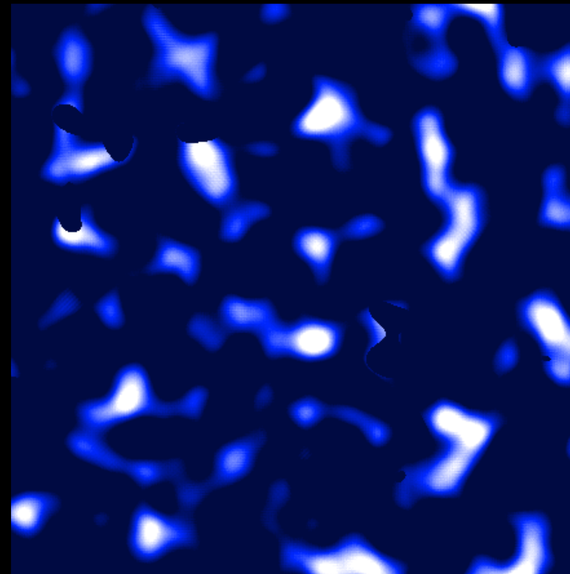
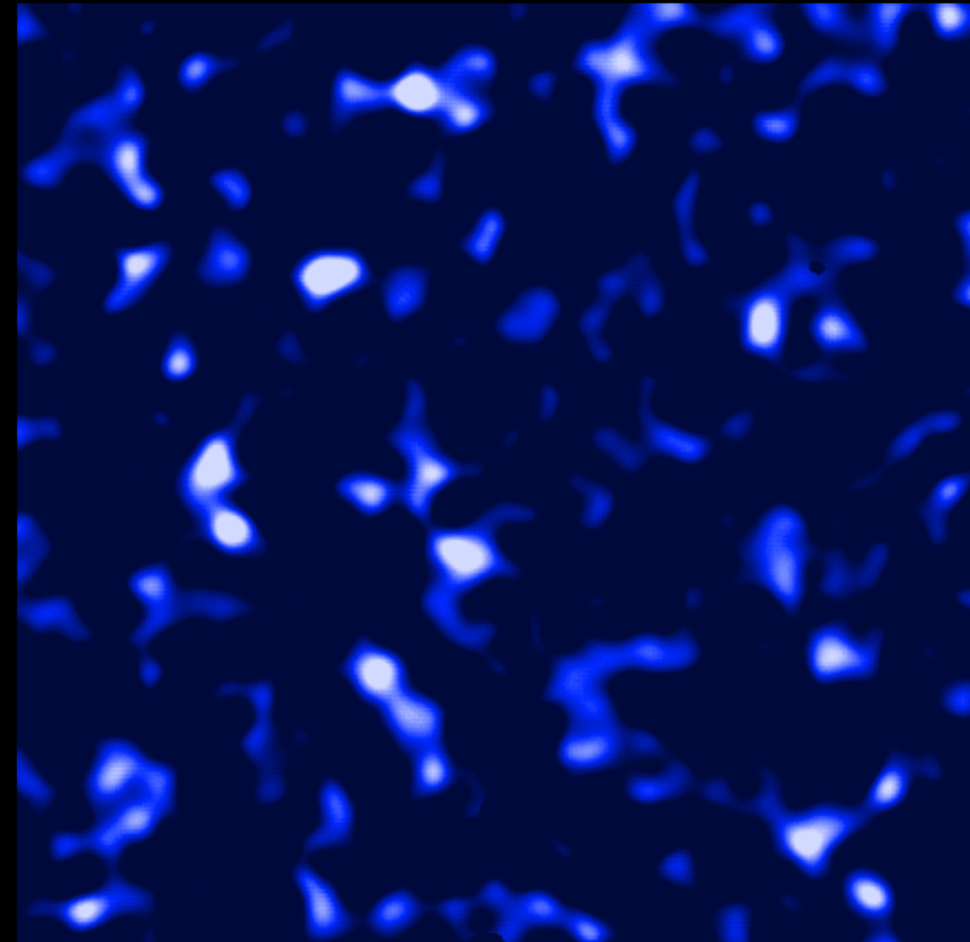
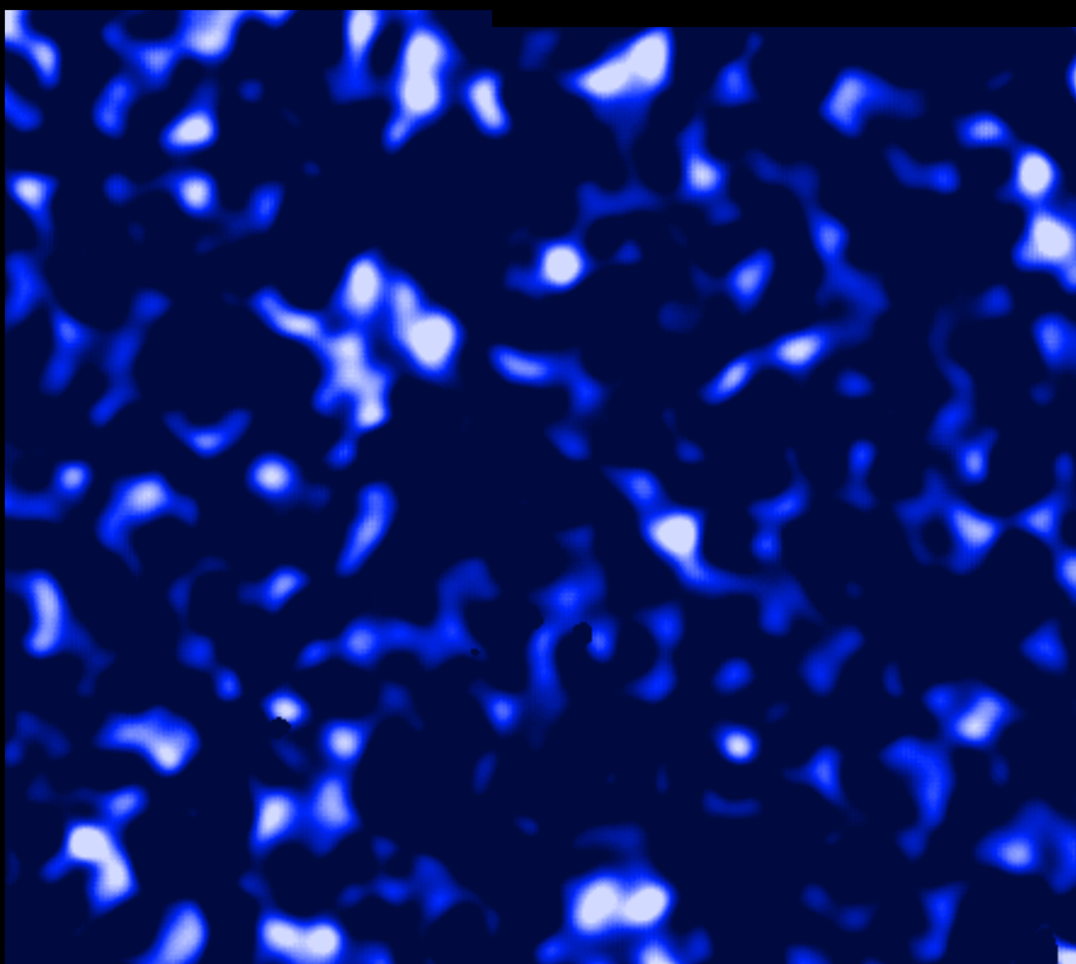
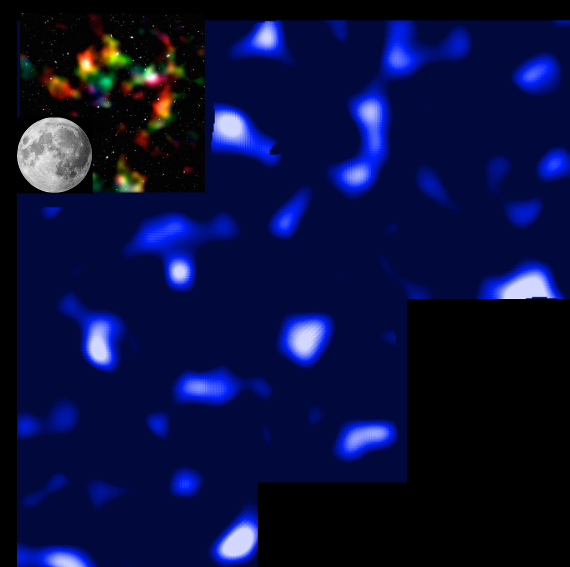
Testing the laws of gravity with the Canada-France Hawaii Telescope Lensing Survey







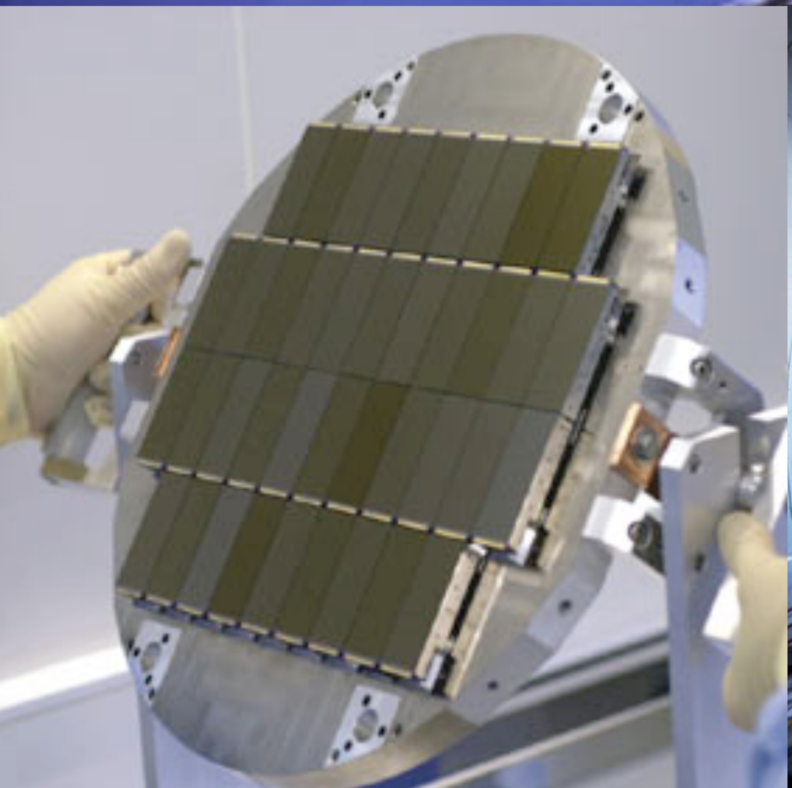


Catherine Heymans

Institute for Astronomy, University of Edinburgh

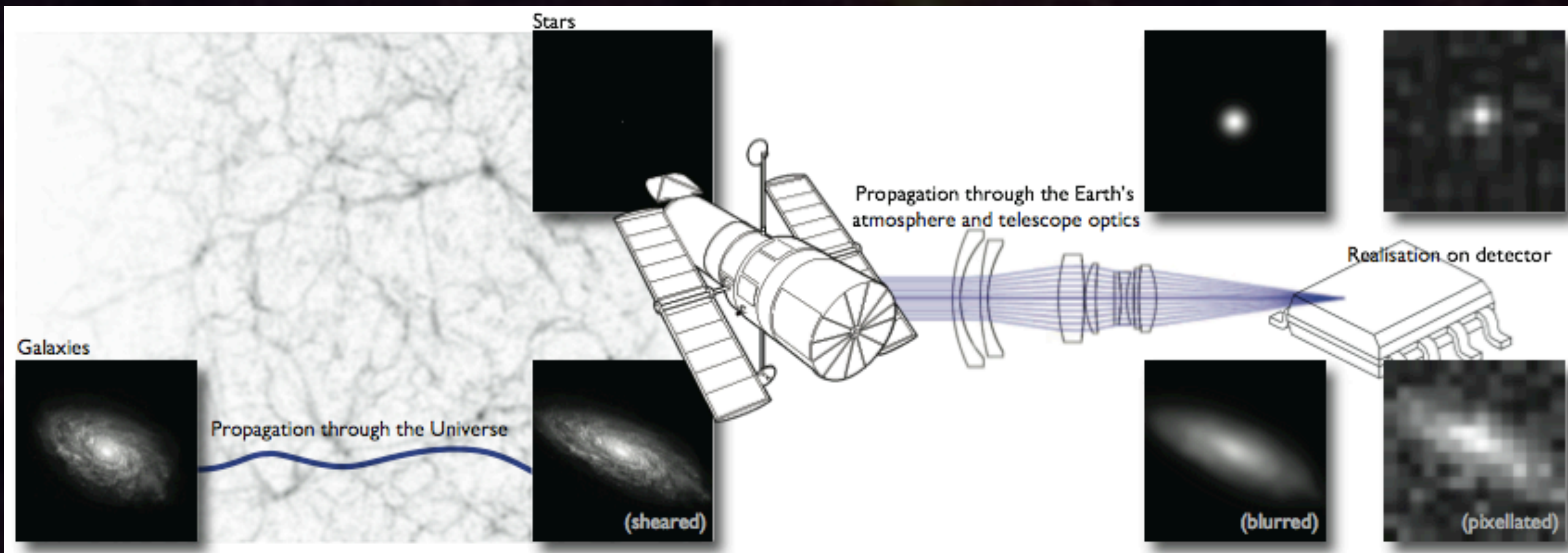
CFHTLenS

- 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



Dark Matter changes the shapes of galaxies by ~1%

Telescopes and the Atmosphere change the shapes of galaxies by ~15%



Kitching et al 2010

We need to understand our instrumentation to a higher precision than ever before

The CFHT Lensing Survey

UBC	Edinburgh	Bonn	Leiden
L. Van Waerbeke (PI)	**C. Heymans (PI)**	T. Erben	H. Hoekstra
J. Benjamin	T. Kitching	P. Simon	K. Kuijken
H.Hildebrandt	E. Grocutt	T. Schrabback	E. Semboloni
M. Milkeraitis	A. Heavens	K. Holhjem	E. van Uitert
S.Vafaei	F. Simpson		M. Smit
Oxford	**IAP**	**Munich**	**Waterloo**
L. Miller	Y. Mellier	M. Kilbinger	M Hudson
M.Velander	R. Gavazzi		B. Gillis
CSIC/IEEC	**Shanghai**	**Tohoku**	**UCL/JPL**
C. Bonnett	L. Fu	J. Coupon	B. Rowe

Argelander-Institut für Astronomie

University of Waterloo

上海师范大学 Shanghai Normal University since 1954

TOHOKU UNIVERSITY

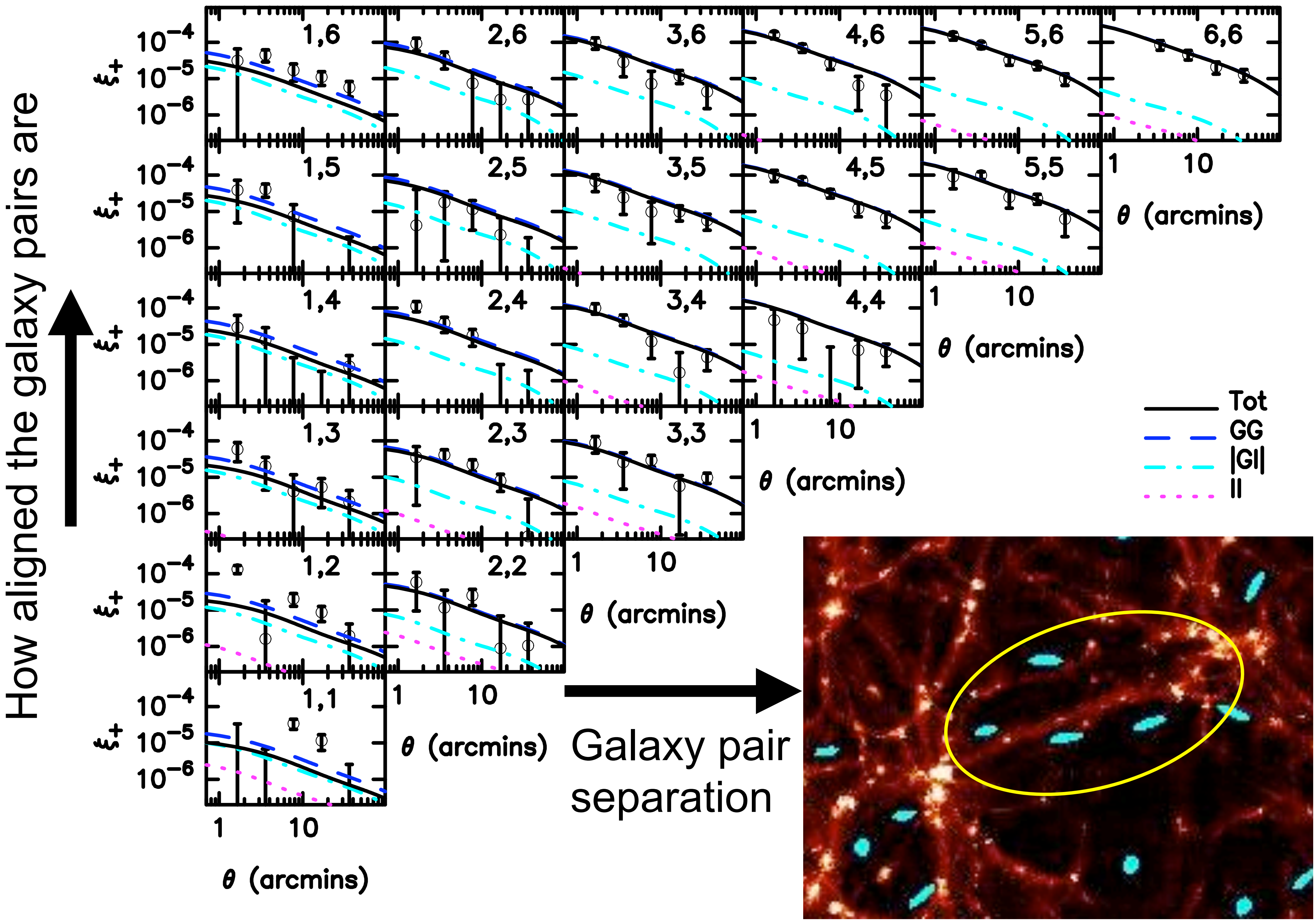
Universiteit Leiden

MegaPrime CFH MegaCam Legacy Survey CFHTLS

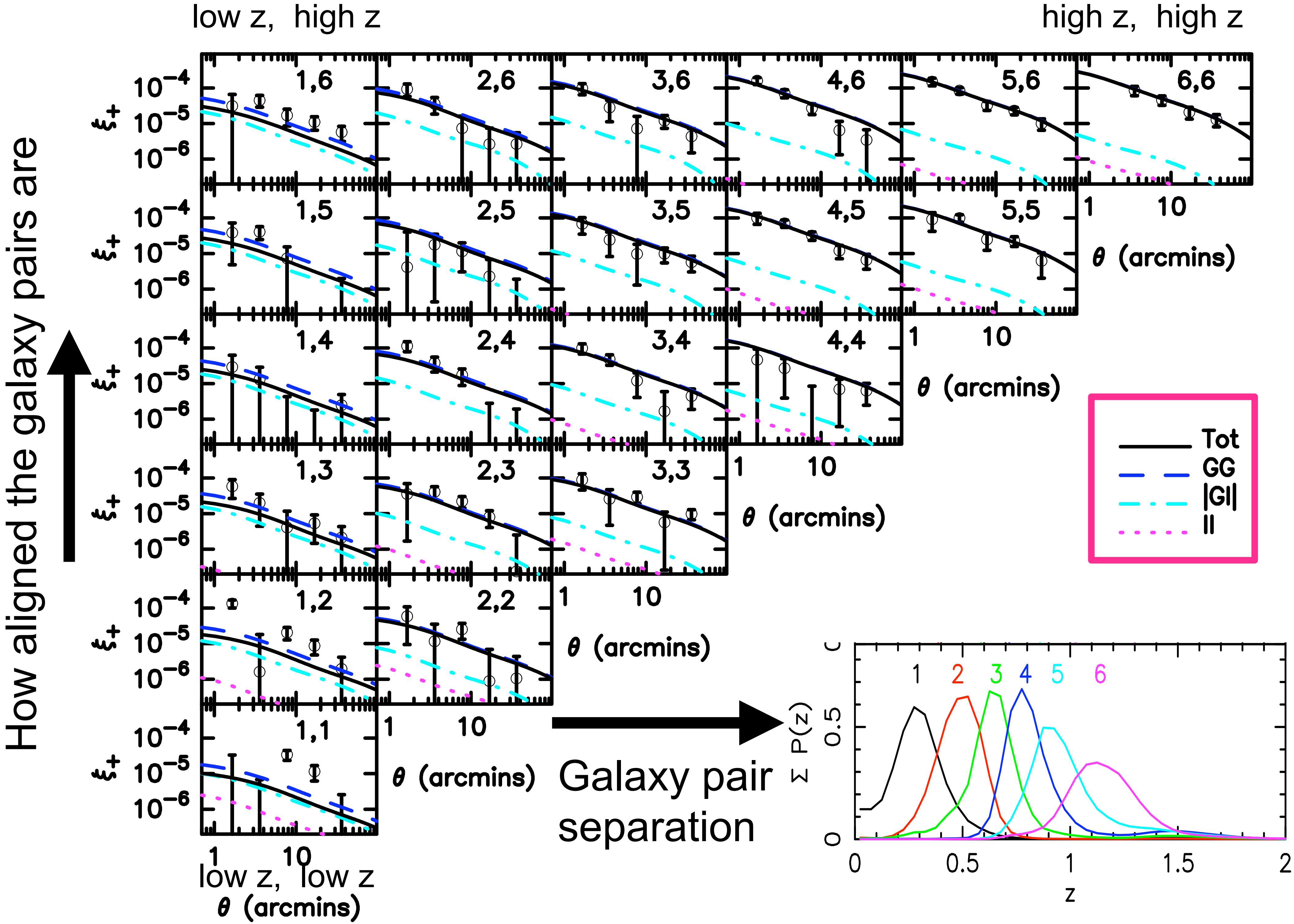
CFHTLenS Survey Statistics

- **High resolution**: 17 gals per sq arcmin
- **Deep imaging:** $z_m = 0.75$
- **Accurate redshifts:** $\sigma_z = 0.04(1+z)$ with 4% outliers
- **Accurate shear:** weak calibration corrections

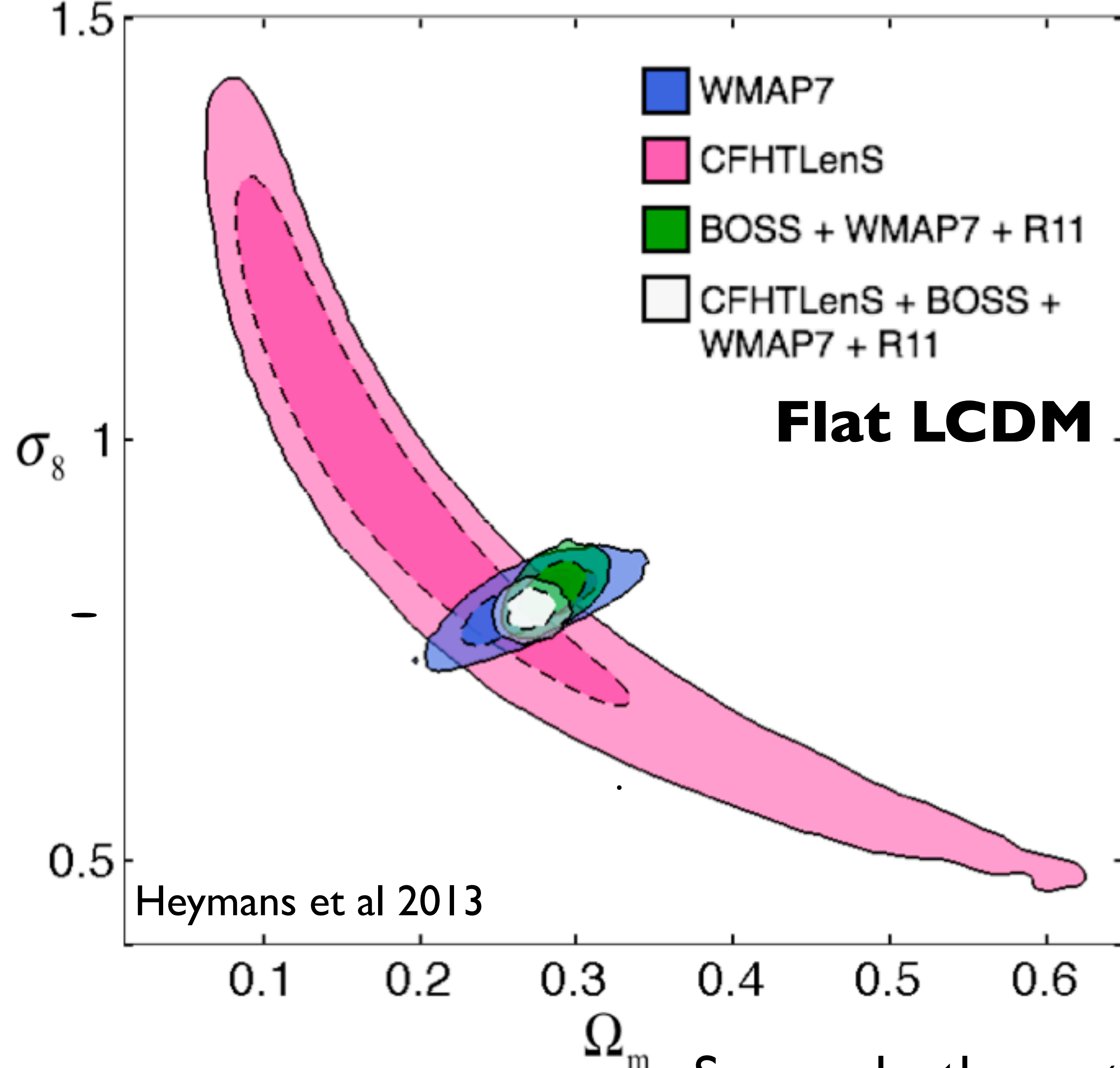
  <m> = - 0.06 <c> = 0.001
- **Robust to systematic errors:** 75% of the data used



How aligned the galaxy pairs are
1,6
2,6
3,6
4,6
5,6
6,6
1,5
2,5
3,5
4,5
5,5
1,4
2,4
3,4
4,4
1,3
2,3
3,3
1,2
2,2
1,1
ξ_+
10^{-4}
10^{-5}
10^{-6}
1
10
θ (arcmins)
Tot
GG
|GI|
II
Galaxy pair separation



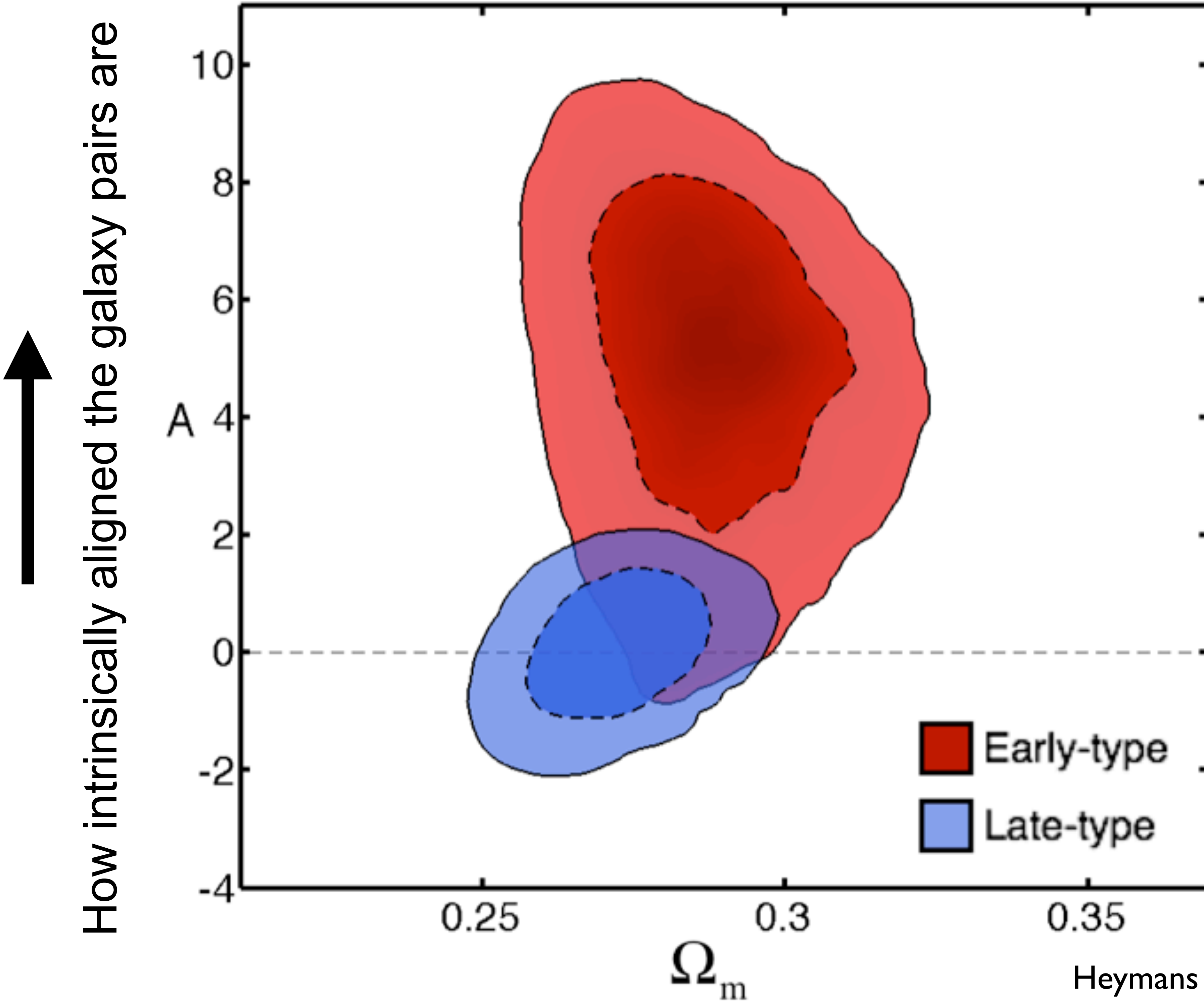
low z, high z
high z, high z
How aligned the galaxy pairs are
1,6
2,6
3,6
4,6
5,6
6,6
1,5
2,5
3,5
4,5
5,5
1,4
2,4
3,4
4,4
1,3
2,3
3,3
1,2
2,2
1,1
ξ+
10−4
10−5
10−6
1
10
θ (arcmins)
low z, low z
Tot
GG
|GI|
II
Galaxy pair separation
Σ P(z)
z
1
2
3
4
5
6
0
0.5
1
1.5
2



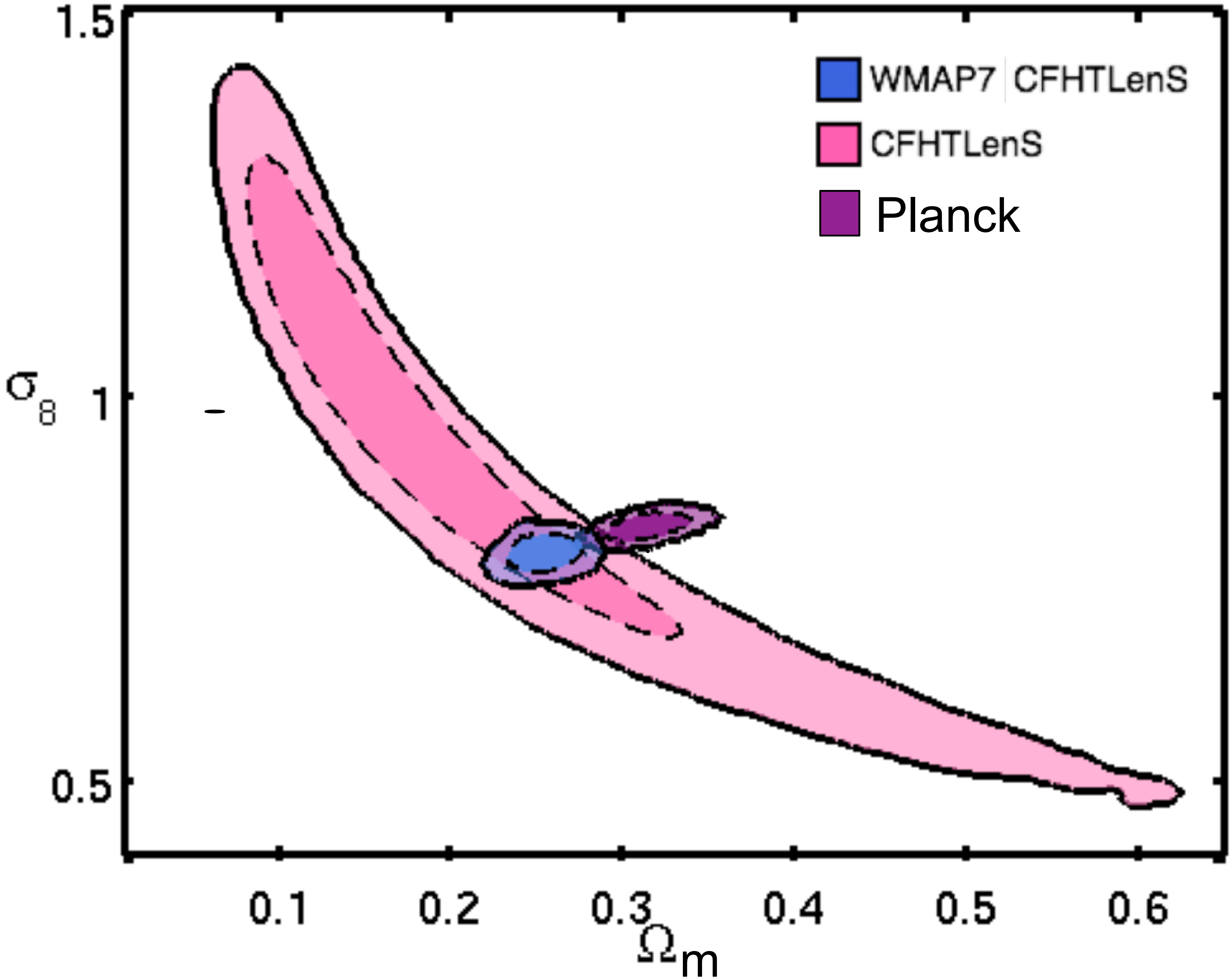
Non-linear PS (Ω_m Ω_Δ σ_8 w H_0 ..)

Survey depth

$$\xi_+^{ij}(\theta) = \int dk\, k\, J_0(k\theta) \int dw\, G_i(w)\, G_j(w)\, P_\delta\left(\frac{k}{f_k(w)}, w\right)$$



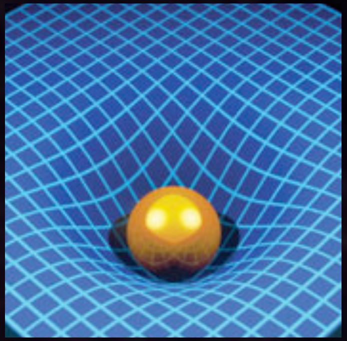
Heymans et al 2013



WMAP7 | CFHTLenS
CFHTLenS
Planck
1.5
1
0.5
σ8
0.1
0.2
0.3
0.4
0.5
0.6
Ωm

Beyond-Einstein gravity theories

$$ds^2 = (1 + 2\Psi)dt^2 + a^2(t)(1 + 2\Phi)dx^2$$



Dynamical Potential

Space Curvature Potential

Poissons Equation $\nabla^2\Phi = 4\pi G a^2 \bar{\rho}\delta$

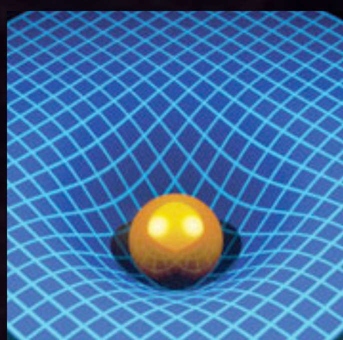
GR fully tested on solar system scales, so any modification must be length or time dependent

Beyond-Einstein gravity theories

$$ds^2 = (1 + 2\Psi)dt^2 + a^2(t)(1 + 2\Phi)dx^2$$

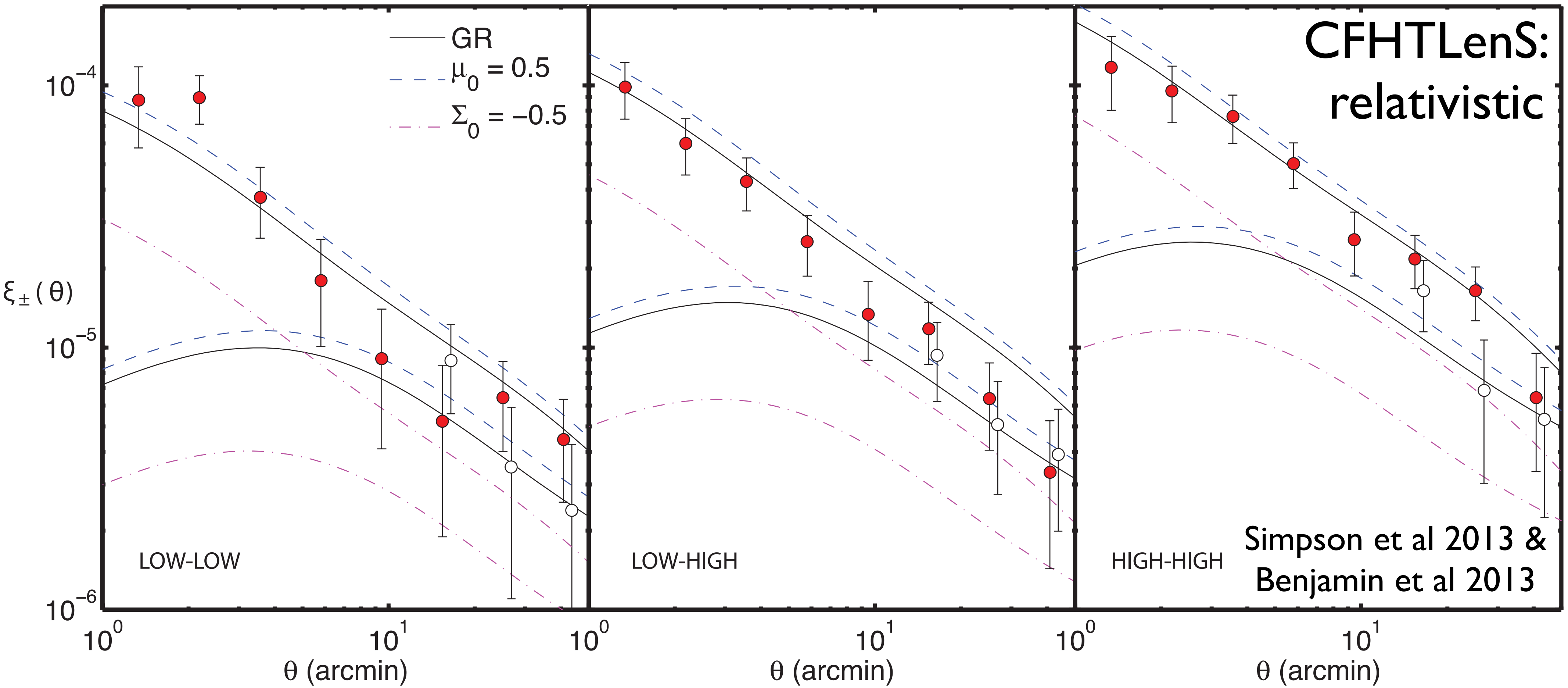
Dynamical Potential

Space Curvature Potential

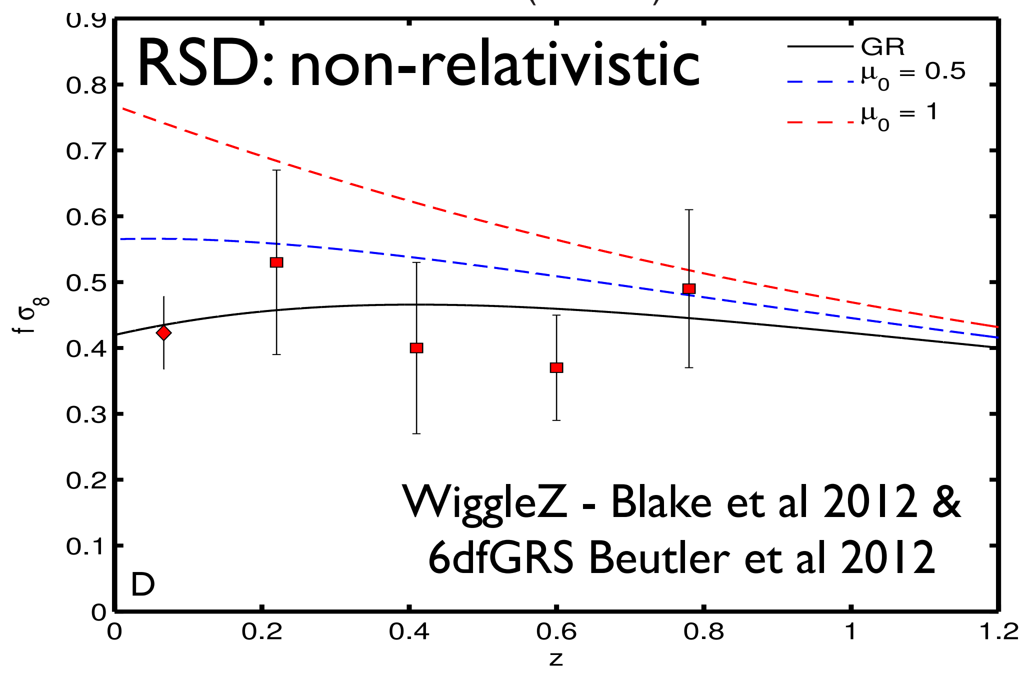


$$\nabla^2 \Psi = 4\pi G a^2 \bar{\rho}\delta[1 + \mu(a)]$$

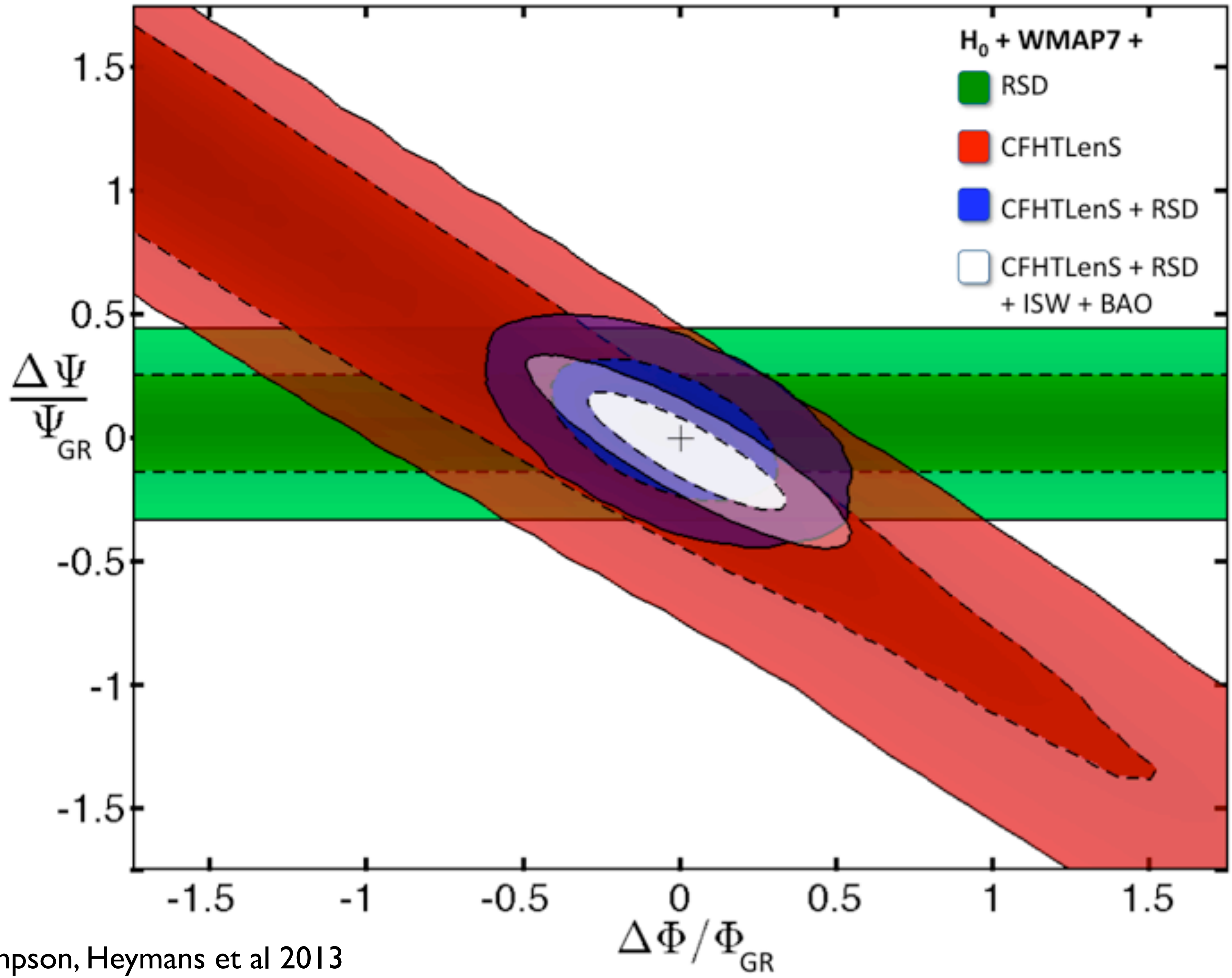
$$\nabla^2[\Phi + \Psi] = 8\pi G a^2 \bar{\rho}\delta[1 + \Sigma(a)]$$



CFHTLenS:
relativistic
GR
$\mu_0 = 0.5$
$\Sigma_0 = -0.5$
$\xi_{\pm}(\theta)$
LOW-LOW
LOW-HIGH
HIGH-HIGH
Simpson et al 2013 &
Benjamin et al 2013
θ (arcmin)



RSD: non-relativistic
GR
$\mu_0 = 0.5$
$\mu_0 = 1$
$f\sigma_8$
WiggleZ - Blake et al 2012 &
6dfGRS Beutler et al 2012
D
z



Simpson, Heymans et al 2013

CFHTLenS Data release:

Download now from www.cfhtlens.org:

- 155 sq degrees *ugriz* lensing quality reduced deep pixel data
- Combined Lensing Shear and Photometric redshift catalogues to i<24.7
- Tomographic shear correlation functions, redshift distributions and covariance matrices
- MCMC chains available on request

Technical

Heymans et al. 2012 "CFHTLenS: The Canada-France-Hawaii Telescope Lensing Survey"

Erben et al. 2013 "CFHTLenS: The Canada-France-Hawaii Telescope Lensing Survey - Imaging Data and Catalogue Products"

Miller et al. 2013 "Bayesian Galaxy Shape Measurement for Weak Lensing Surveys -III. Application to CFHTLenS"

Hildebrandt et al. 2012 "CFHTLenS: improving the quality of photometric redshifts with precision photometry"

Heymans & Rowe et al. 2012 "The impact of high spatial frequency atmospheric distortions on weak-lensing measurements"

Cosmology

Kilbinger et al. 2013 "CFHTLenS: Combined Probe Cosmological Model Comparison using 2D Weak Gravitational Lensing"

Simpson et al. 2013 "CFHTLenS: Testing the Laws of Gravity with Tomographic Weak Lensing and Redshift Space Distortions"

Benjamin et al. 2013 "CFHTLenS tomographic weak lensing: Quantifying accurate redshift distributions"

Heymans et al. 2013 "CFHTLenS tomographic weak lensing cosmological parameter constraints: Mitigating the impact of intrinsic galaxy alignments"

Van Waerbeke et al. 2013 "CFHTLenS: Mapping the Large Scale Structures"

Galaxy-galaxy Lensing

Gillis et al. 2013 "CFHTLenS: The Environmental Dependence of Galaxy Halo Masses from Weak Lensing"

Simon et al. 2013 "CFHTLenS: Higher-order galaxy-mass correlations probed by galaxy-galaxy-galaxy lensing"

Velander et al. 2013 "CFHTLenS: The Relation Between Galaxy Dark Matter Haloes and Baryons from Weak Gravitational Lensing"