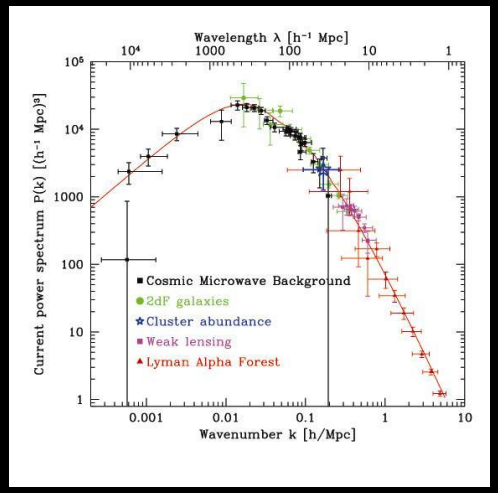
Cosmic Microwave Background z~1100

Large scale structures z~0





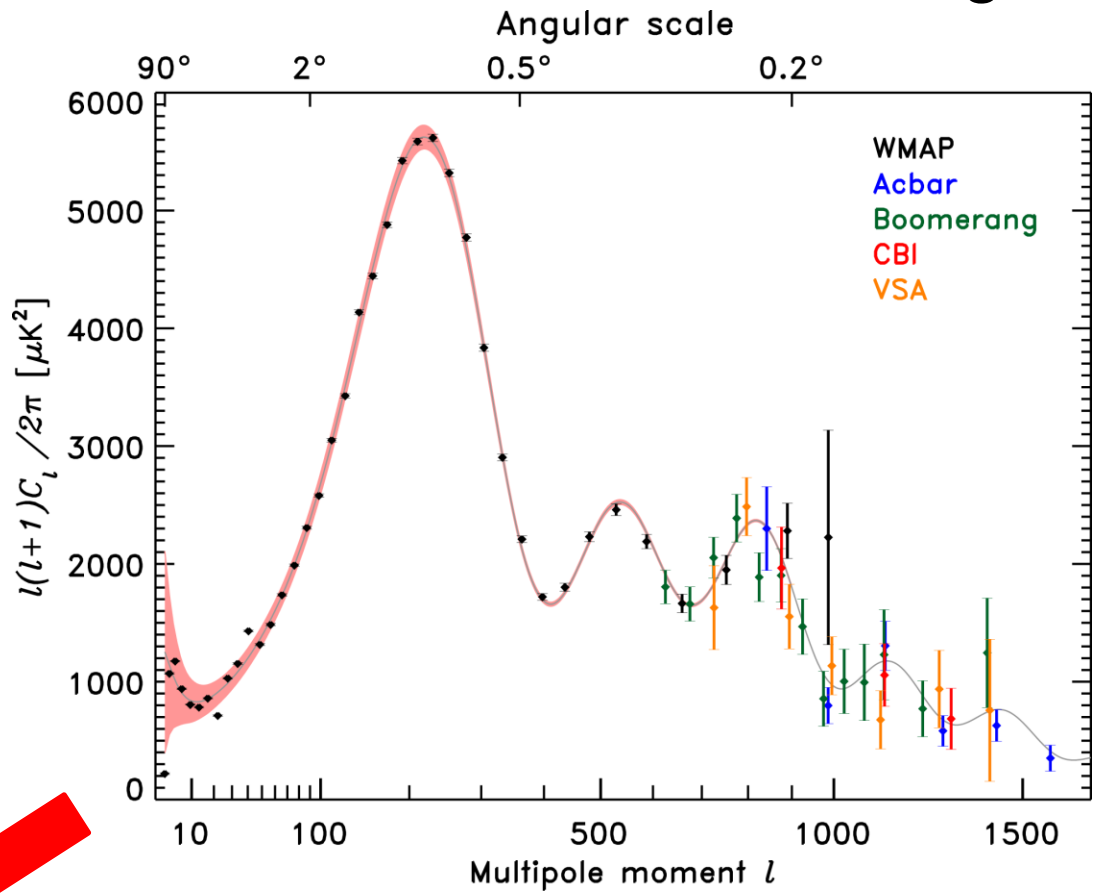




~13 billion years separate the two

The most convincing proof of the existence of dark matter:

The cosmic microwave background

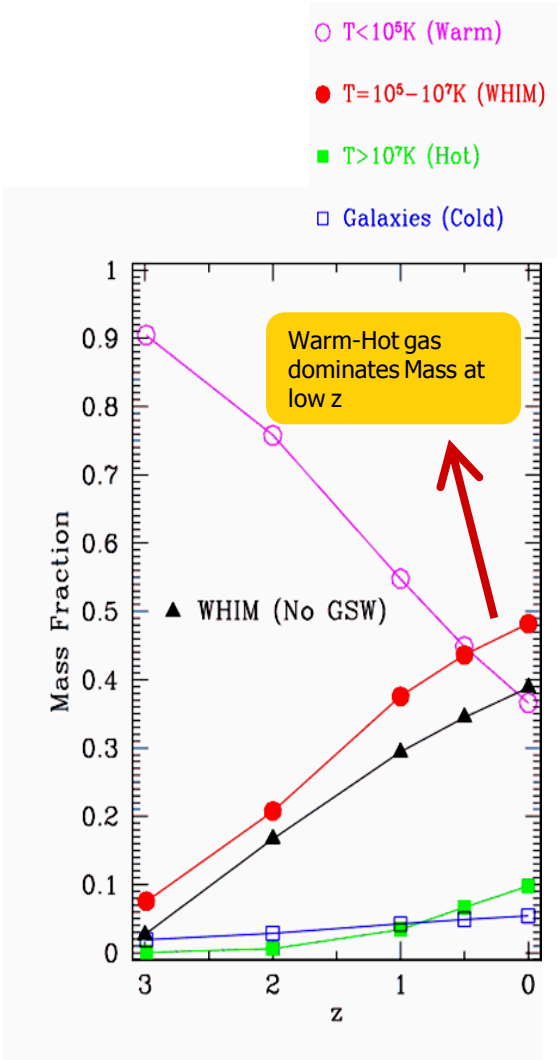


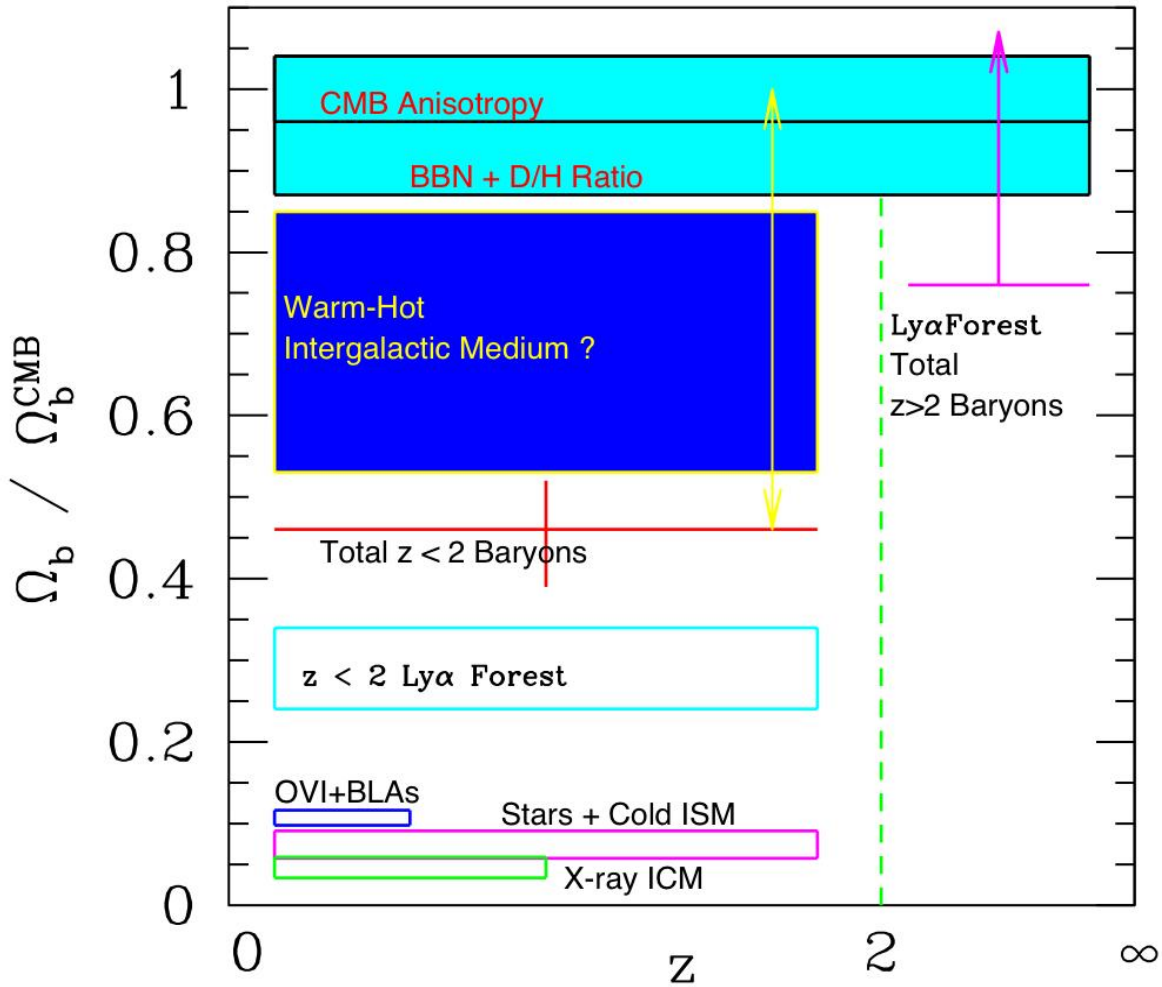
Dark matter crisis

Baryons crisis

Where are the Baryons?

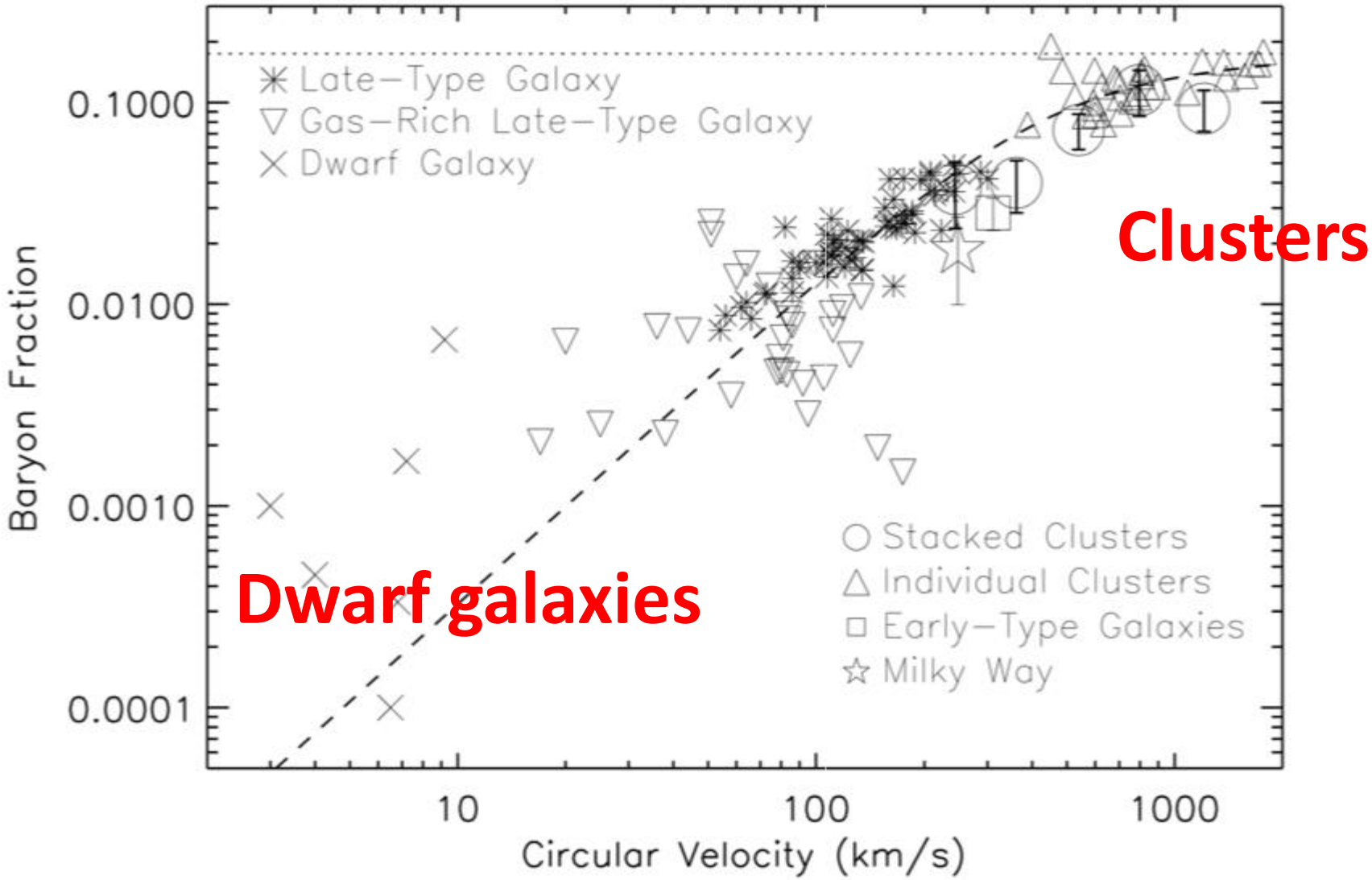
Were they expelled from galaxies or did they ever fall in galaxies?



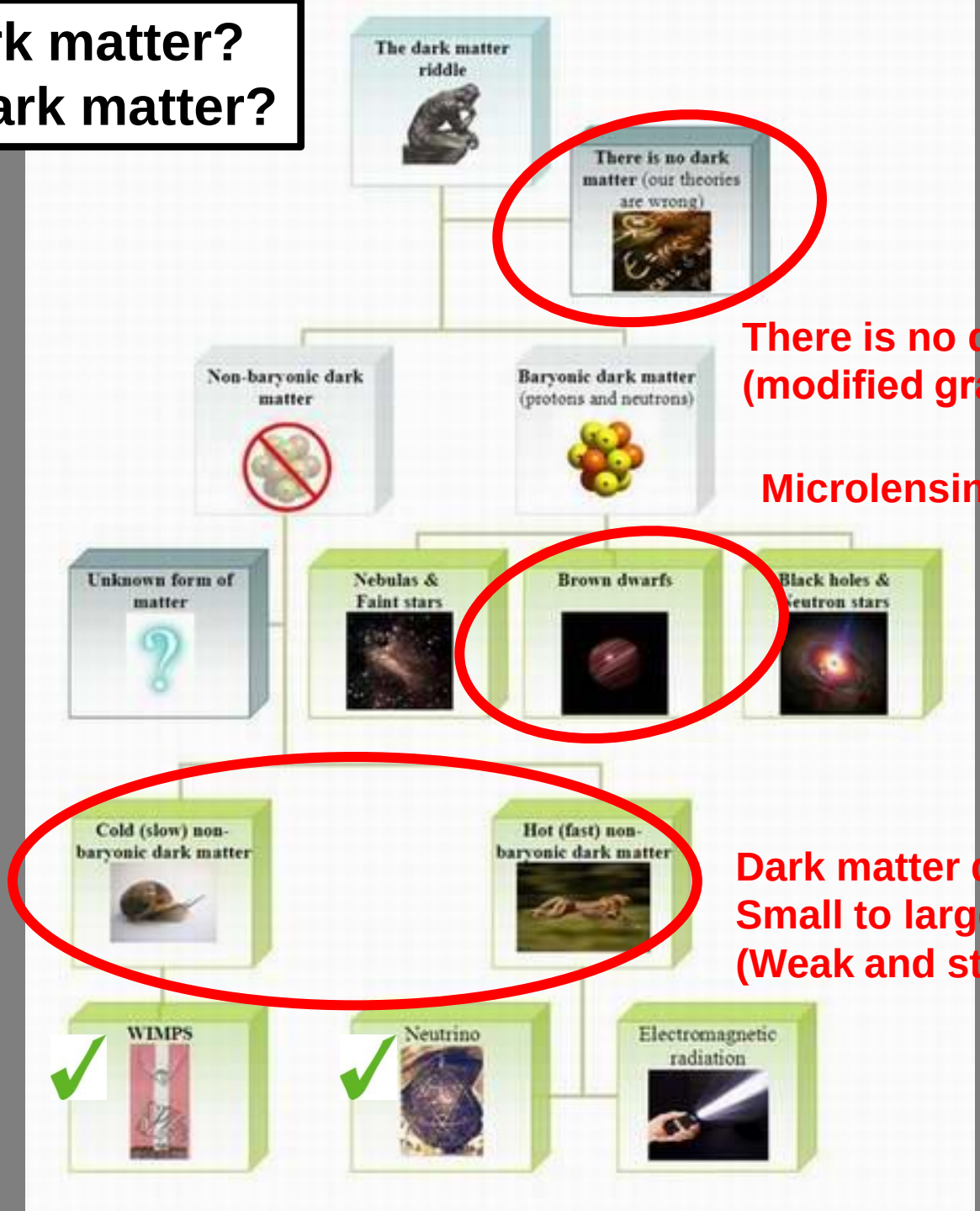


Courtesy: F. Nicastro (Sydney 2009)

Scale dependence of the missing baryon problem (Dai et al. 2010)



What is dark matter?
Where is dark matter?



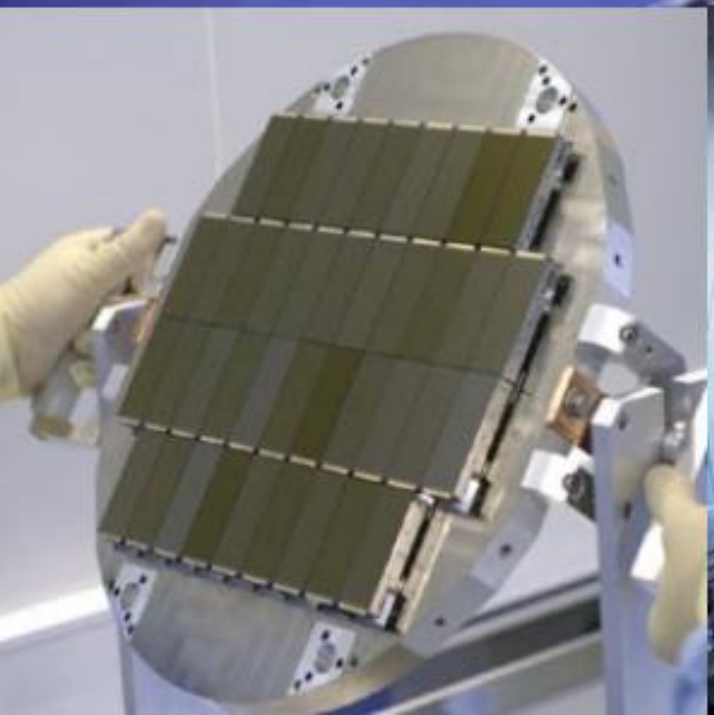
There is no dark matter
(modified gravity, f(R), etc…)

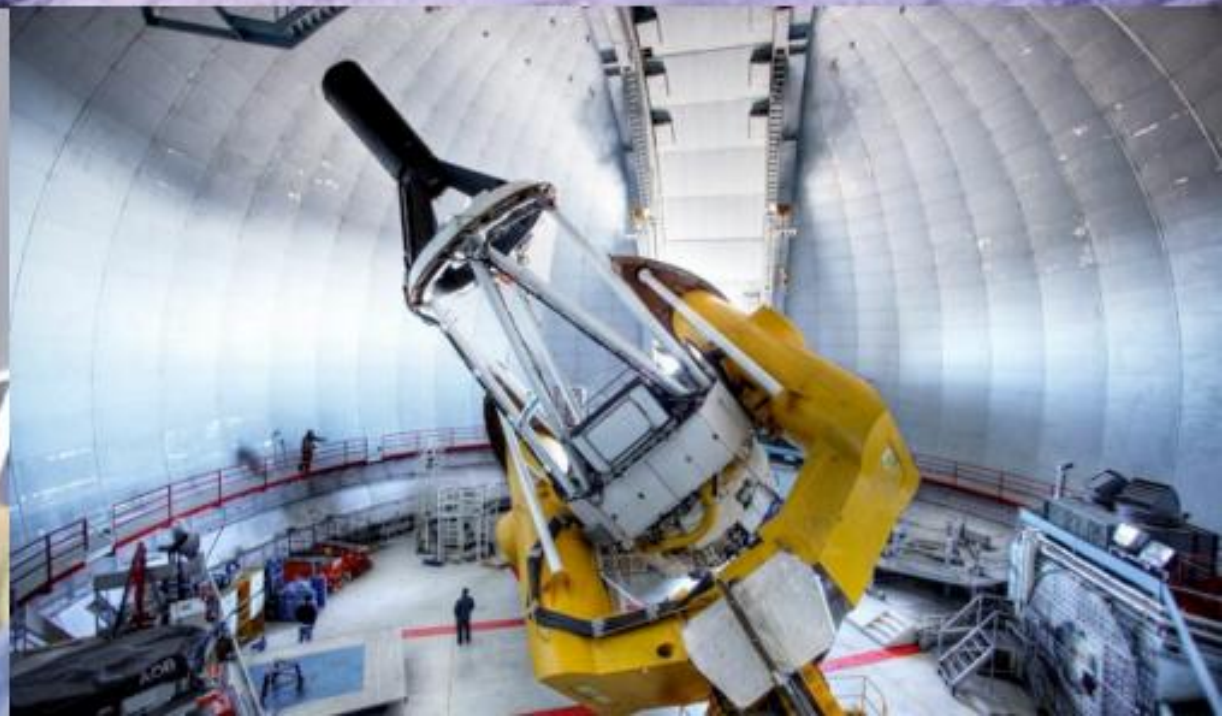
Microlensing

Dark matter distribution from
Small to large angular scales
(Weak and strong lensing)

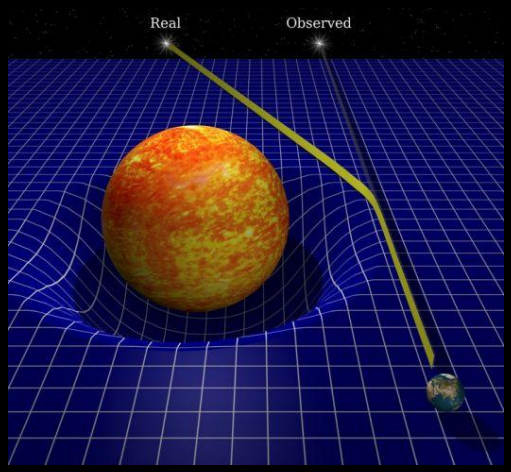
CFHTLenS (PIs: Van Waerbeke & Heymans)

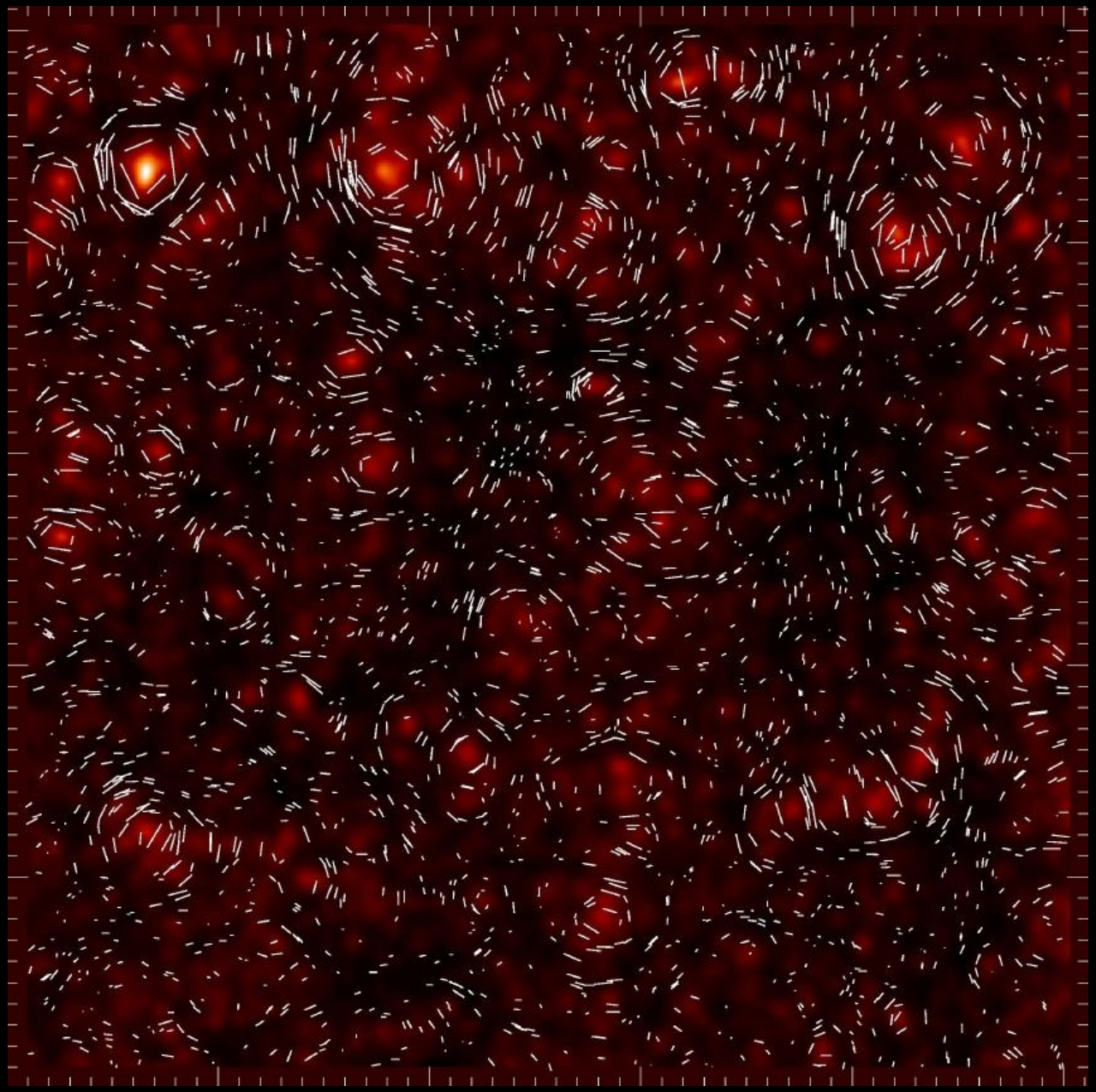
- The state-of-the-art cosmological survey with 155 sq degrees, ugriz to i<24.7 (7σ extended source)
- Uses 5 yrs of data from the Deep, Wide and Pre-survey components of the CFHT Legacy Survey

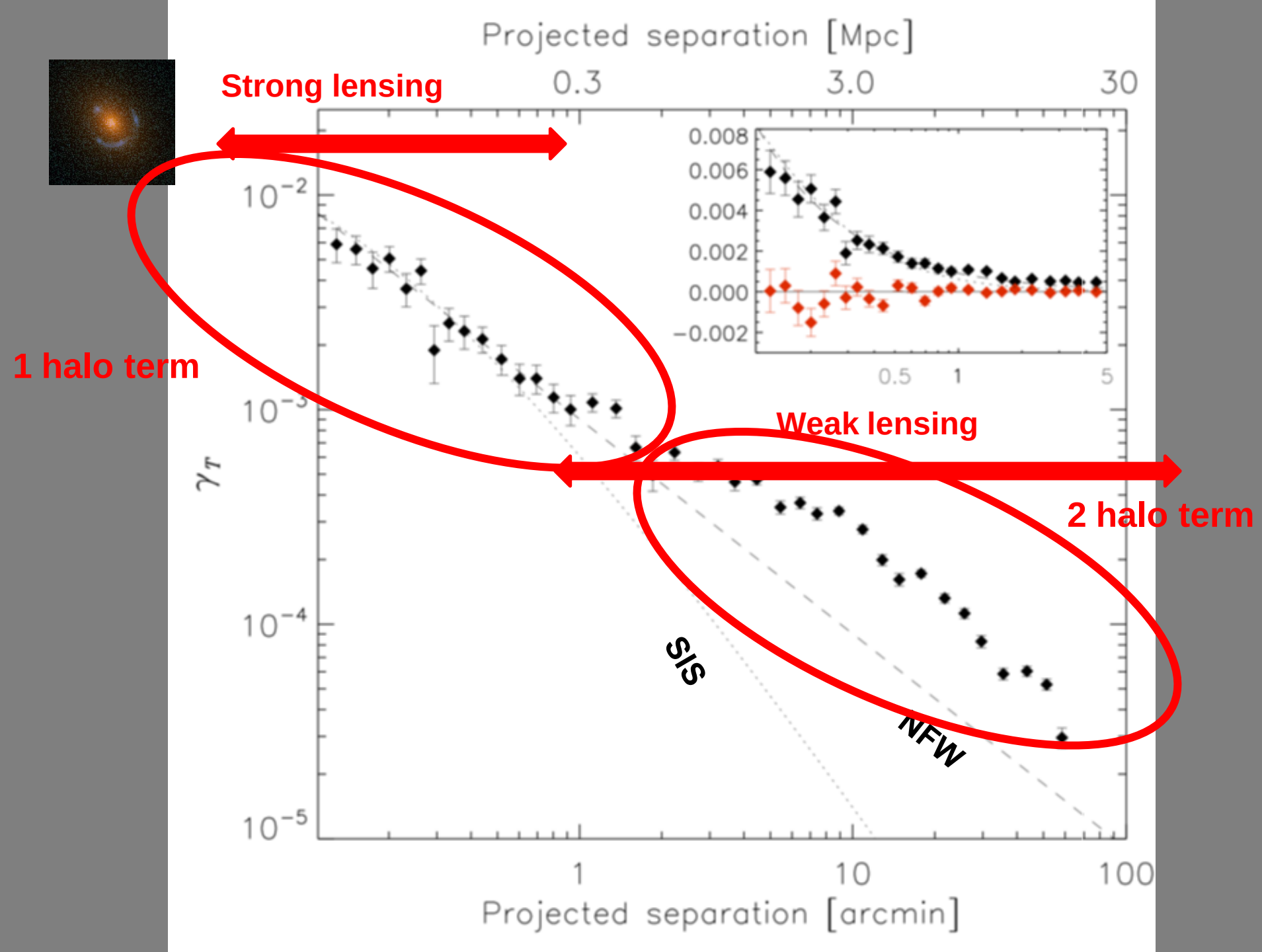




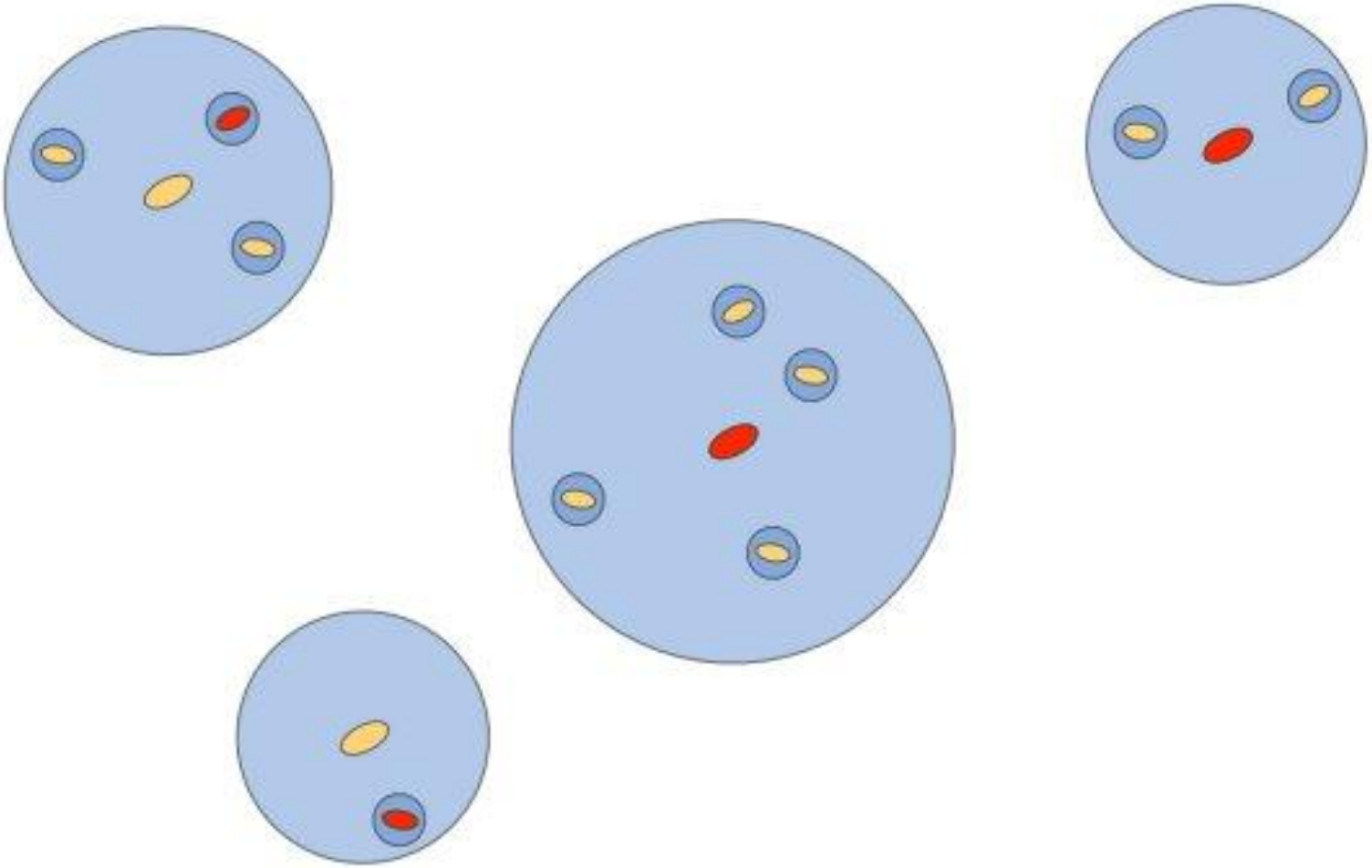
Gravitational lensing: lensed galaxies mapping foreground matter

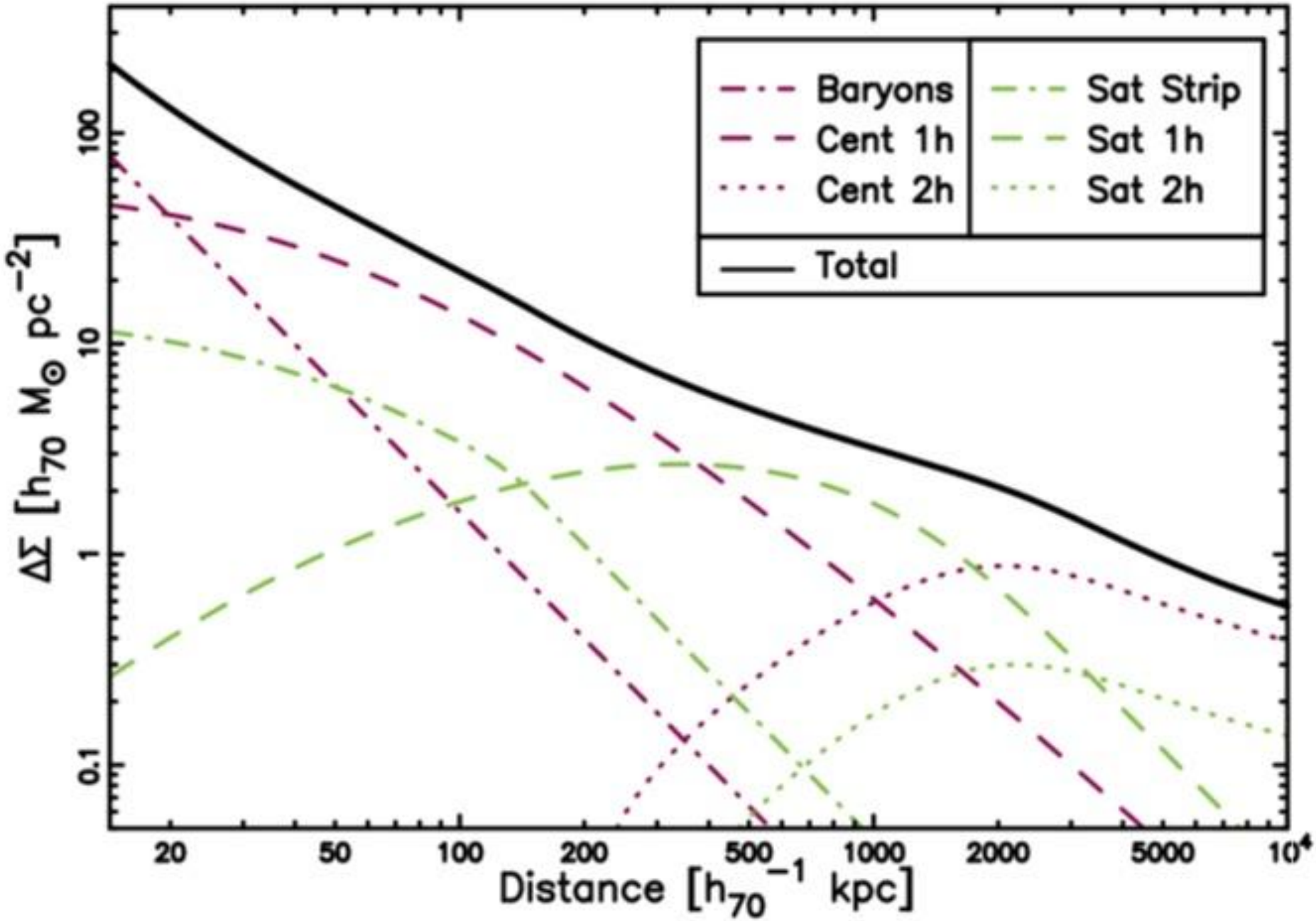





Strong lensing
Projected separation [Mpc]
0.3
3.0
30
1 halo term
Weak lensing
2 halo term
SIS
NFW
γ_T
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1
10
100
Projected separation [arcmin]
0.008
0.006
0.004
0.002
0.000
−0.002
0.5
1
5

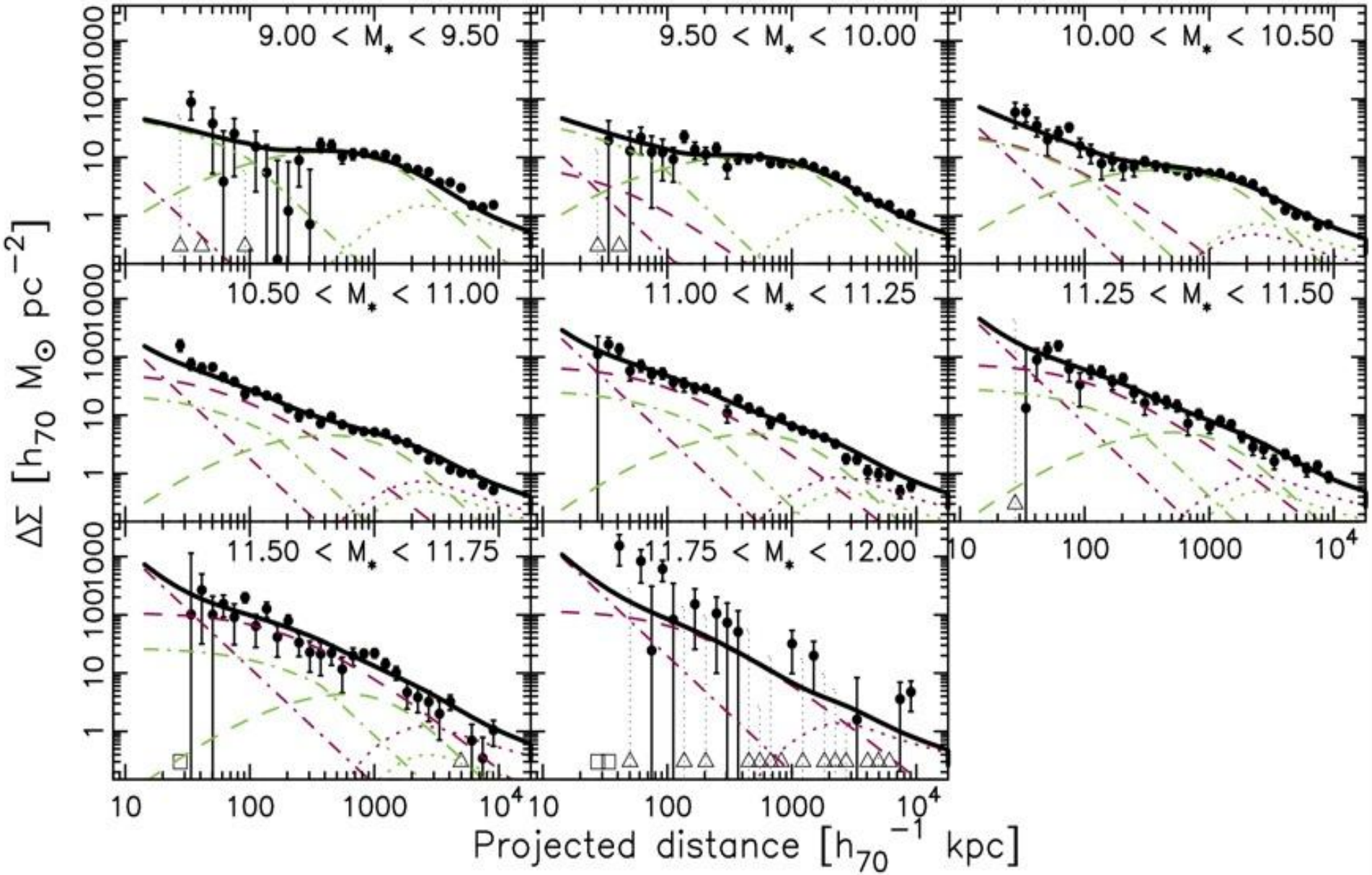
The halo model



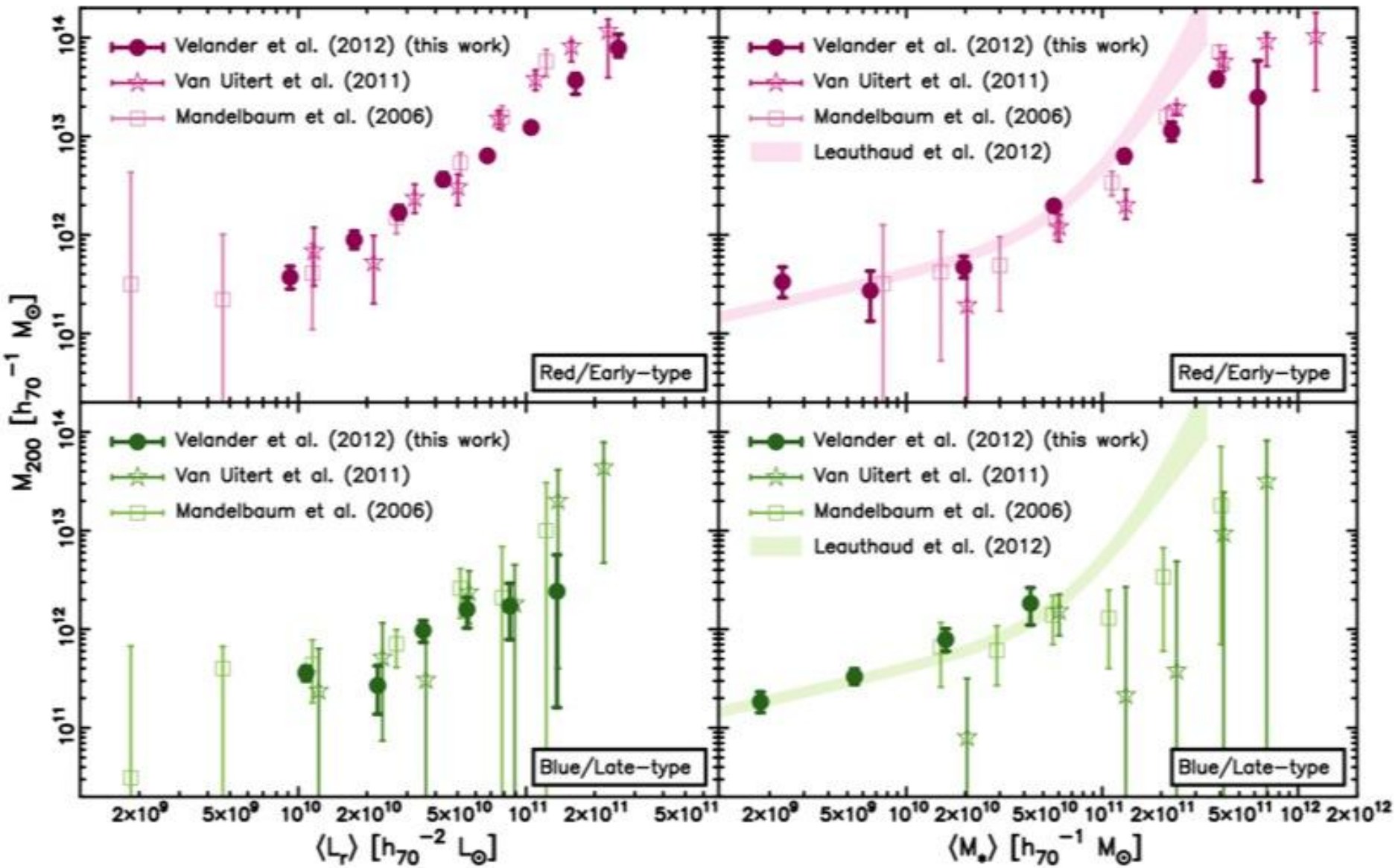

Baryons
Cent 1h
Cent 2h
Sat Strip
Sat 1h
Sat 2h
Total
$\Delta\Sigma$ [h_{70} $M_\odot$ pc^{-2}]
100
10
1
0.1
20
50
100
200
500
1000
2000
5000
10^4
Distance [h_{70}^{-1} kpc]

CFHTLenS measurement on red (early type) galaxies

Velander et al., 2012

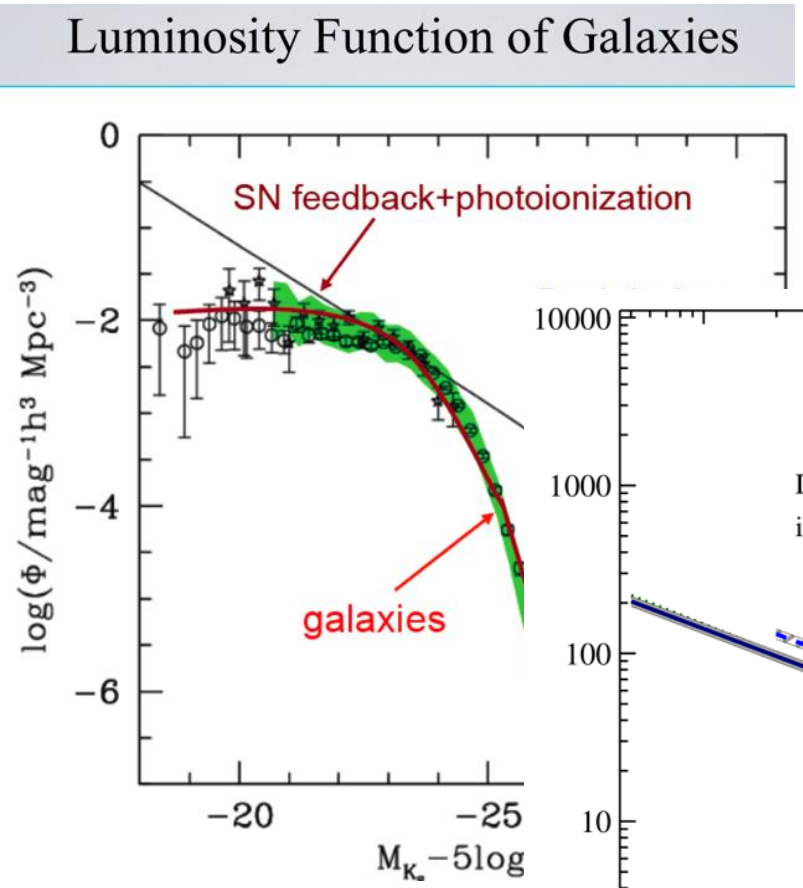


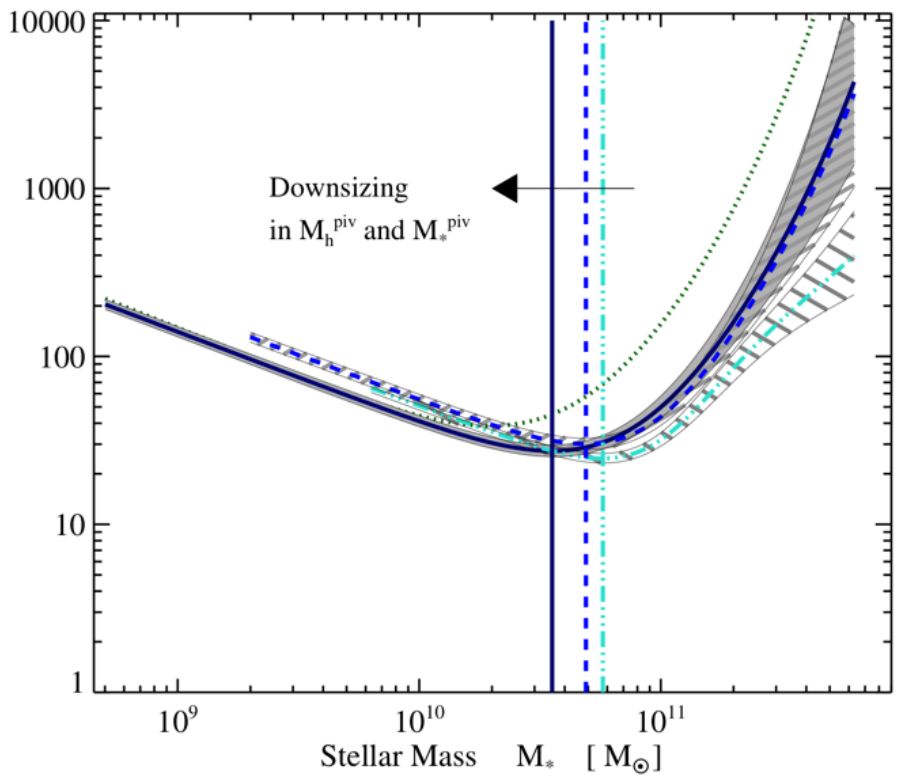
DM halo mass to baryon (L,M) scaling

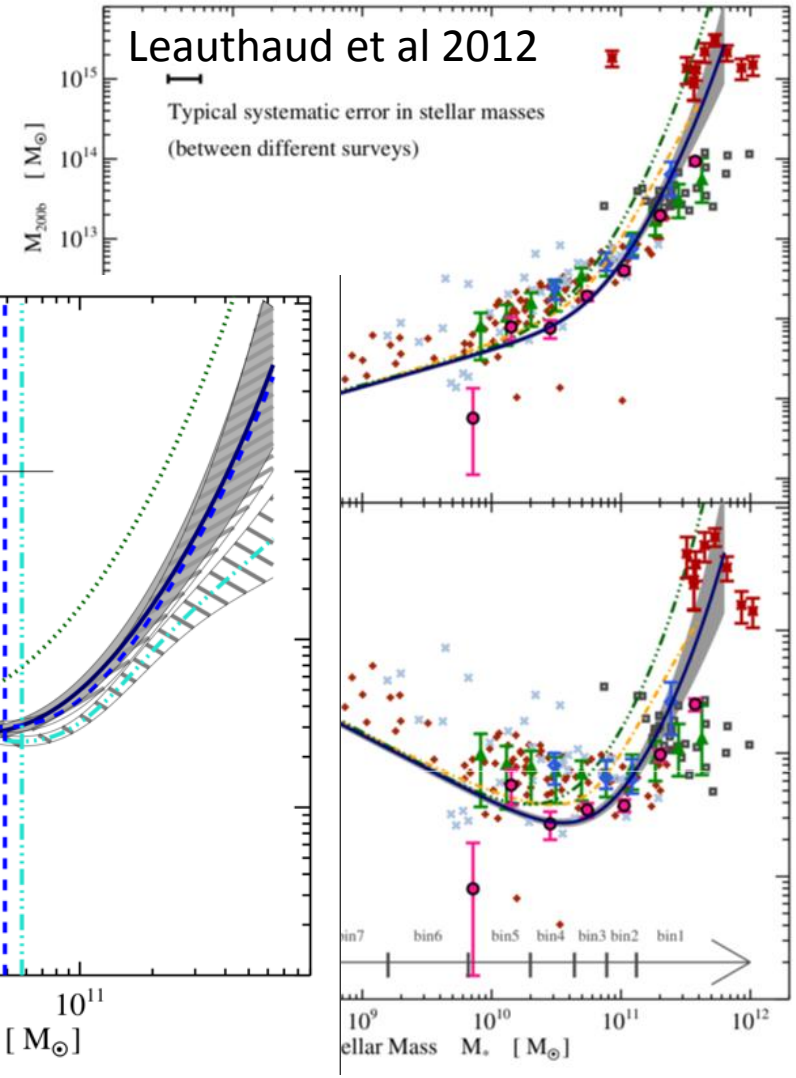


CFHTLenS: Velander et al. 2012

What lensing is teaching us about galaxy formation?







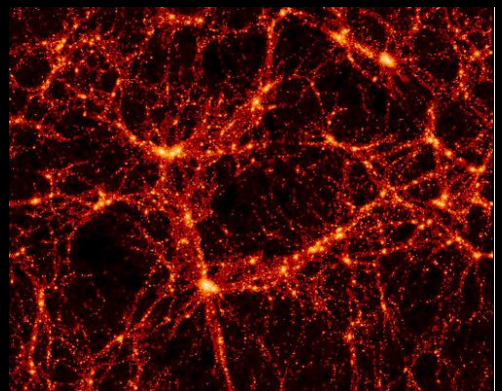
Also indicative of the satellite fraction per type, redshift, mass range.

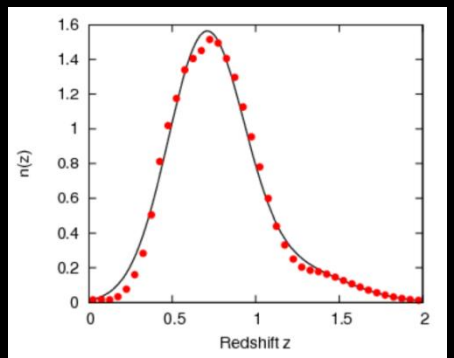
Cosmic Shear two-points Statistics and mass Power Spectrum

Shear correlation function at separation Θ:

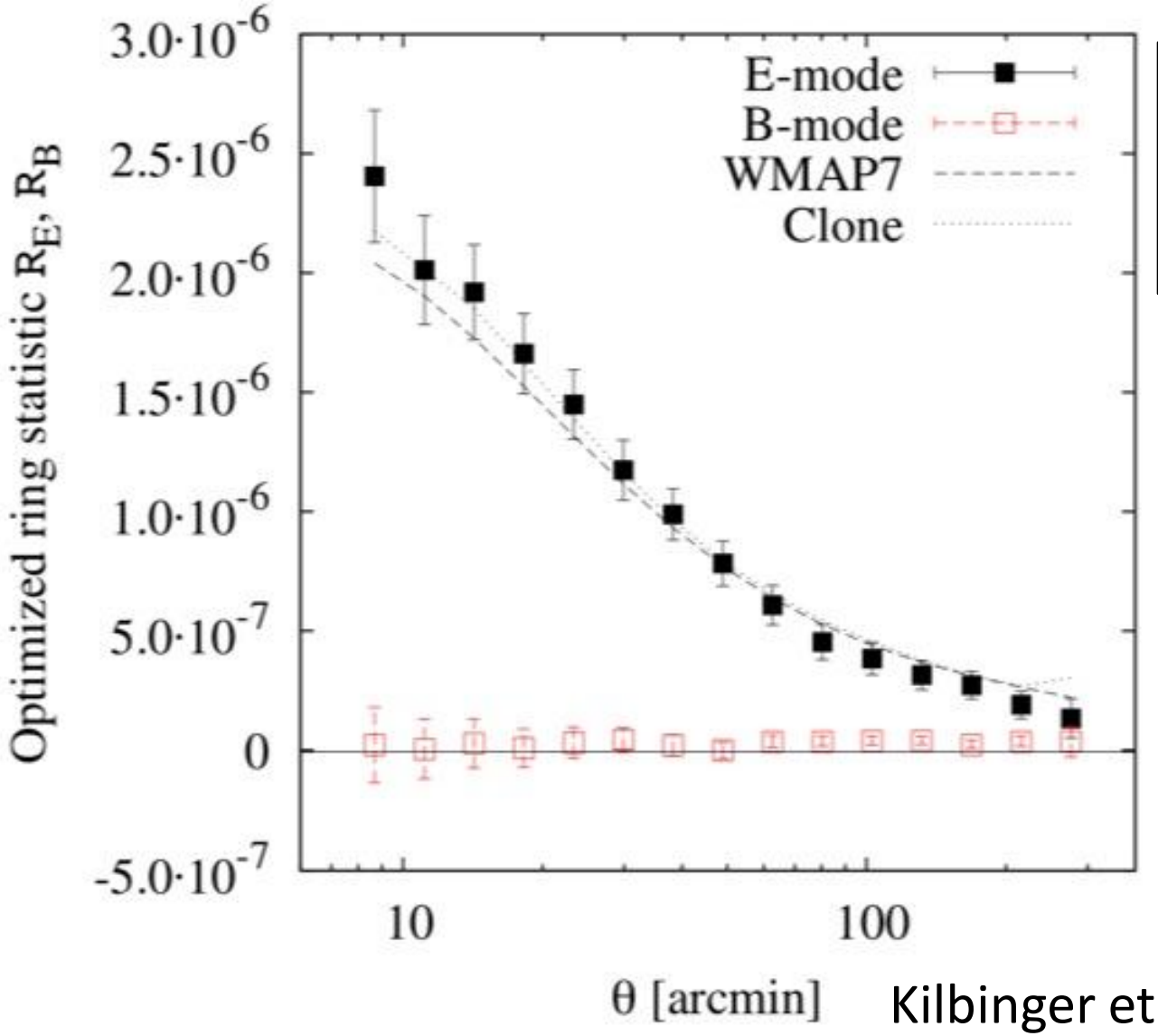
$$\langle \gamma(r)\gamma(r+\theta)\rangle_r = \frac{1}{2\pi}\int_0^\infty dk\, k\, P_\kappa(k)\, J_0(k\theta)$$

$$P_\kappa(k) = \frac{9}{4}\Omega_0^{\,2}\int_0^\infty dz\, P_{3D}\left(\frac{k}{D_L(z)}; z\right) F[z, z_{source}]^2$$





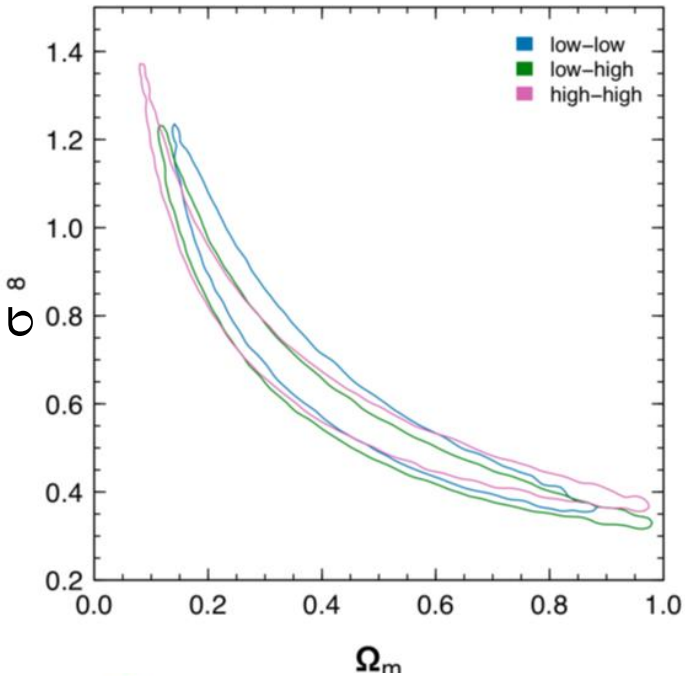
CFHTLenS: shear correlation function and systematics tests



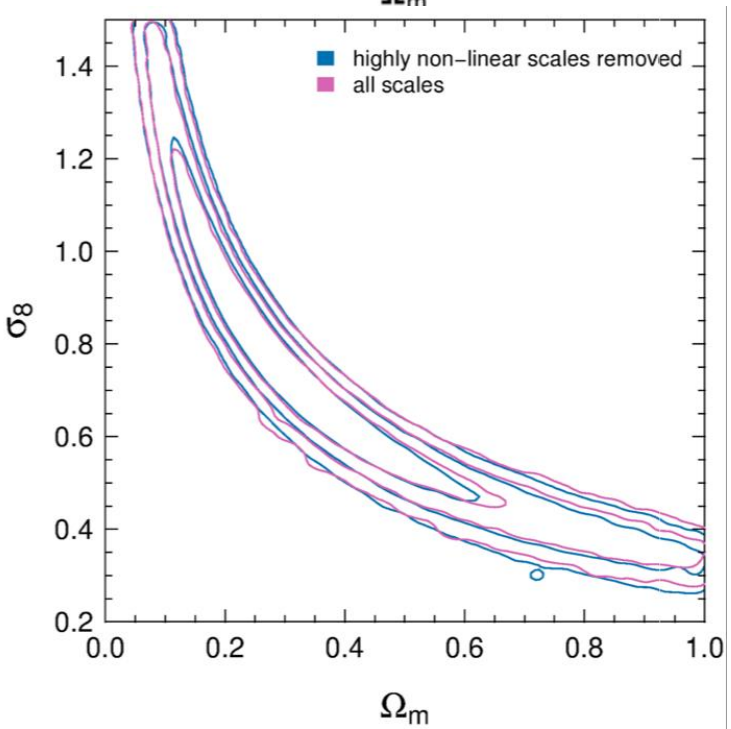
P(k) analysis underway

Cosmological parameters Analysis done

Kilbinger et al 2012



Different source redshifts
Give consistent results



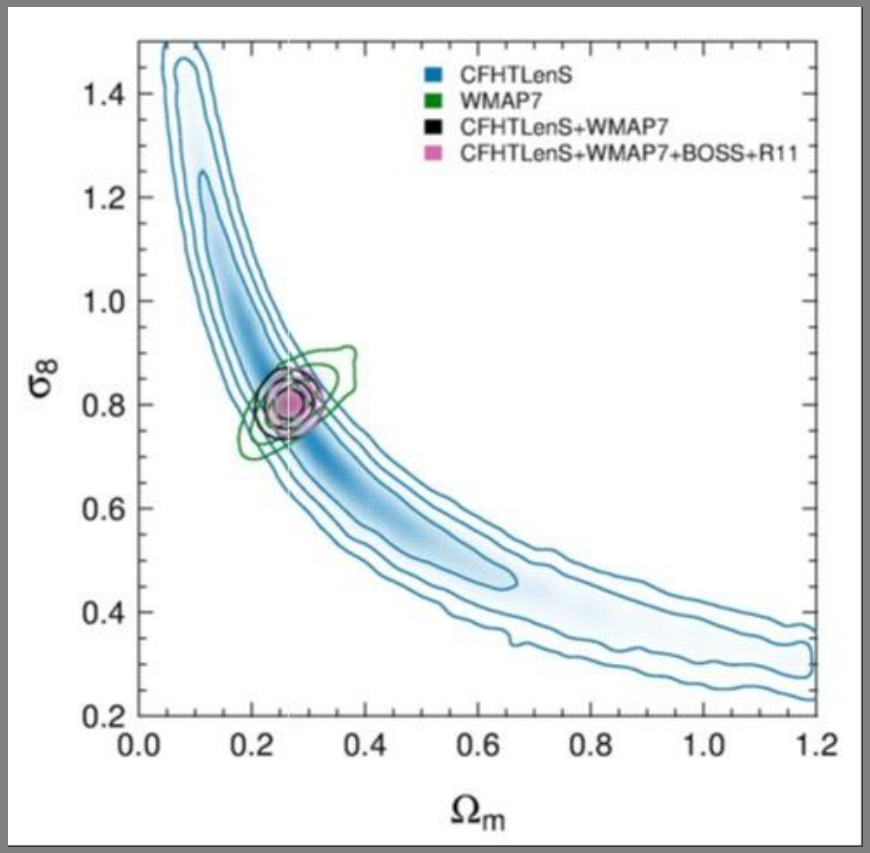
Non-linear clustering
Give consistent results

Benjamin et al. 2012

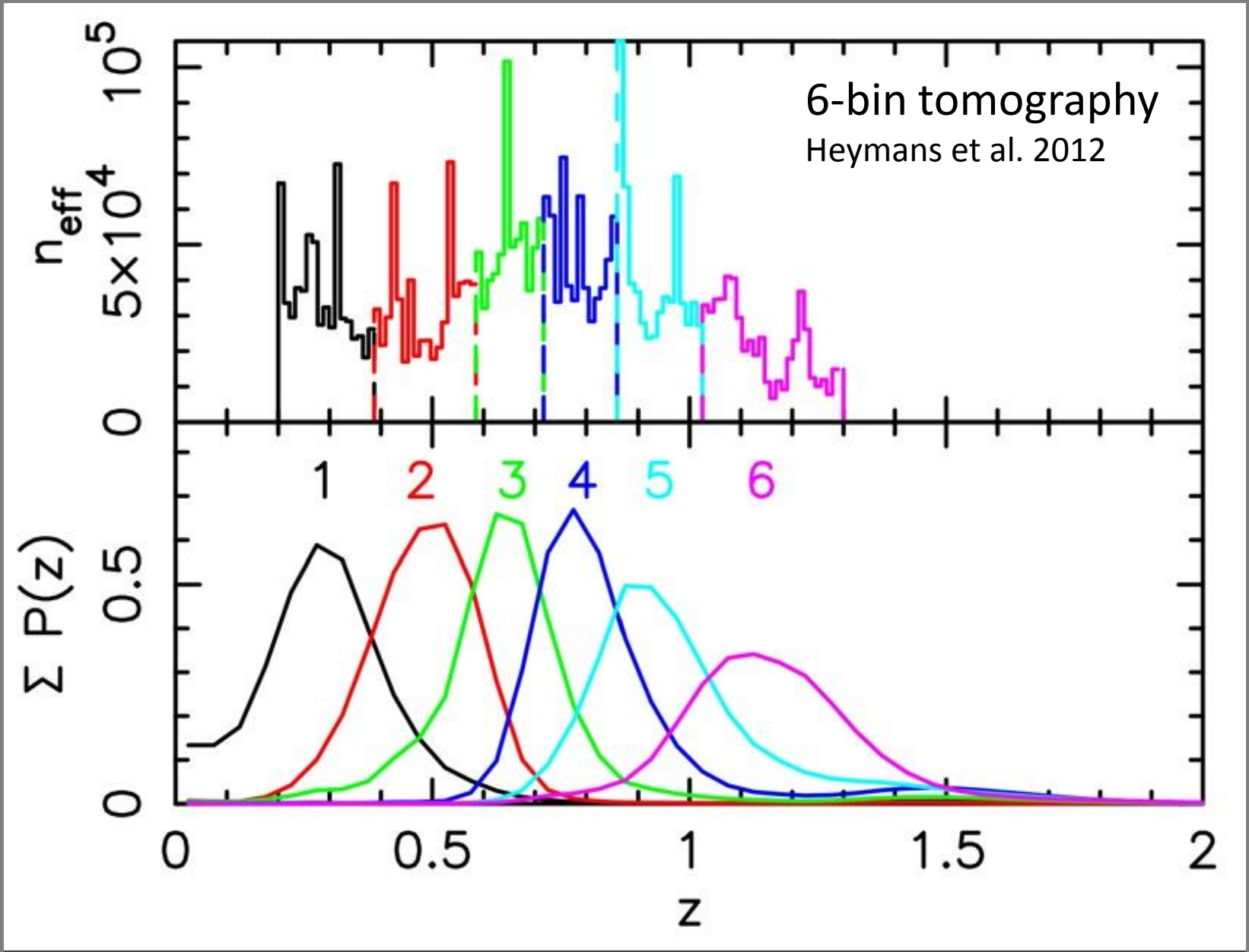
Table 3. Parameter constraints with 68.3 per cent confidence limits. The following parameters are deduced for CFHTLenS: Ω_K and q_0. When combining data sets are the deduced parameters are: σ_8, Ω_Λ, and q_0. The label CFHTLenS+Others refers to the combination of CFHTLenS, WMAP7, BOSS, and R11.

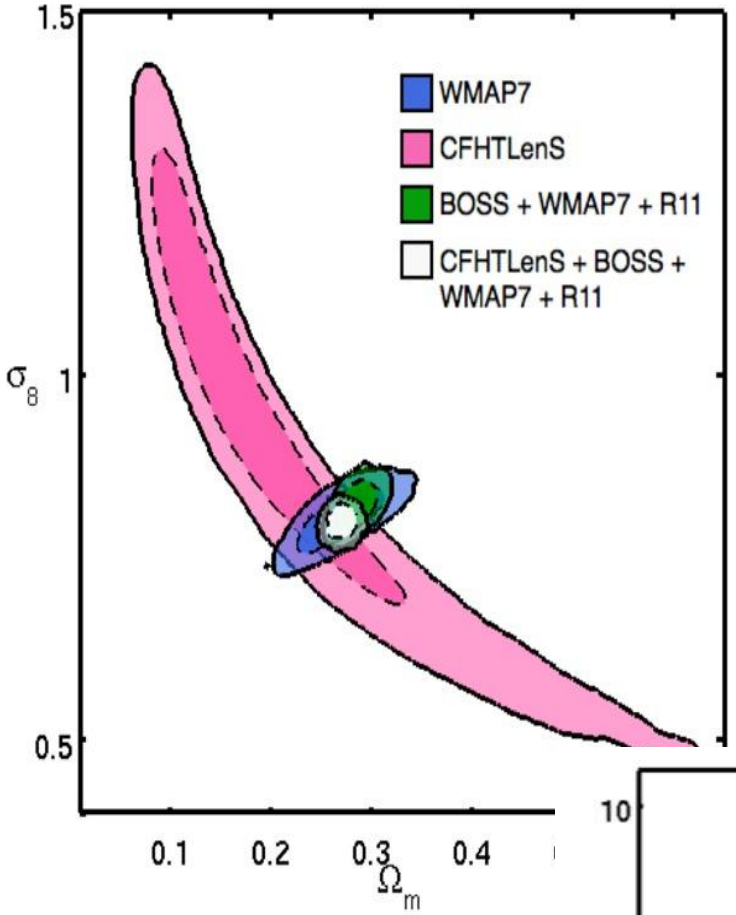
Parameter	flat ΛCDM	curved ΛCDM	Data
Ω_m	0.27 ± 0.17	0.28 ± 0.17	CFHTLenS
	0.288 ± 0.010	0.285 ± 0.014	WMAP7+BOSS+R11
	0.2762 ± 0.0074	0.2736 ± 0.0085	CFHTLenS+Others
σ_8	0.67 ± 0.23	0.69 ± 0.29	CFHTLenS
	0.828 ± 0.023	0.819 ± 0.036	WMAP7+BOSS+R11
	0.802 ± 0.013	0.795 ± 0.013	CFHTLenS+Others
Ω_Λ	$1 - \Omega_m$	0.38 ± 0.36	CFHTLenS
	$1 - \Omega_m$	0.717 ± 0.019	WMAP7+BOSS+R11
	$1 - \Omega_m$	0.7312 ± 0.0094	CFHTLenS+Others
Ω_K	0	0.19 ± 0.43	CFHTLenS
	0	-0.0020 ± 0.0061	WMAP7+BOSS+R11
	0	-0.0042 ± 0.0040	CFHTLenS+Others
h	0.84 ± 0.25	0.81 ± 0.24	CFHTLenS
	0.692 ± 0.0088	0.694 ± 0.012	WMAP7+BOSS+R11
	0.6971 ± 0.0081	0.693 ± 0.011	CFHTLenS+Others
Ω_b	0.030 ± 0.029	0.031 ± 0.030	CFHTLenS
	0.0471 ± 0.0012	0.0472 ± 0.0016	WMAP7+BOSS+R11
	0.04595 ± 0.00086	0.0470 ± 0.0015	CFHTLenS+Others
q_0	-0.57 ± 0.27	-0.29 ± 0.40	CFHTLenS
	-0.568 ± 0.016	-0.574 ± 0.025	WMAP7+BOSS+R11
	-0.585 ± 0.011	-0.594 ± 0.014	CFHTLenS+Others
n_s	0.93 ± 0.17	0.91 ± 0.17	CFHTLenS
	0.965 ± 0.012	0.969 ± 0.014	WMAP7+BOSS+R11
	0.960 ± 0.011	0.972 ± 0.012	CFHTLenS+Others
τ	0.086 ± 0.014	0.086 ± 0.015	WMAP7+BOSS+R11
	0.081 ± 0.013	0.085 ± 0.015	CFHTLenS+Others
$\Delta^2_{\mathcal{R}}$	2.465 ± 0.086	2.45 ± 0.13	WMAP7+BOSS+R11
	2.429 ± 0.081	2.361 ± 0.094	CFHTLenS+Others
A_{SZ}	0.97 ± 0.62	1.35 ± 0.61	WMAP7+BOSS+R11
	1.33 ± 0.60	1.39 ± 0.57	CFHTLenS+Others

Marginal tension between CFHTLenS and WMAP/BAO that could be indicative of massive neutrinos.
Similar to SDSS (Mandelbaum et al 2012)



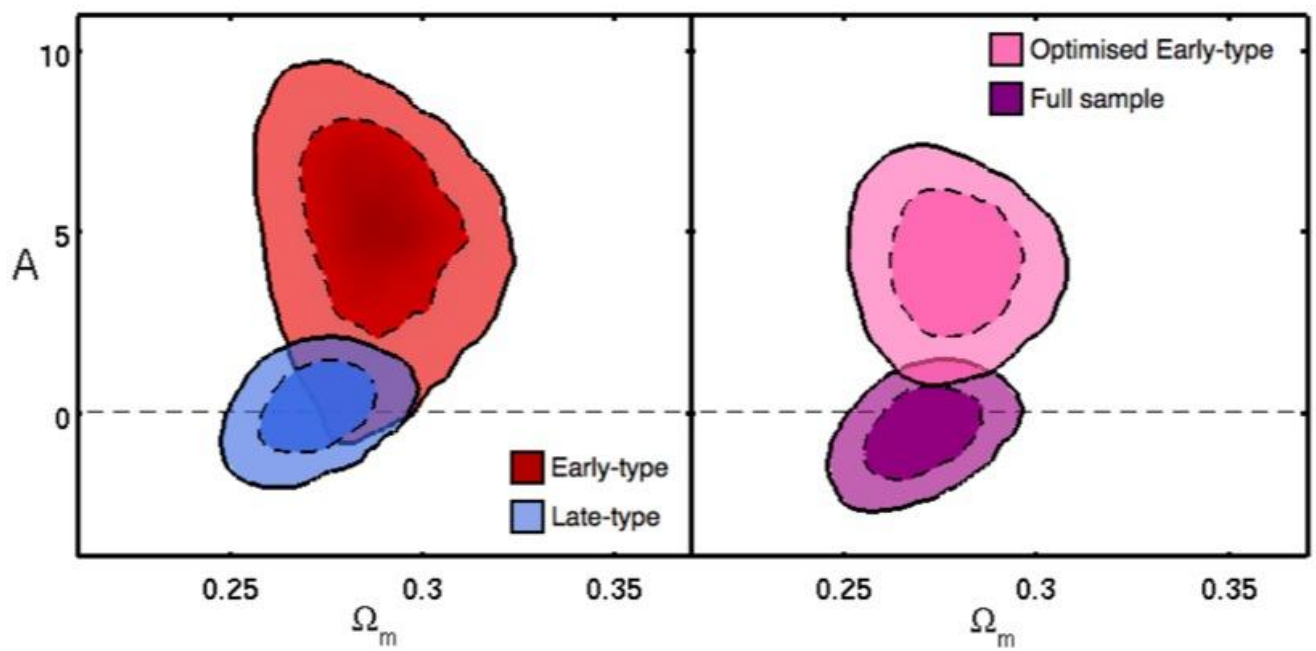
CFHTLenS: weak lensing and intrinsic alignment





Cosmology and intrinsic alignment can be Simultaneously fitted.

An intrinsic alignment model is necessary: At least one parameter (A) needed (Bridle et al 2011)



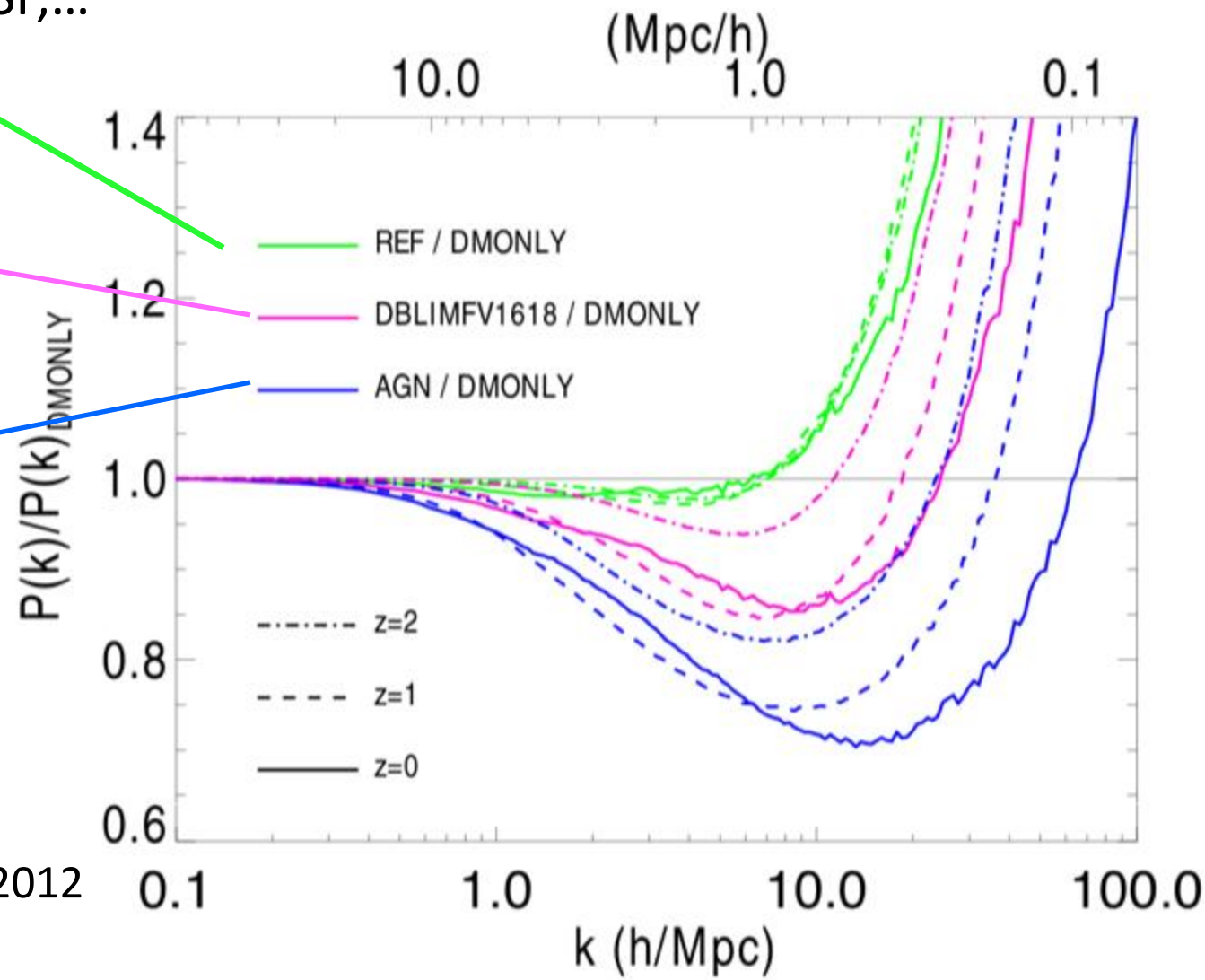
Heymans et al. 2012

Effect of baryonic physics on the mass power spectrum compared to the Dark Matter Only Power spectrum

SN winds, cooling, SF,…
No AGN feedback

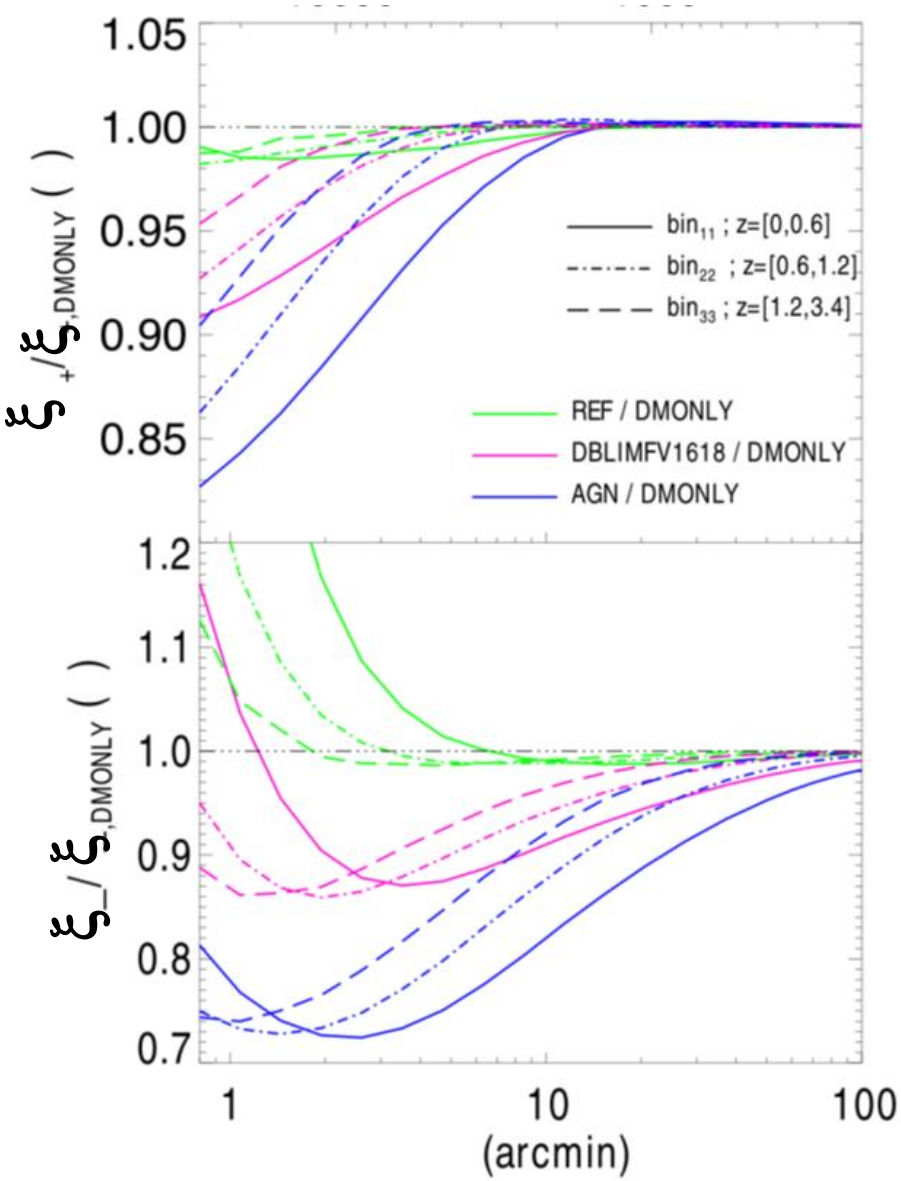
Top heavy IMF

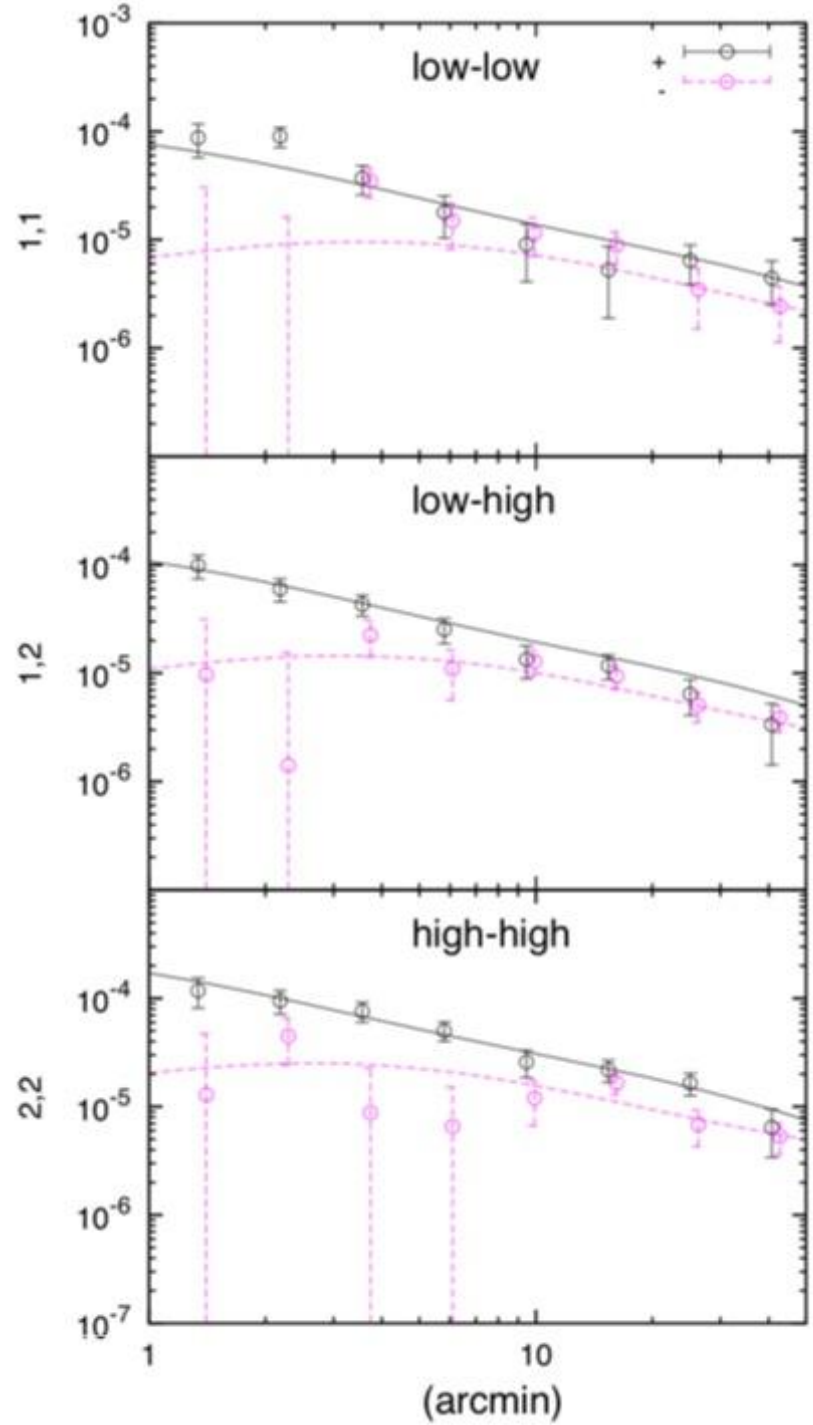
All (Booth & Shaye 2009)



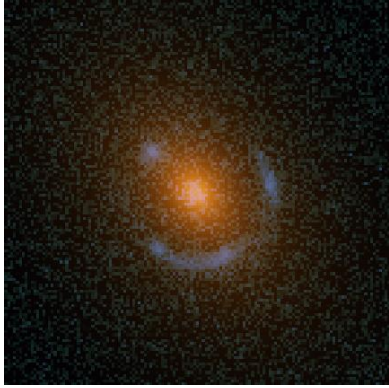
Van Daalen et al, 2011
Semboloni et al, 2011,2012

Impact on the weak lensing





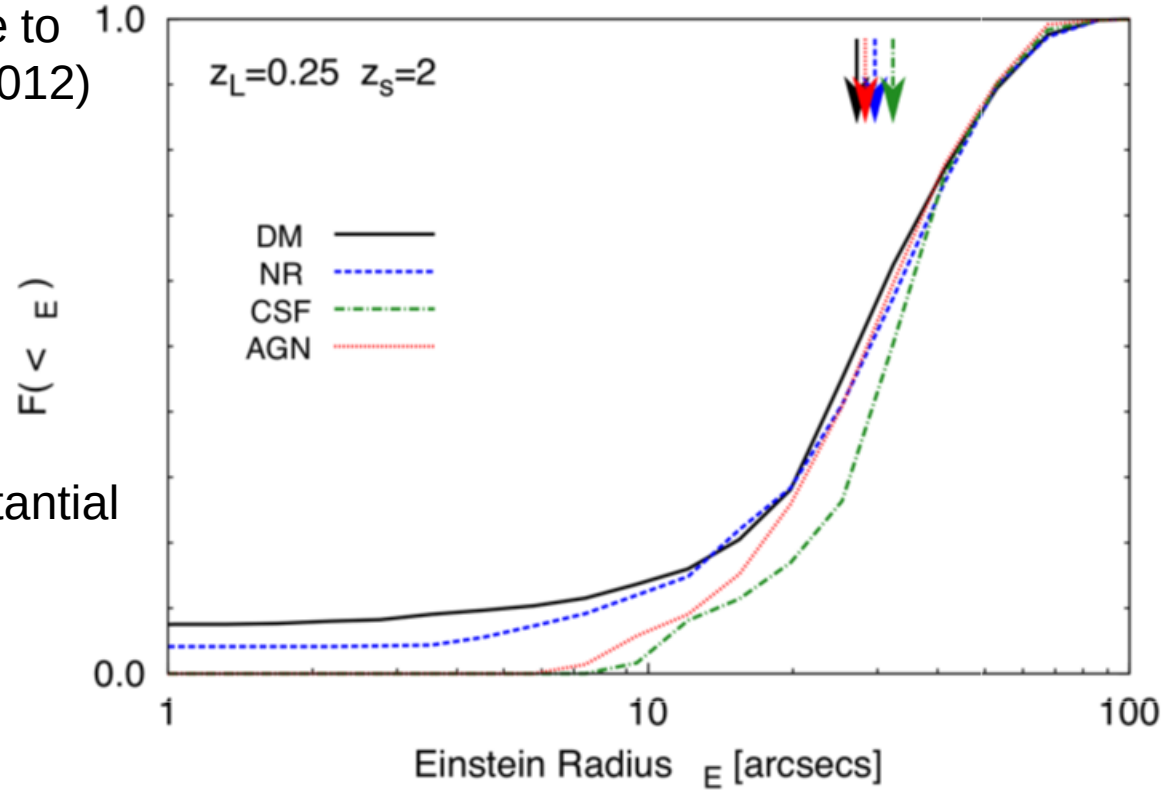
Strong lensing and baryons



Wiesner et al 2012: SDSS cluster strong lensing suggest some clusters appear over Concentrated than predicted for a LCDM model.

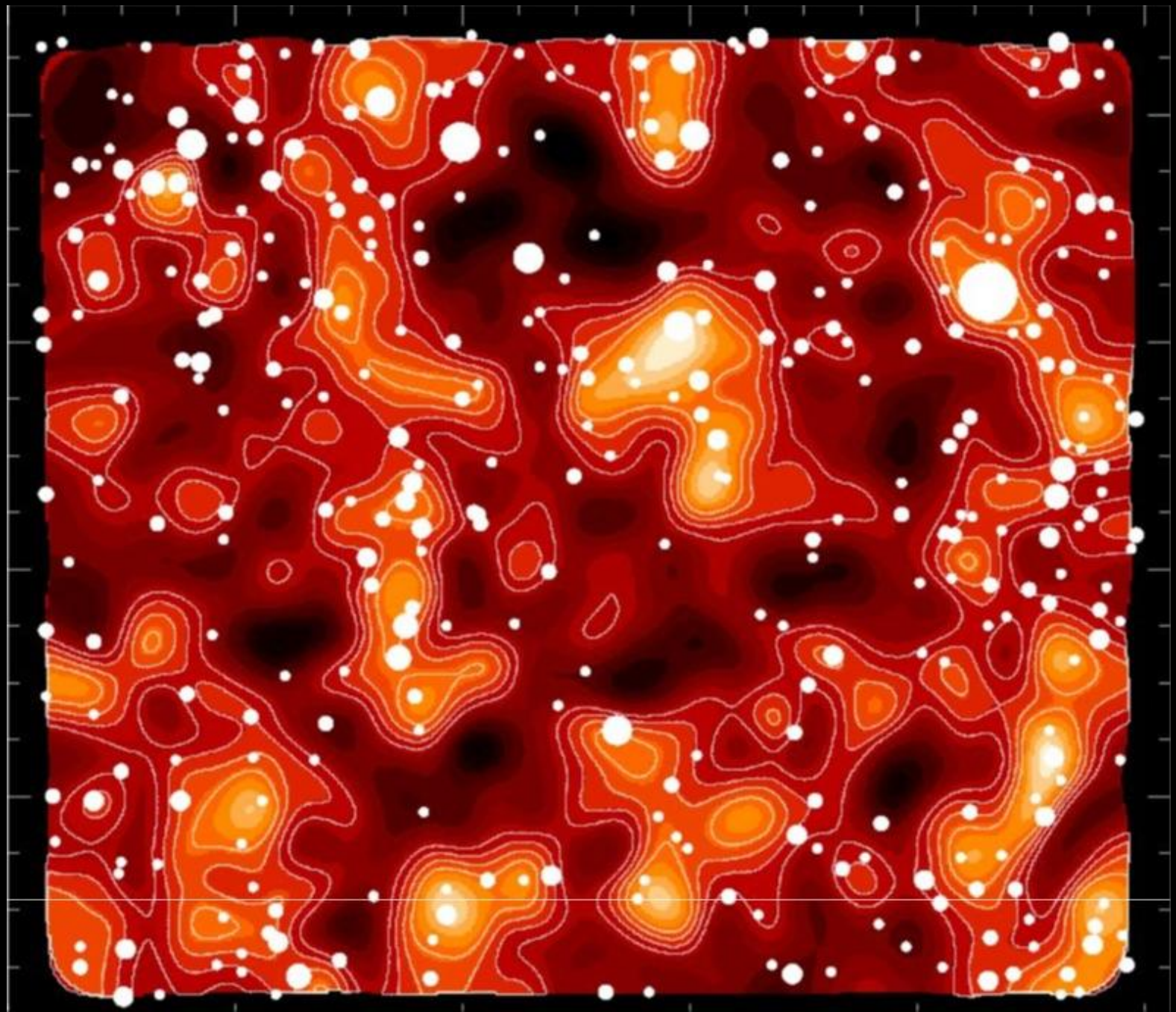
Zitrin et al 2012: statistical analysis of 10000 SDSS clusters show more of the large Einstein radii than predicted by LCDM.

The Einstein radius very sensitive to baryonic physics (Killedar et al. 2012)

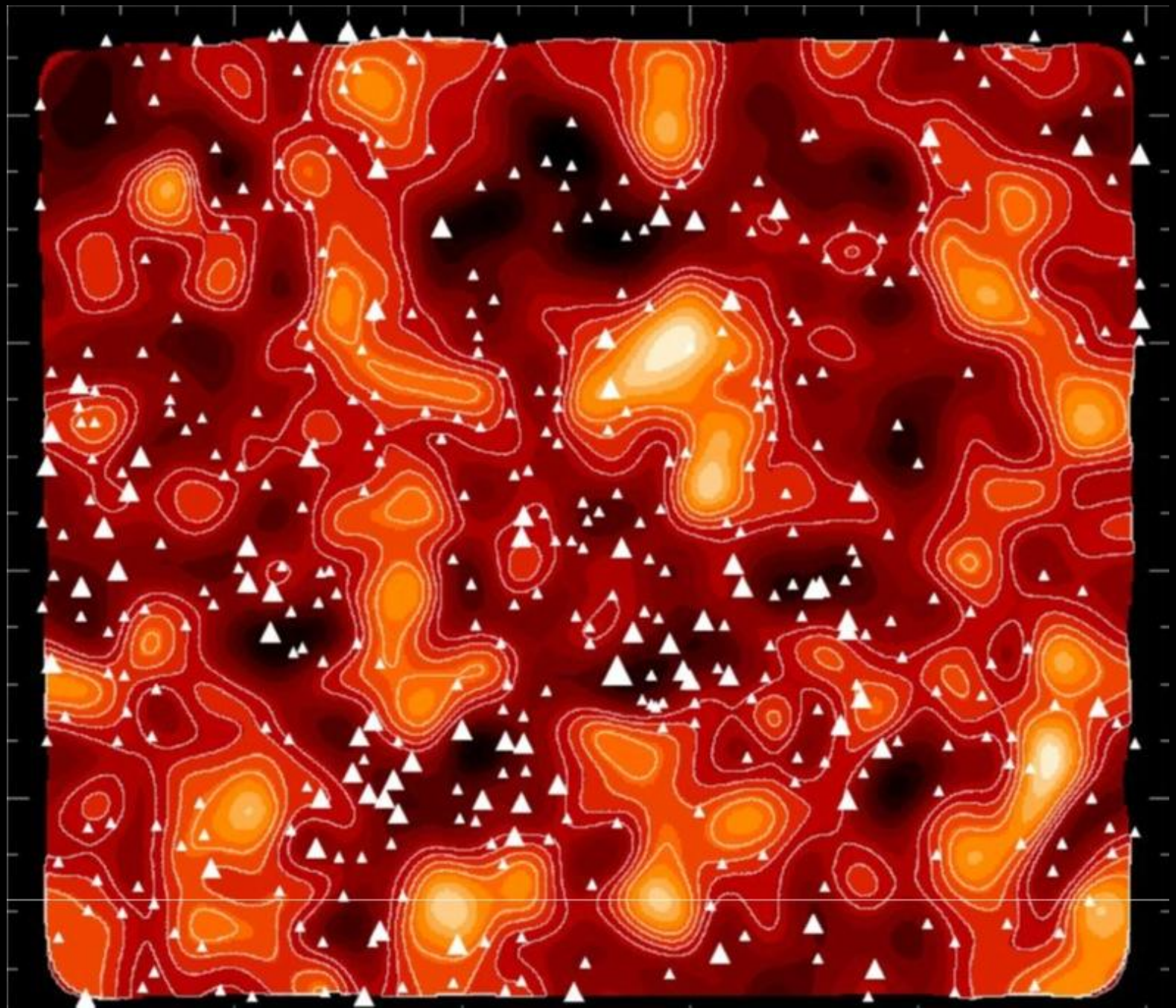


Mandelbaum et al. 2009:
SL selection biases can be substantial

CFHTLenS: mass map and baryon distribution (Van Waerbeke et al 2012)



CFHTLenS: mass map and voids (Van Waerbeke et al 2012)



CFHTLenS proved that lensing can be done at the 1% shape accuracy

Future surveys (Euclid, LSST) will need a factor 10 improvement in order to measure dark energy and map dark matter and not be limited by systematics.

Stage III surveys are in between (DES, KiDS, HSC(?))

What are the upcoming challenges?

great3challenge.info/

Challenge #1: galaxy shape measurement

GREAT3

The third GRavitational lEnsing Accuracy Testing challenge

Home | Details | Timeline | GalSim | Links | Working Meeting Oct12 | Contacts

This work is supported in part by the IST Programme of the European Community, under the PASCAL2 Network of Excellence, IST-2007-216886. This website only reflects the authors' views.

PASCAL2 Pattern Analysis, Statistical Modelling and Computational Learning

The third GRavitational lEnsing Accuracy Testing challenge, or ***GREAT3***, is a blind data challenge held by the world-wide weak lensing community to test weak lensing measurement algorithms.

With several major astronomical surveys beginning to make large-scale cosmological weak lensing measurements in 2013 in order to better understand our cosmological model (including the mysterious dark matter and dark energy), this challenge will play an important role in identifying promising measurement algorithms and quantifying their performance.

The challenge itself will occur in 2013, with preparations actively underway now. For more information about the challenge under development, see the links above.

This work is supported in part by NASA via the Strategic University Research Partnership (SURP) Program of the Jet Propulsion Laboratory, California Institute of Technology.

NASA

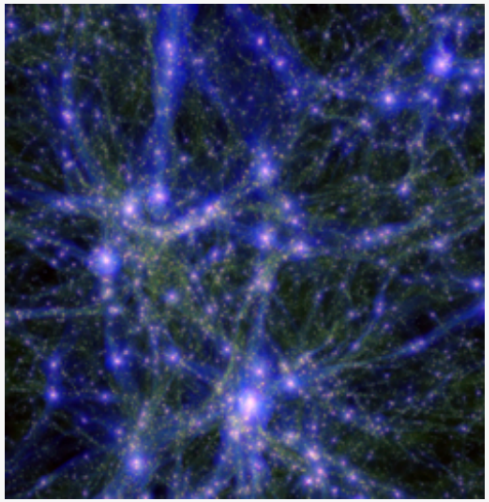
Challenge #2: signal interpretation

The Horizon Project

by Legrand François (Sunday 17 February 2008)

Scientific Highlights:

- the Horizon simulation performed at CCRT (CEA)
- the MareNostrum simulation performed at BSC (Spain)
- the GALMER database is now online.



Composite image of MareNostrum
red: dark matter gree: gas density blue: temperature. also available at full res here and in false colour

The objective of the HORIZON Project is to federate numerical simulations activities with a program focussed on Galaxy and Large Scale Structure Formation. In a context favorable to HPC (High Performance Computing), the PNC (Programme National Cosmologie), the PNG (Programme National Galaxies) and the PAP (Programme AstroParticule), express their needs to stimulate and coordinate individual efforts in HPC among each domain.

The HORIZON Project was build on several research teams in different institutes. The scientific objective is specifically oriented towards studying galaxy formation in a cosmological framework. Its transverse and federative nature will however allow to develop in a few years high-level expertise in parallel and distributed (GRID) computing, in database management and virtual observations, in

News

- **Dark Energy Universe Simulation Series (DEUSS) down to z=0.**

We have completed a series of nine billion-particle simulations for three different dark energy cosmologies. It resolve scale from 4 kpc to 4 Gpc and halo masses from 3.10^10 Msun to 8.10^15 Msun. More info is given here.

DEUSS

- **CINES received a 150 TFlops machine**

GENCI has acquired for the French University Supercomputing Center a 12288 core SGI Altix. It is ranked 14th in the World and first in France.

Site Web du CINES

Challenge #3: photometric redshifts

iPad 9:58 PM 86 %

dame.dsf.unina.it/dame_photoz.html

DAta Mining & Exploration

DA ME

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- PHAT Experiment
- SDSS Experiment
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- Science Publications
- Who is who in DAME

News:

Photometric redshift Estimation

Photometric redshift estimation is a method to evaluate object distances when spectroscopic estimates become impossible due either to poor signal-to-noise ratio, to instrumental systematics, or to the fact that the objects under study are beyond the spectroscopic limit.

Given the high complexity of the photo-z approach and the multiple factors that influence the results, it is reasonable to test the photo-z codes on real photometric data of objects that have also been observed spectroscopically for precise redshift measurements. The following described experiments have been approached by DAME Team with Machine Learning methods, revealing high quality performance and robustness.

PHAT (PHoto-z Accuracy Testing)

The PHAT (**Hildebrandt et al. 2010**) consists of a competition engaged by involving several worldwide groups with the aim at evaluate different (theoretical/empirical) methods to extract photo-z from an ensemble of ground-based and space observation catalogues in several bands, composed to

Drawing of a full cube

Leonardo da Vinci

De Divina Proportione, Luca Pacioli, Milan, 1497

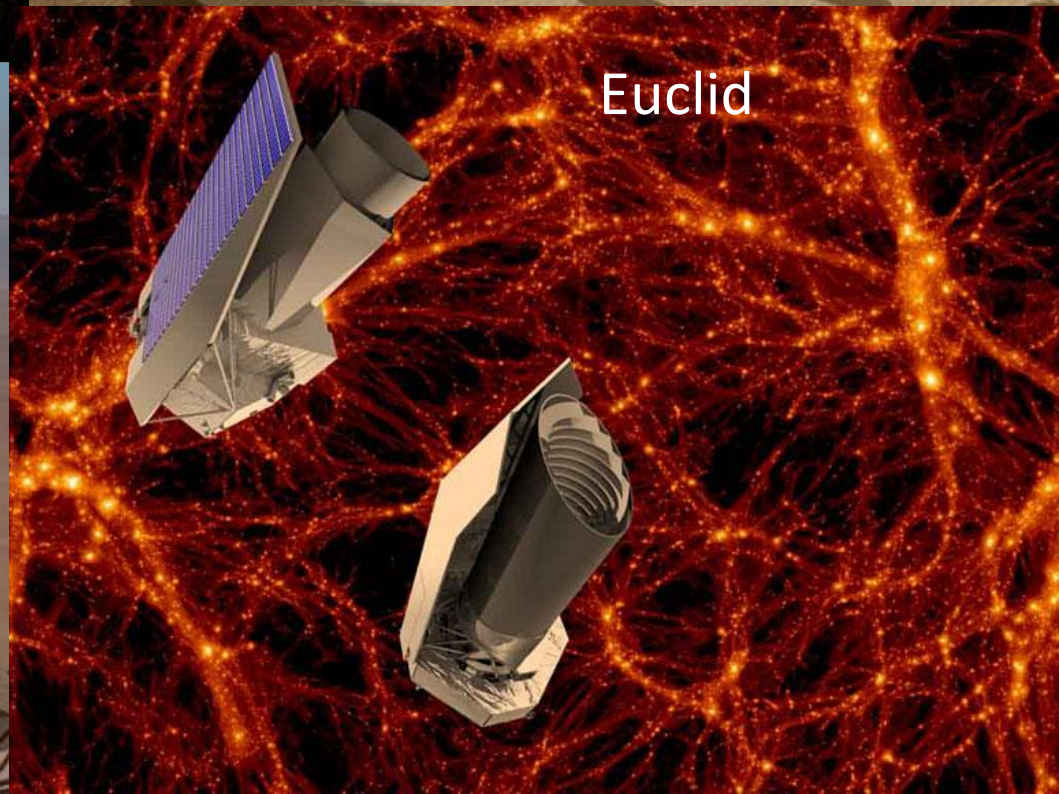
Challenge #4: be imaginative and creative

Challenge #5: work together in peace!


Large synoptic survey telescope


SKA


TMT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