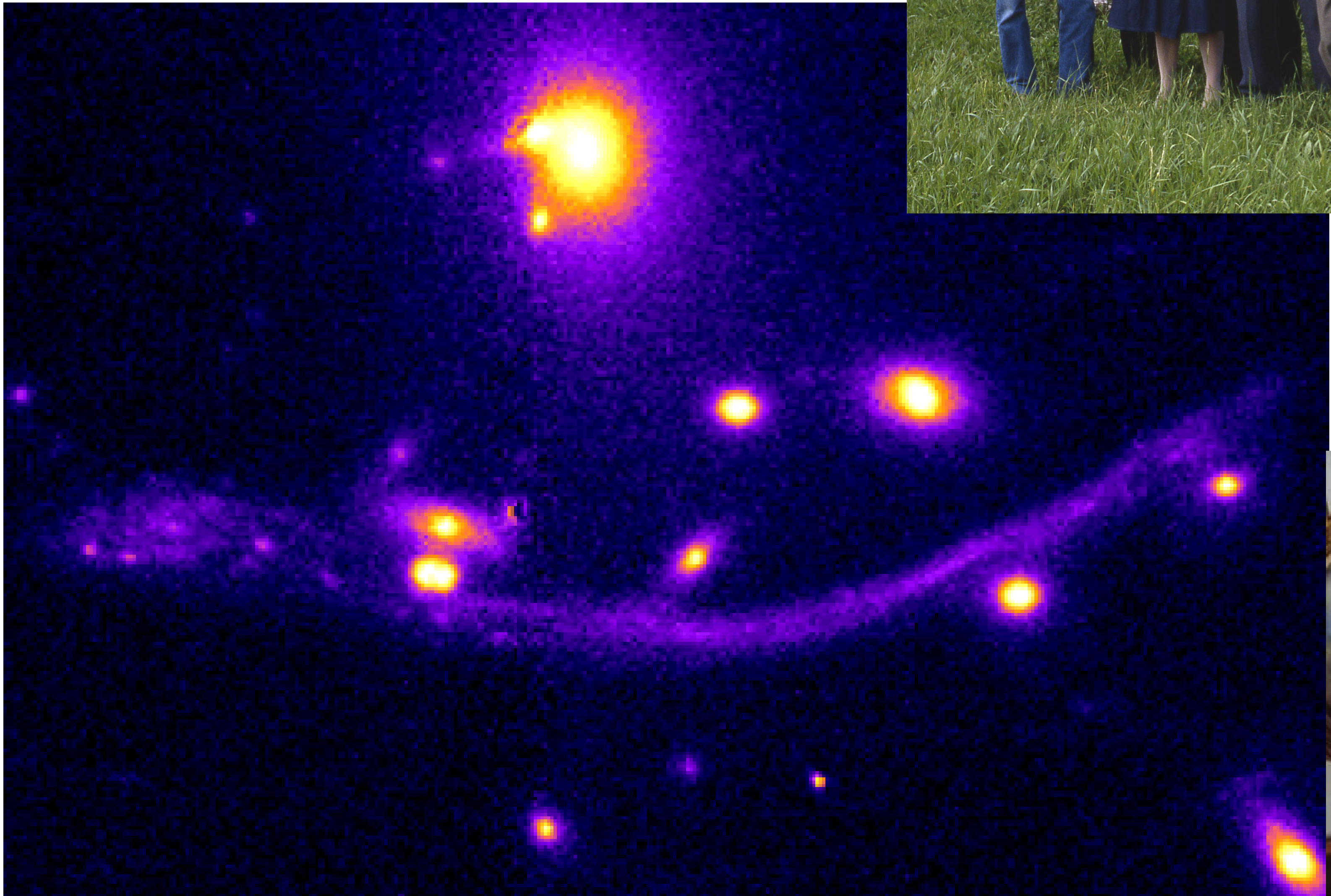
From giant arcs to CMB lensing: 20 years of gravitational distortion



- Weak lensing
    - -- imaging
    - -- shear
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    - -- higher order extensions

- Strong lensing
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- Lensing of other things

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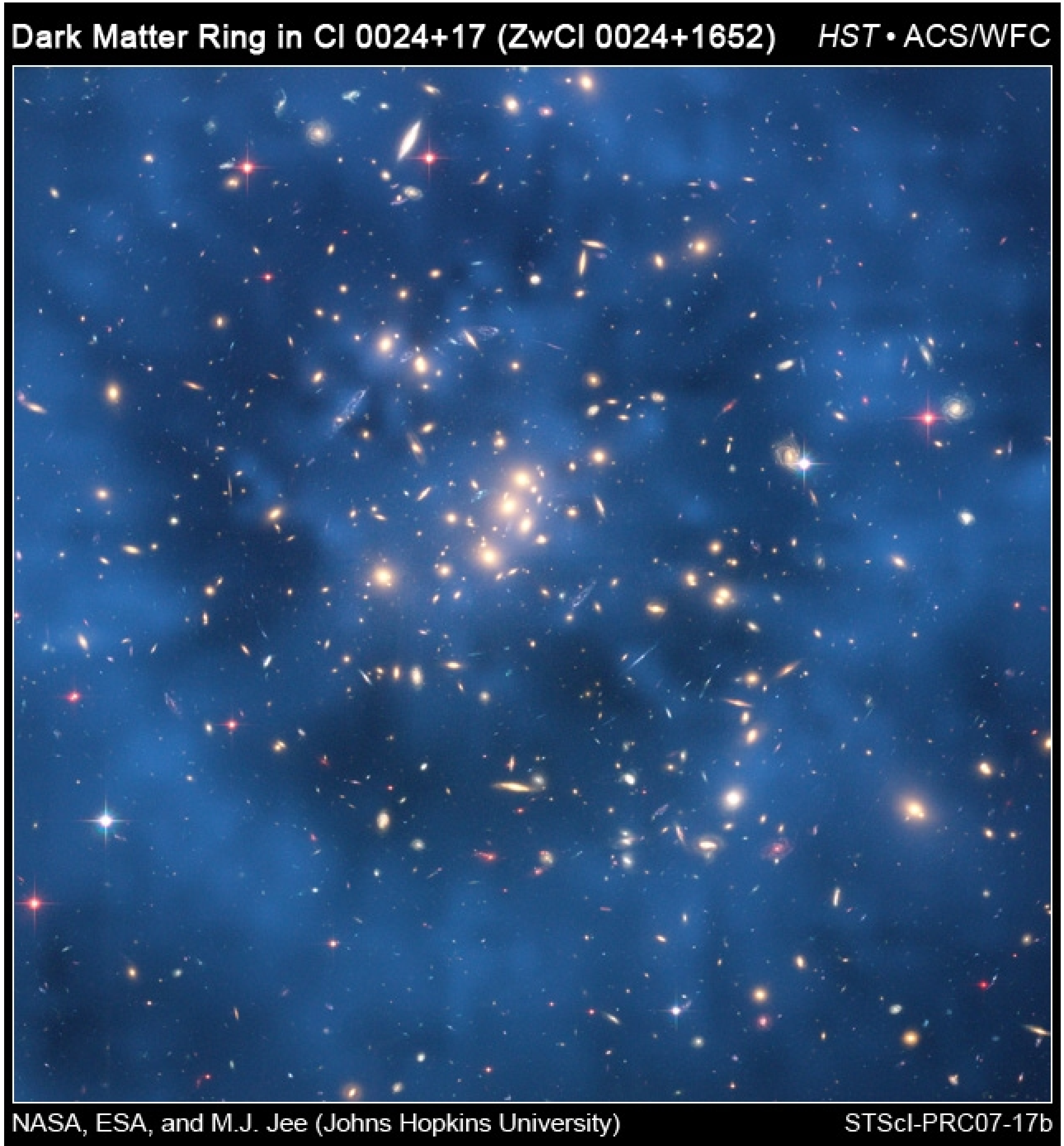
Clowe, Bradac

Jee


Dark Matter Ring in Cl 0024+17 (ZwCl 0024+1652)
HST • ACS/WFC
NASA, ESA, and M.J. Jee (Johns Hopkins University)
STScI-PRC07-17b

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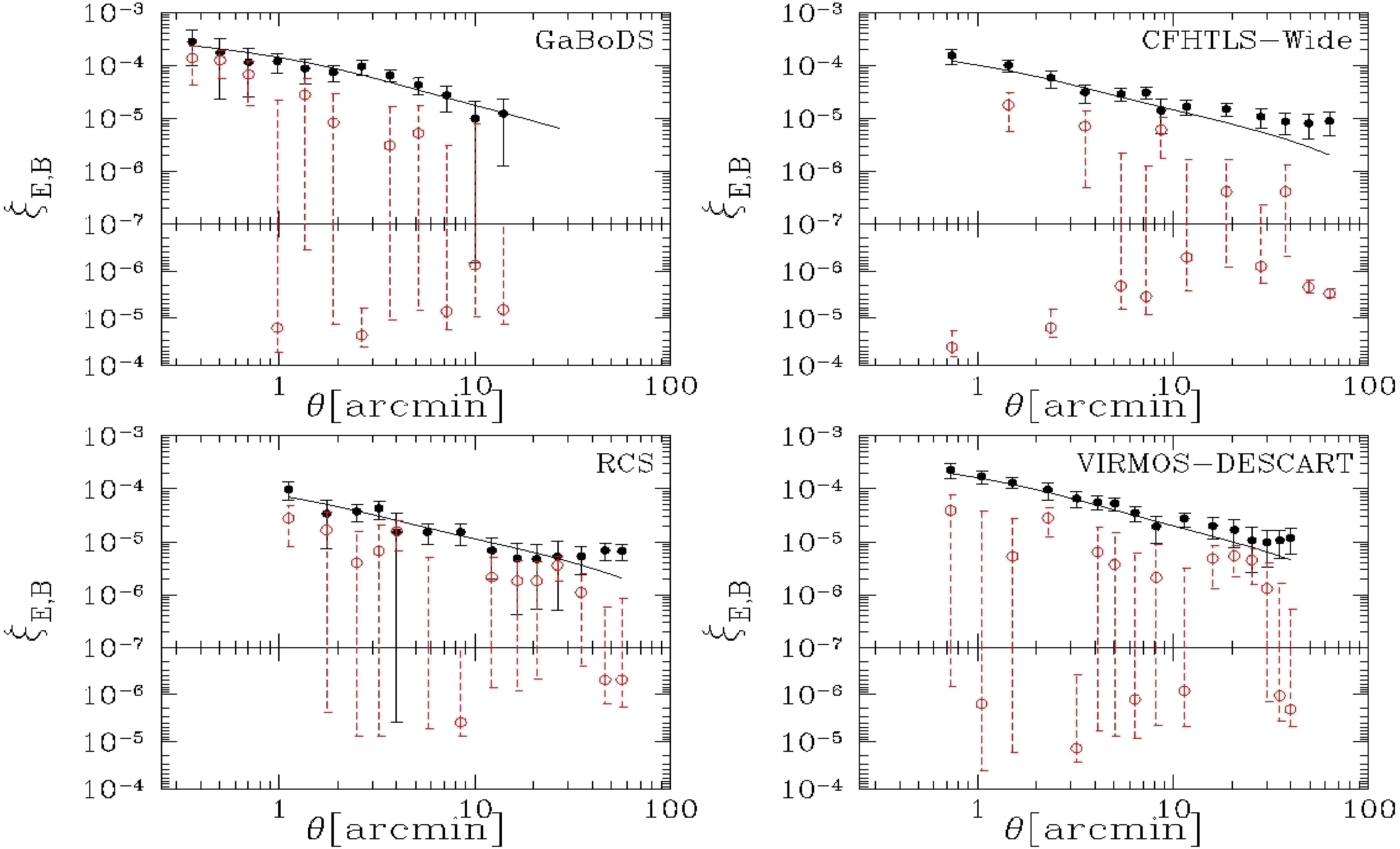
Shear signal

Benjamin

Removing all scales with non zero B-modes from the analysis changes the resulting σ_8 by ~0.01

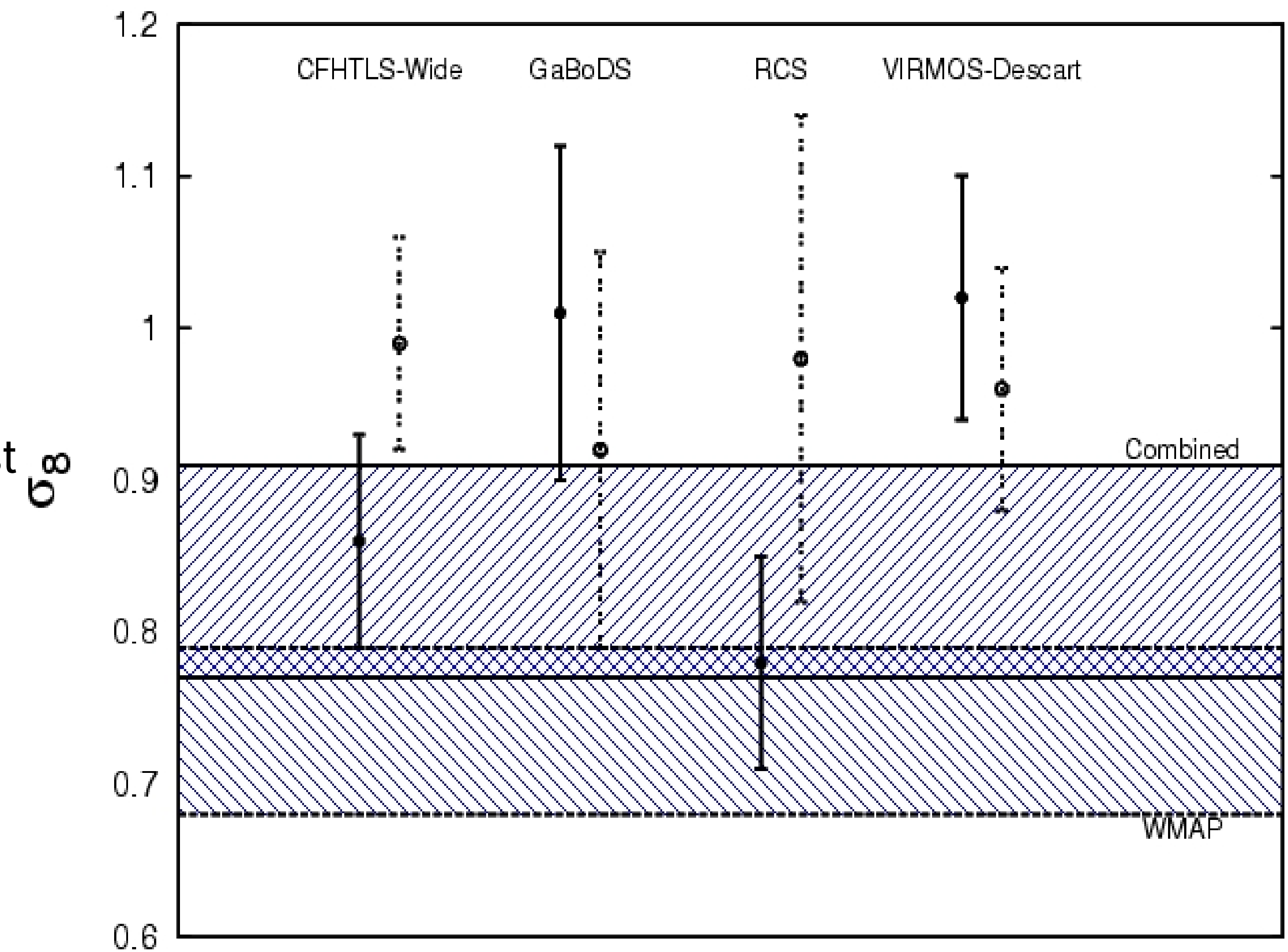


Survey results

Benjamin

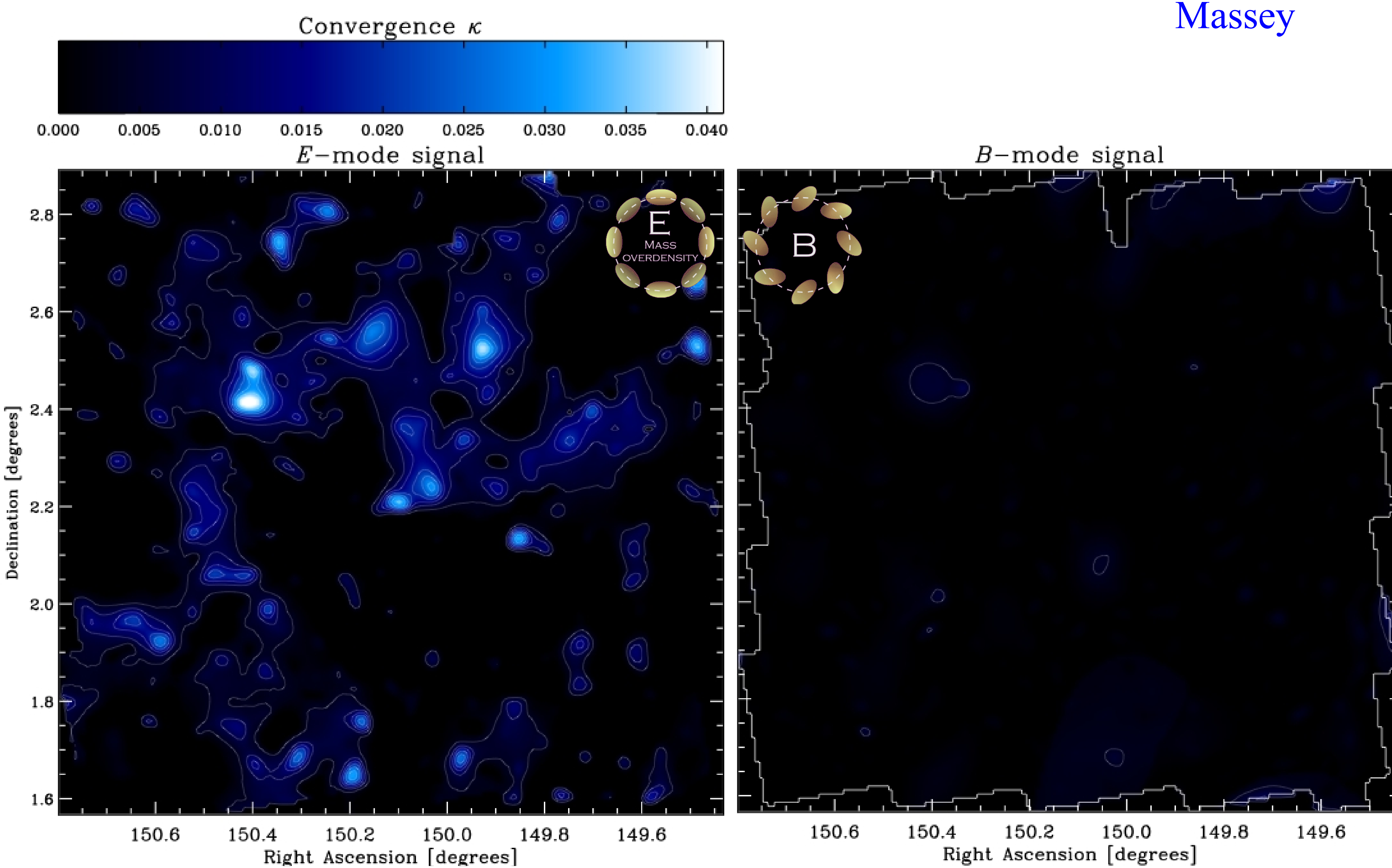
for Ω_m=0.24, error bars denote 1σ region

- Dashed: literature values
- Solid: our results
- Changes are almost entirely due to the updated n(z)



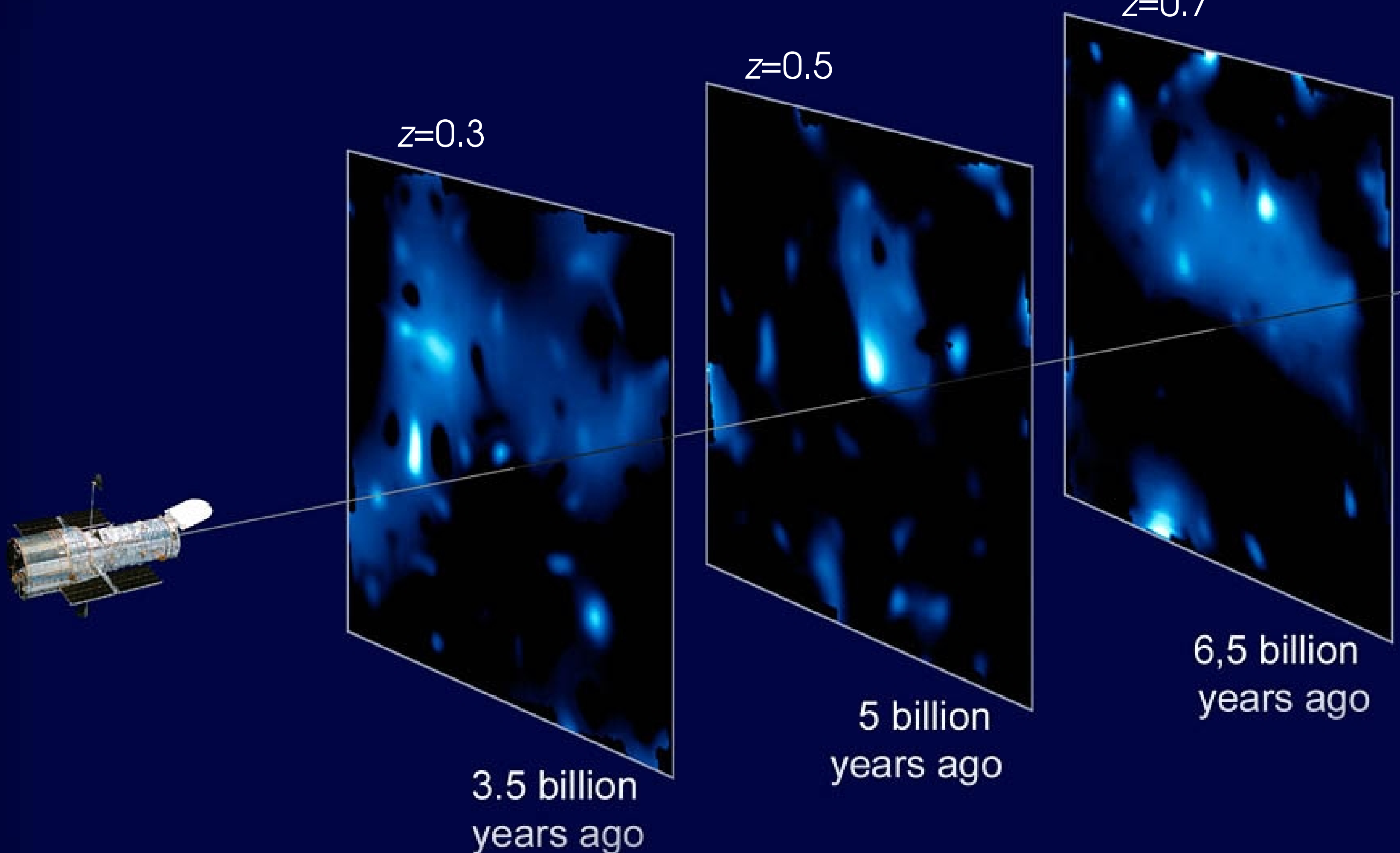
B-mode check for residual systematics

Massey



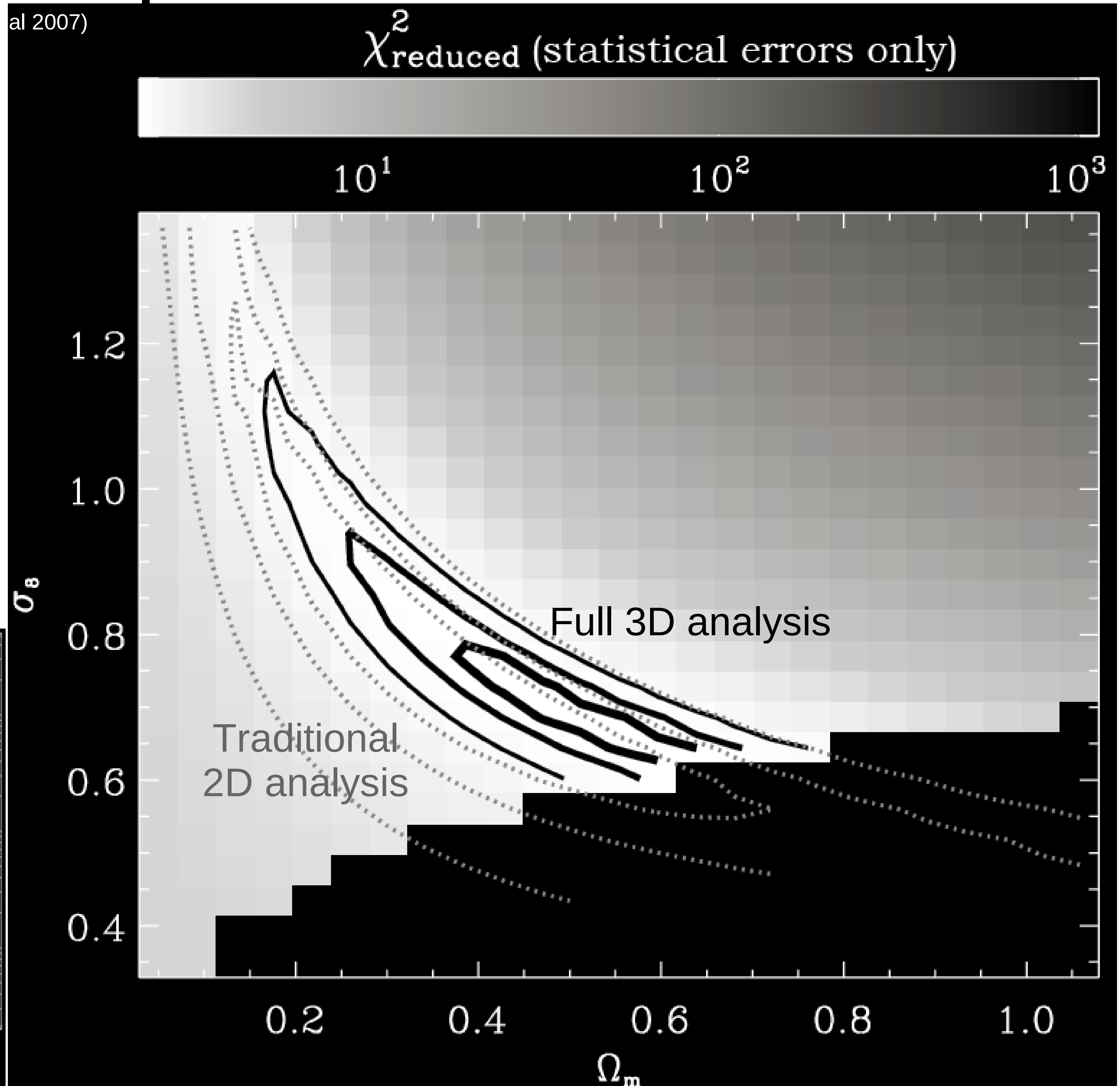
Redshift tomography (palaeocosmology)

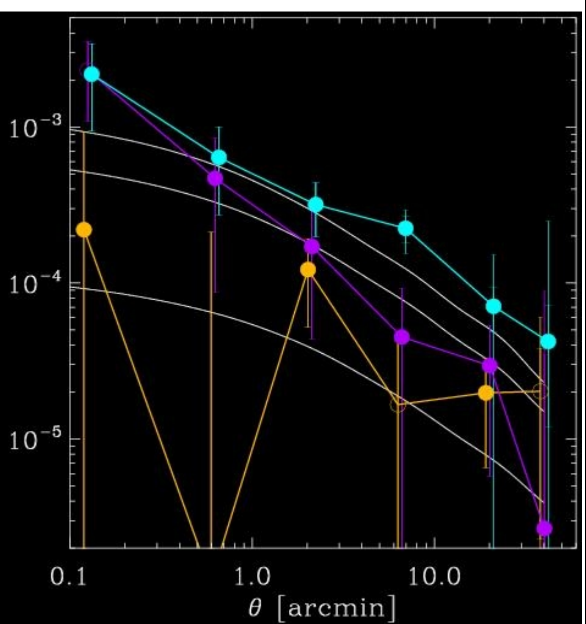
Massey



Cosmological parameter constraints

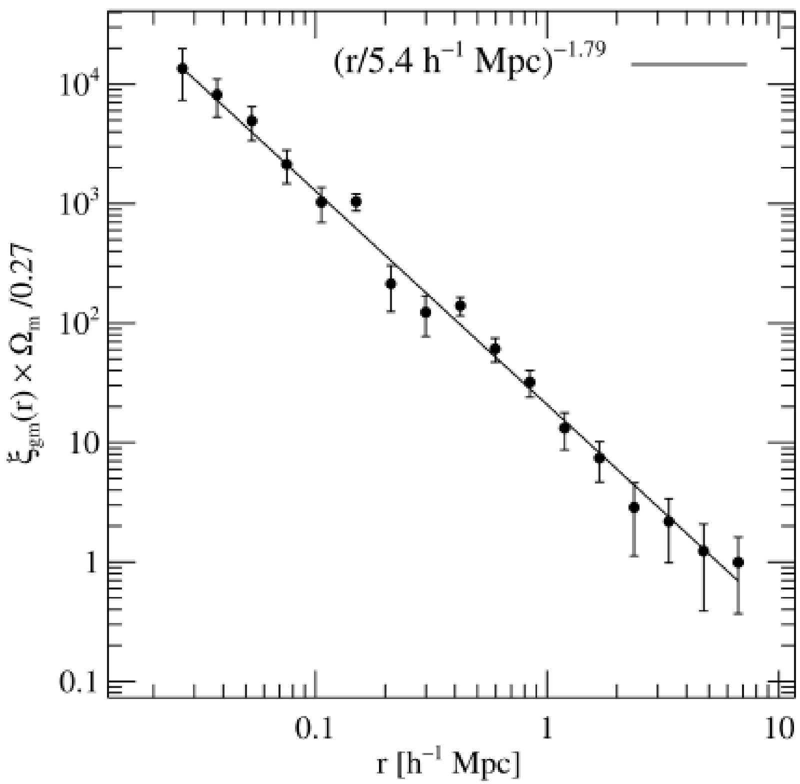
Massey





~3 years ago…

Hoekstra



Sheldon et al. (2004)

Even more SDSS data

120,000 lenses with spectroscopic redshifts!

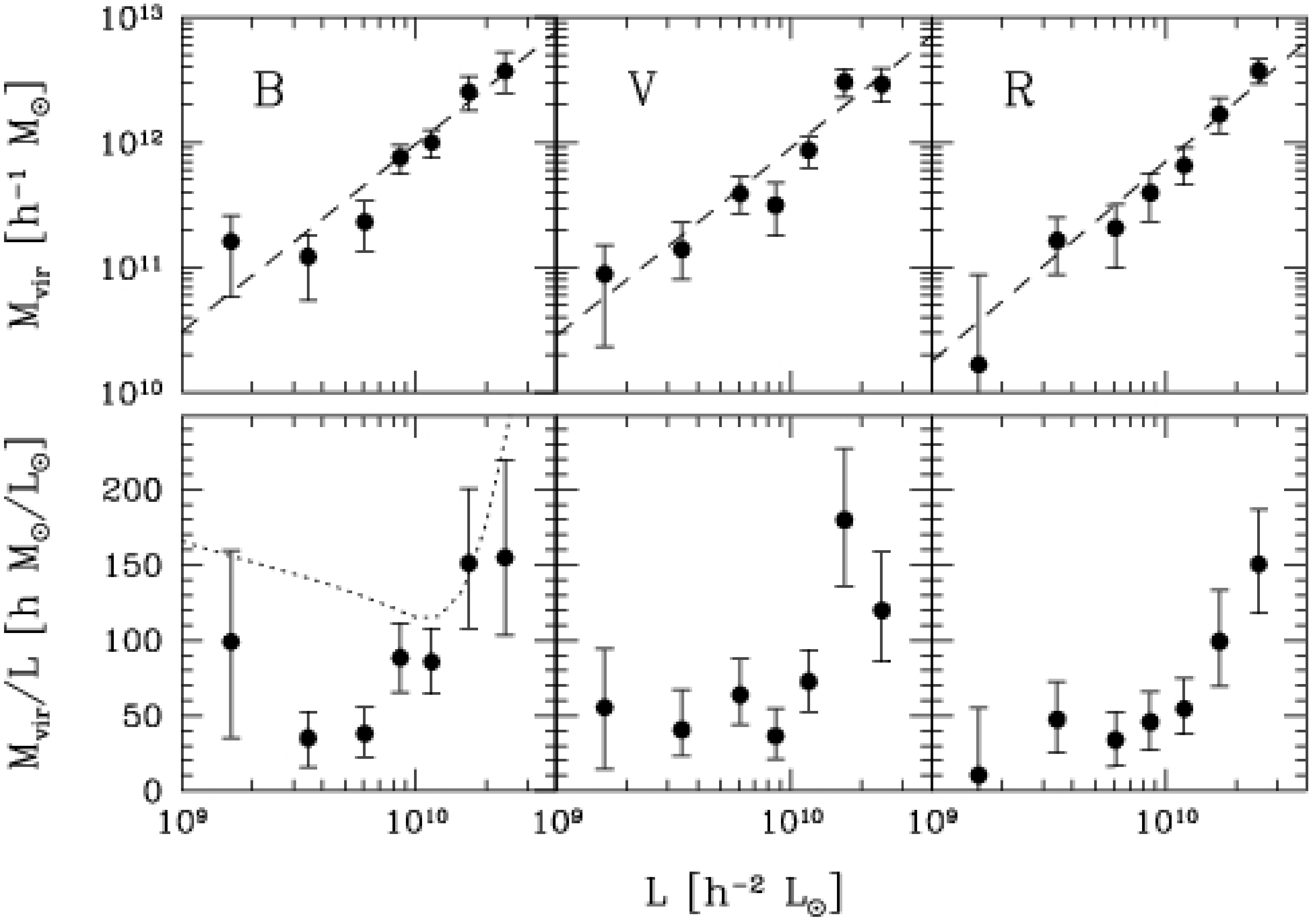
9 million sources with photometric redshifts!

Now we're measuring something!

Mass-luminosity relation

Hoekstra

$M \sim L^{1.5}$



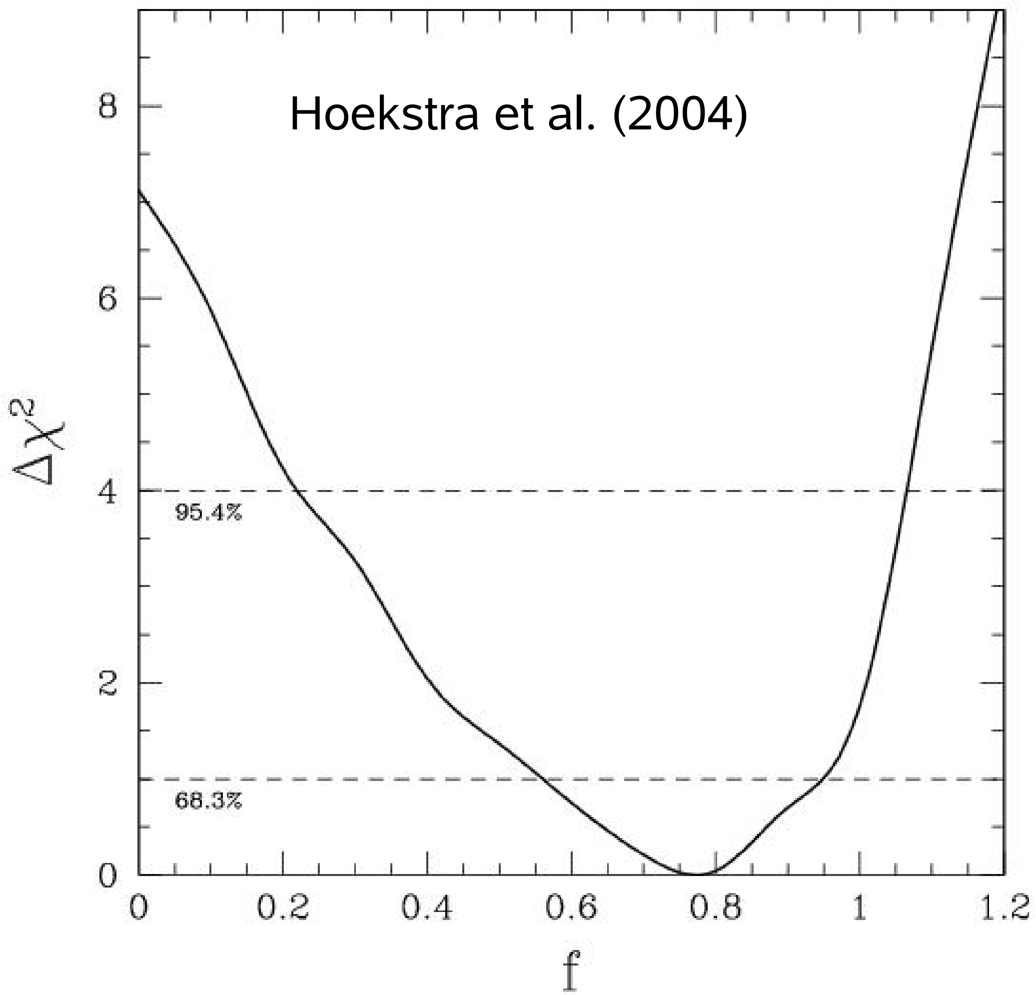
Flattening of dark matter halos

Hoekstra

We use a simple model:

$$e_{halo} = f\, e_{lens}$$

and determine f



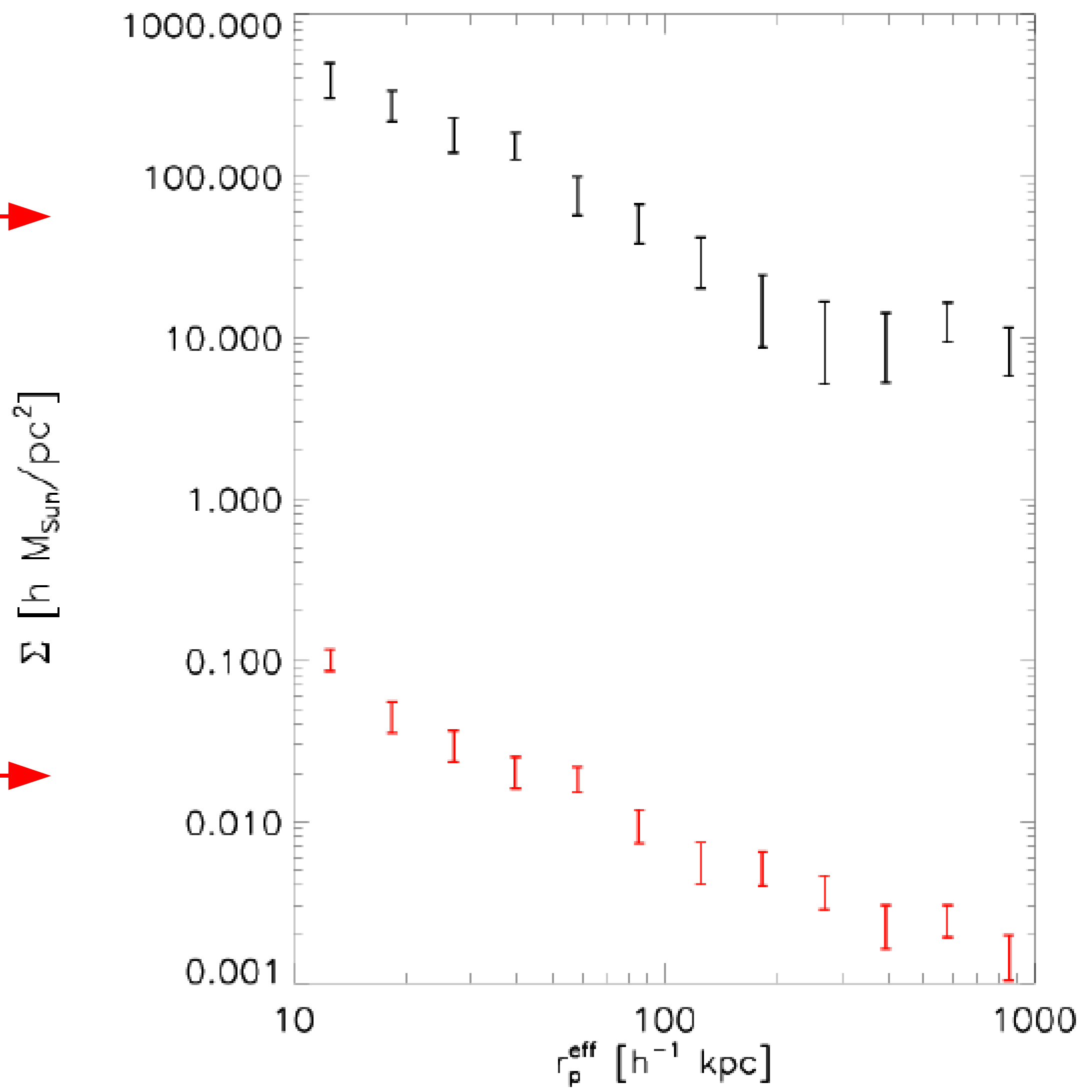
- Halos are aligned with the light
- Spherical halos excluded with 99.5% confidence
- Good agreement with CDM predictions

But see Mandelbaum et al. (2006)!!

Menard

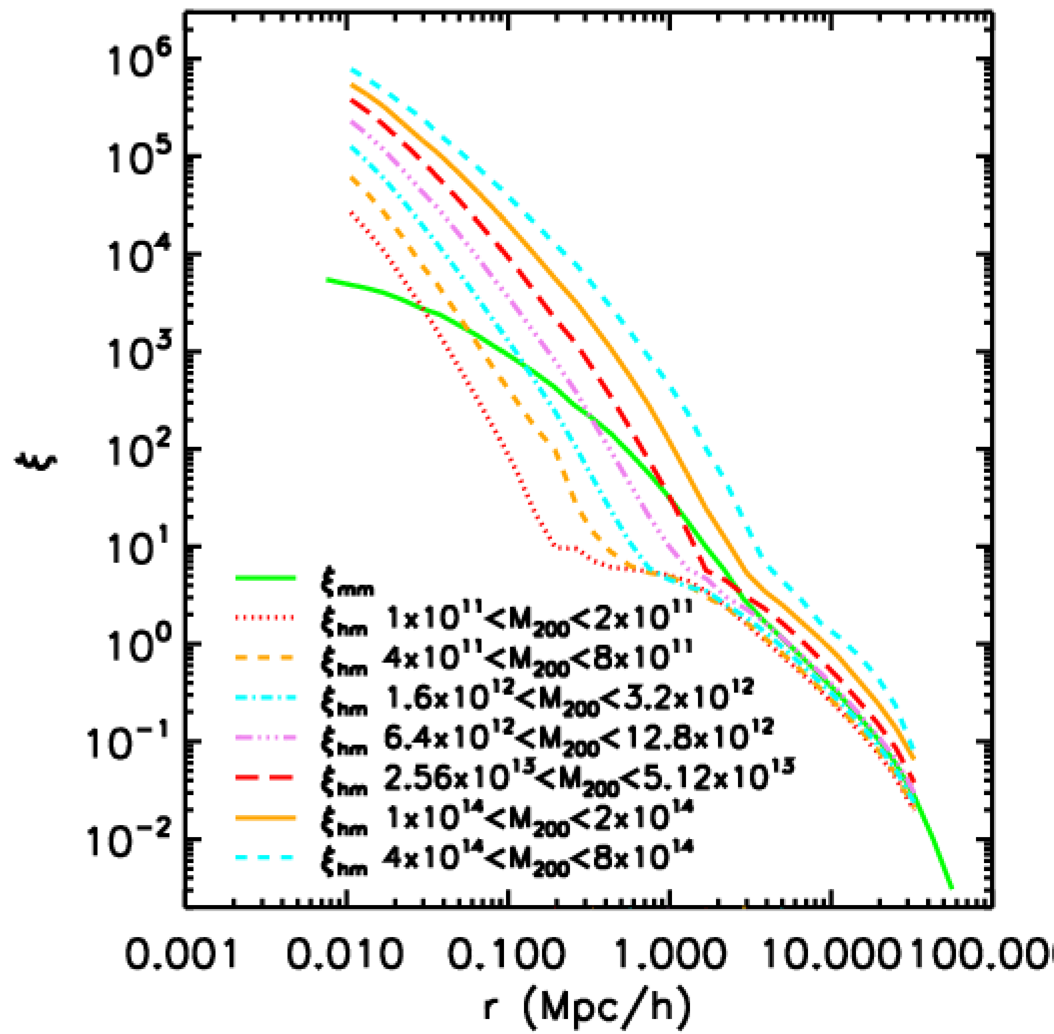
mean mass profile
around galaxies

mean dust mass profile
around galaxies



Hayashi

mean mass profiles
around halo centres



Clear features provide a strong discriminator between ΛCDM and e.g. MOND

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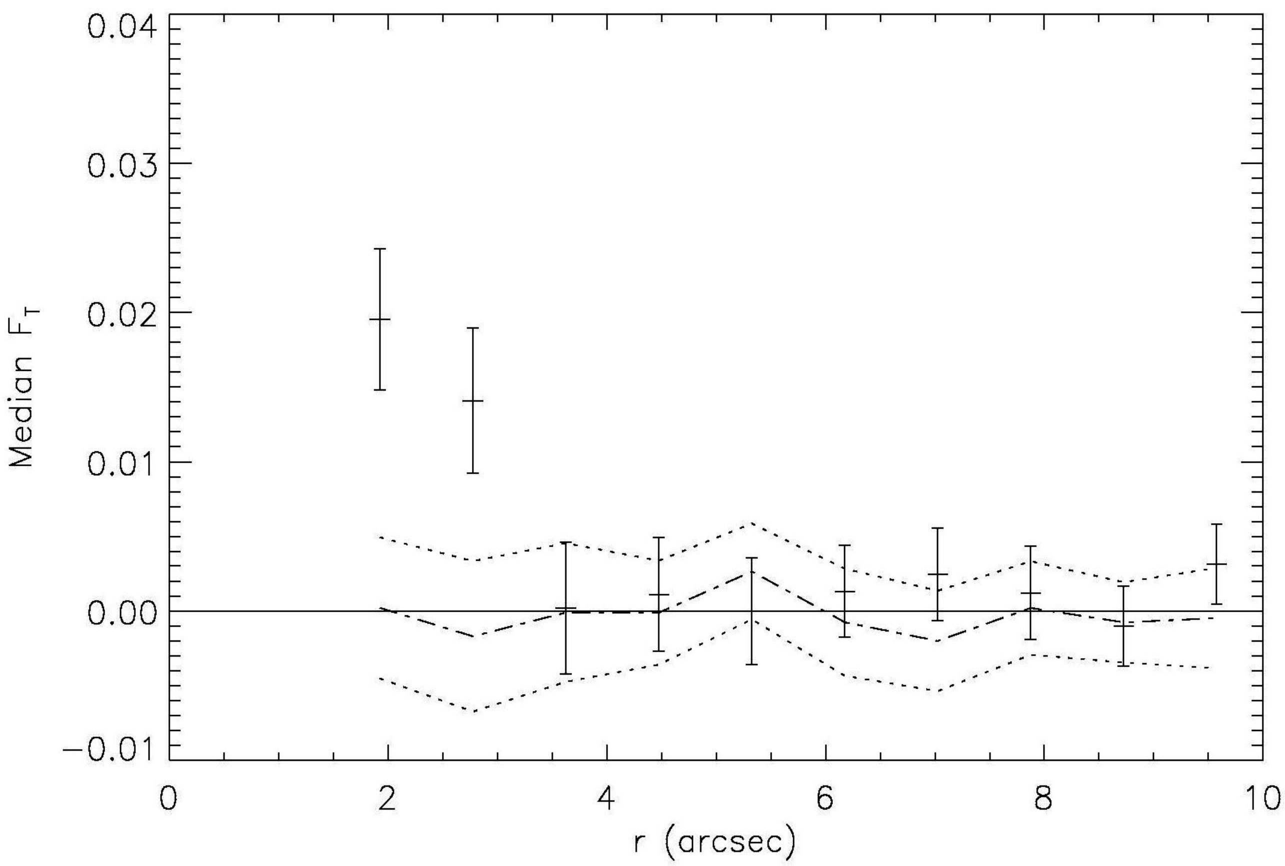
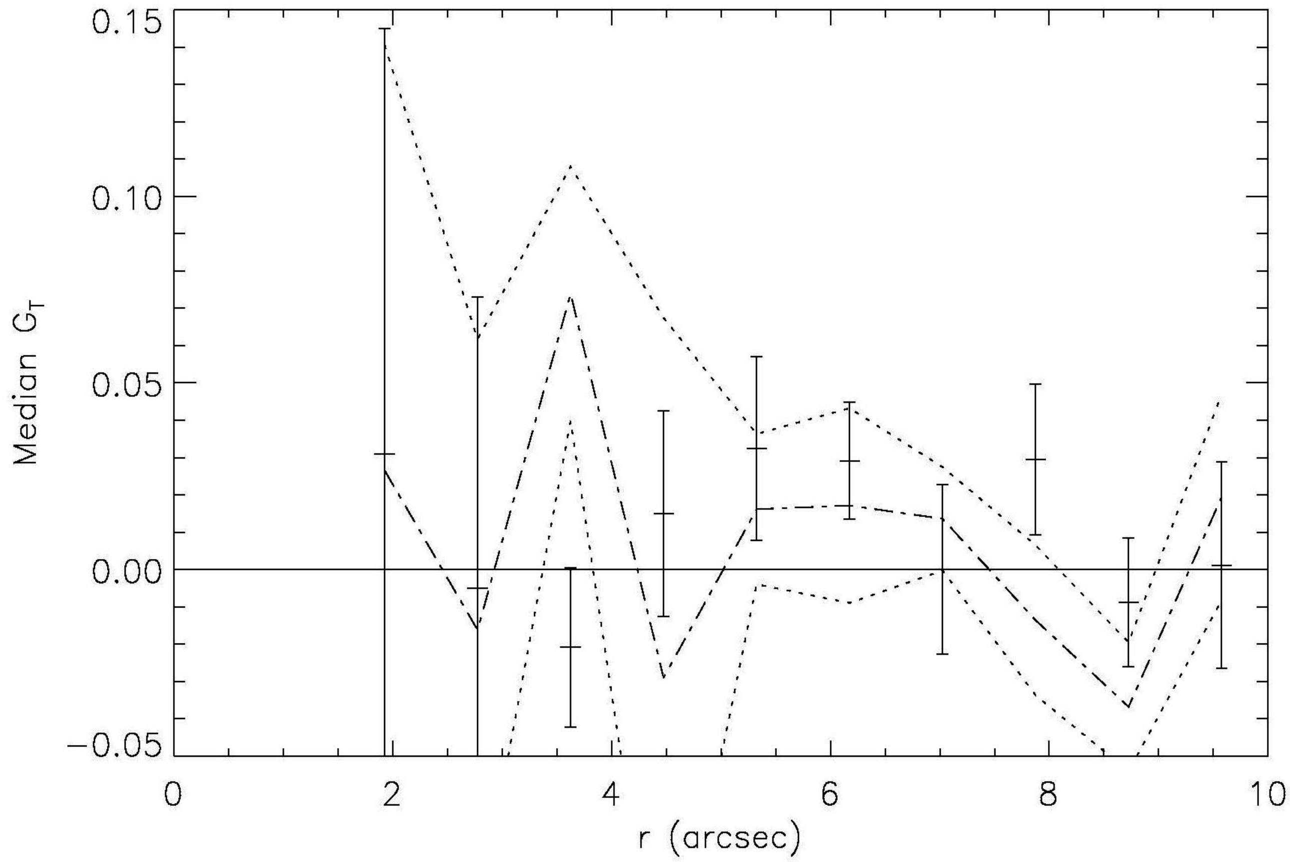
Galaxy-galaxy *F*

Rowe

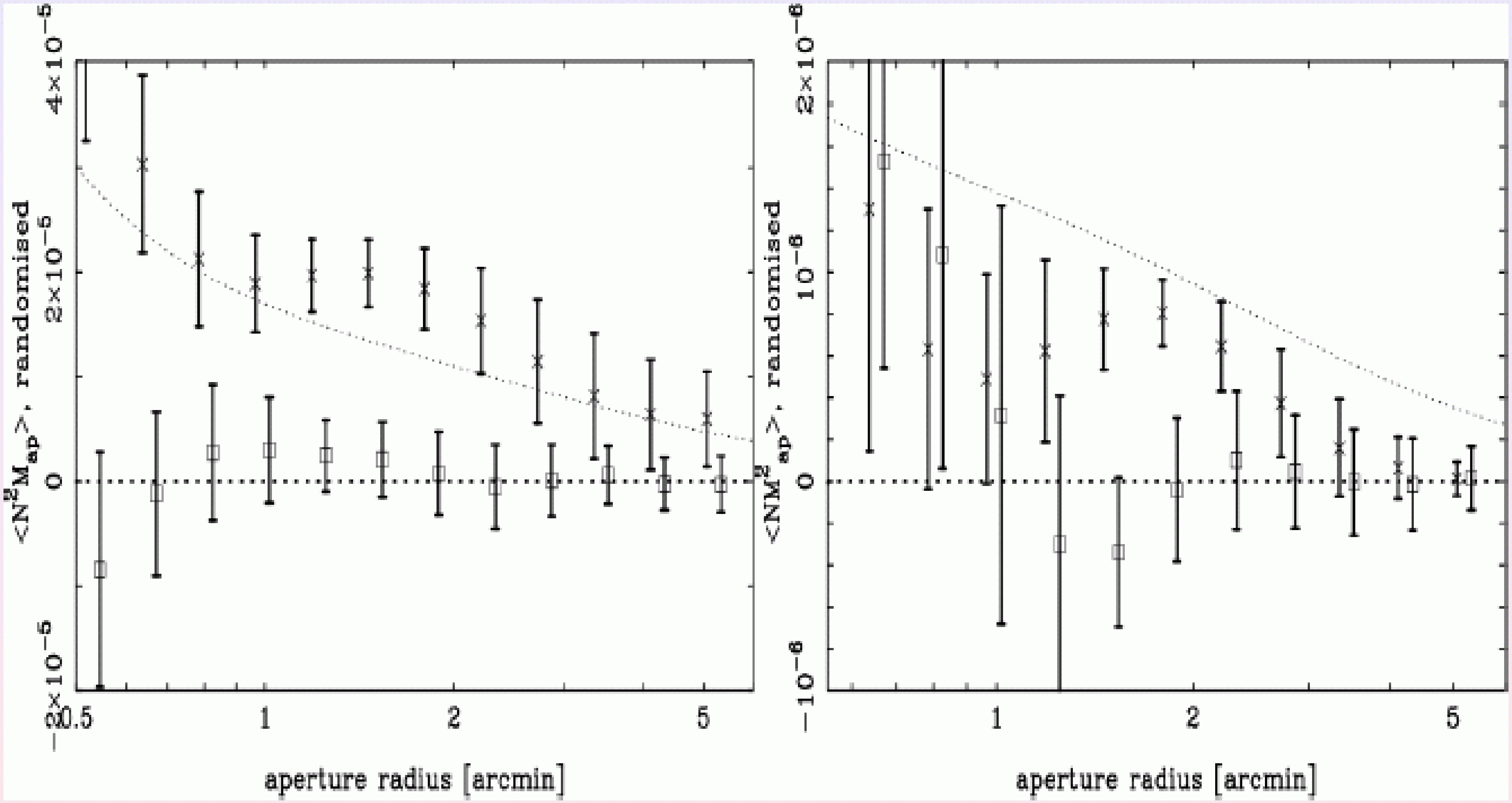


Galaxy-galaxy *G*

Rowe



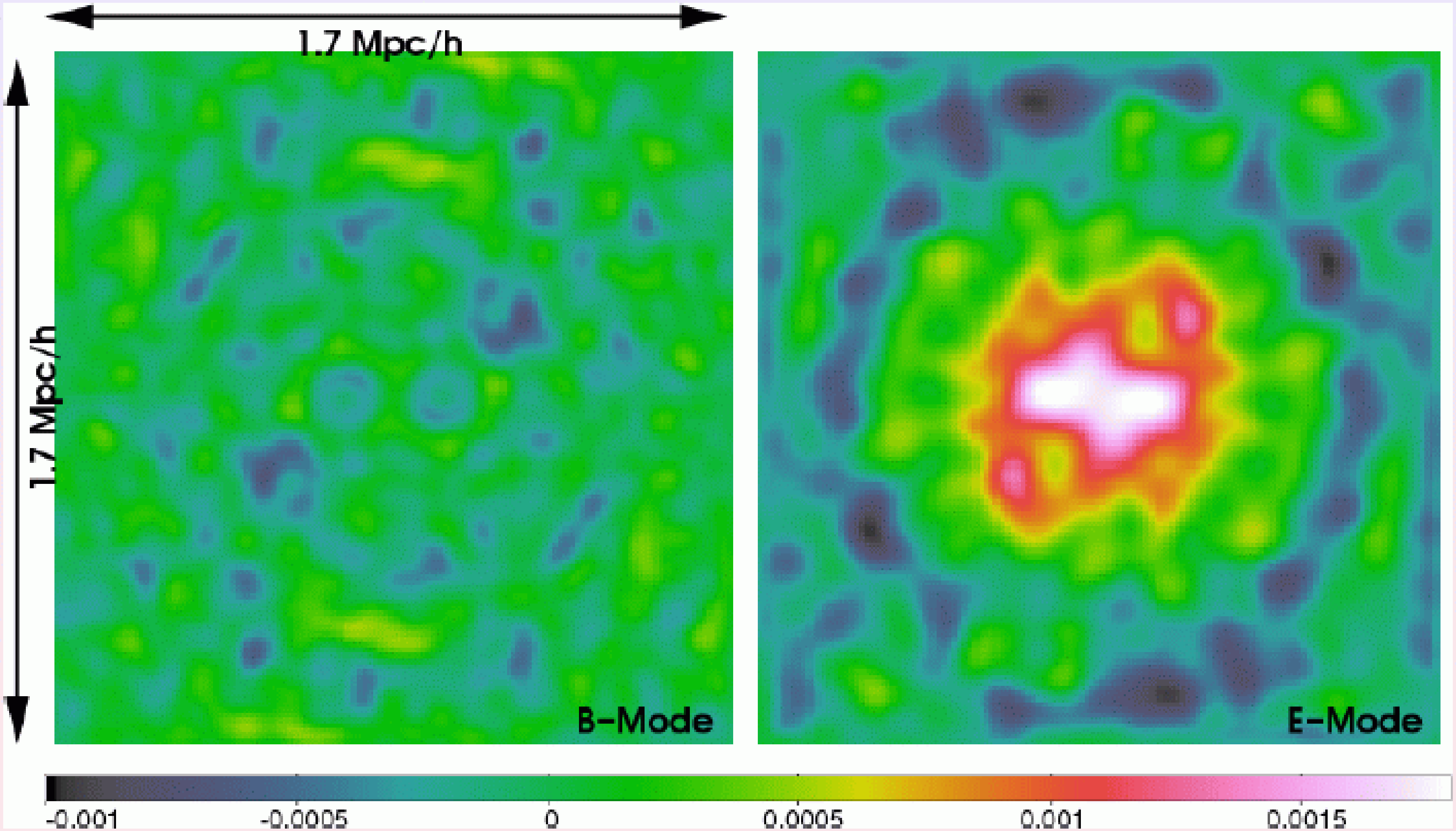
Results: third-order aperture statistics in RCS



lenses: $\bar{z} \sim 0.3$, sources: $\bar{z} \sim 0.85$ *left:* "$\mathcal{G}$", *right:* "$G_\pm$"
halo-model: flat ΛCDM, $\Omega_\mathrm{m} = 0.3$, $\sigma_8 = 0.9$

P.Simon

Map of the galaxy^3-lensing correlator $\mathcal{G}$



P.Simon

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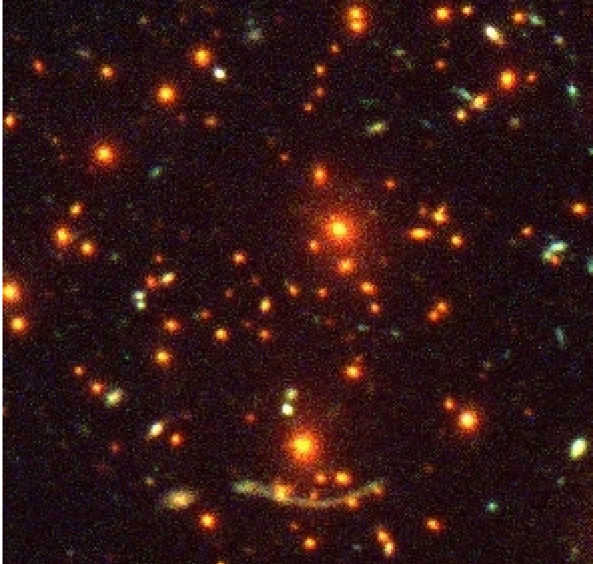
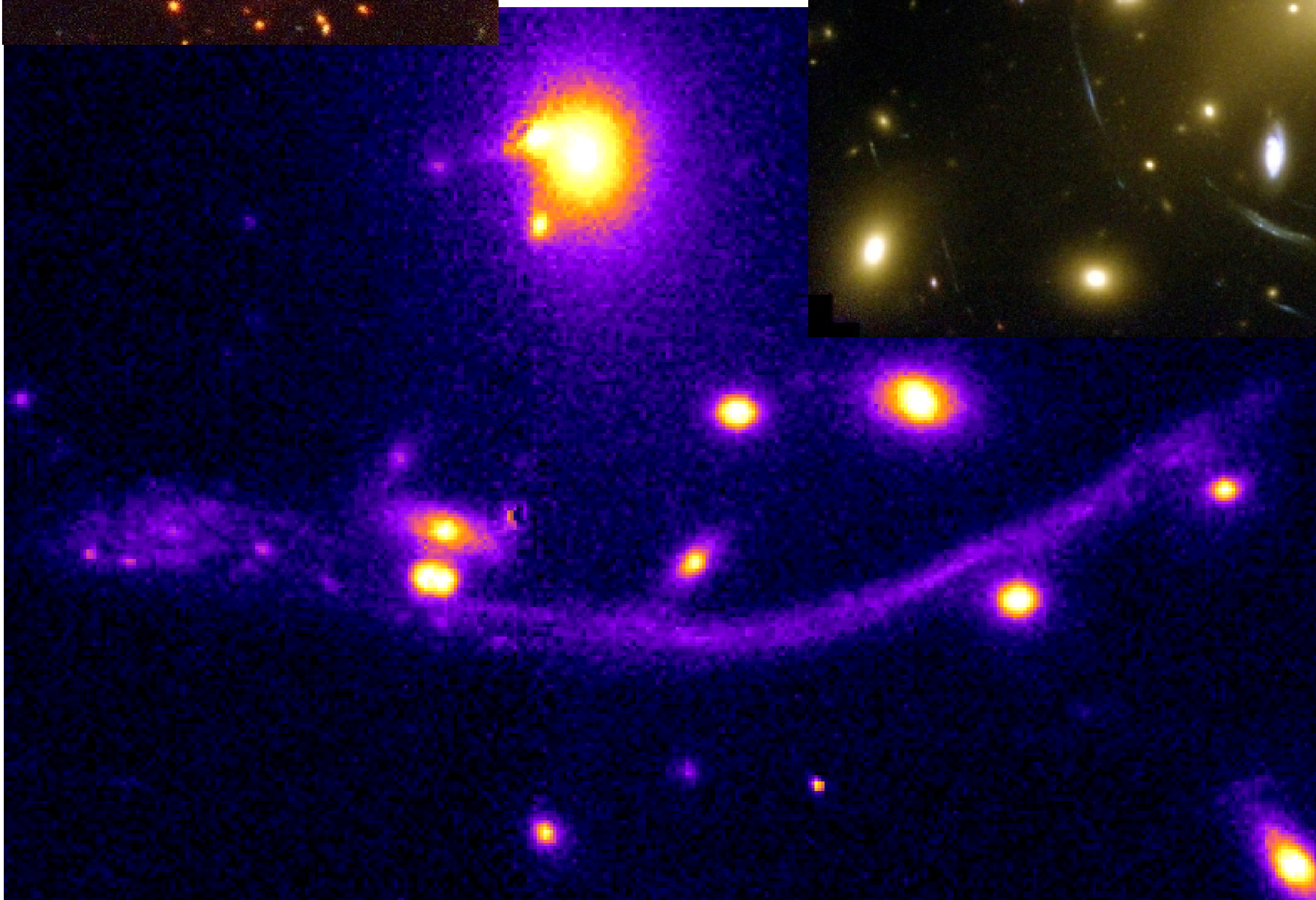
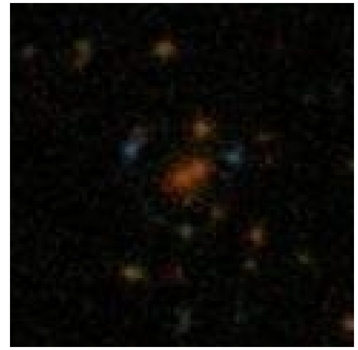
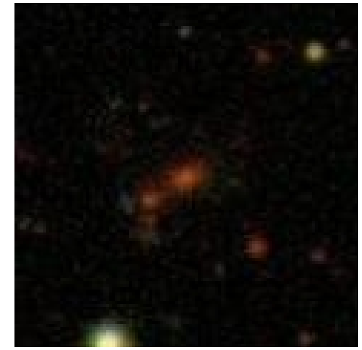
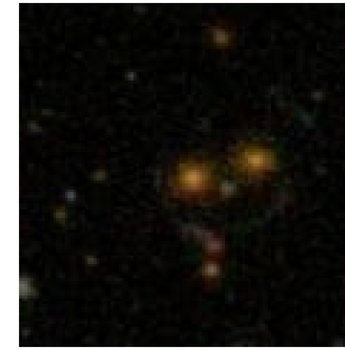


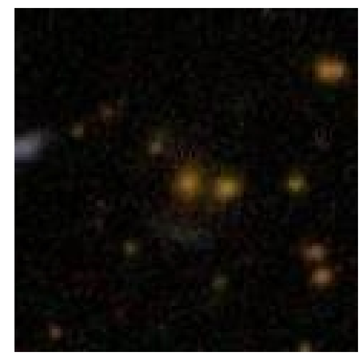


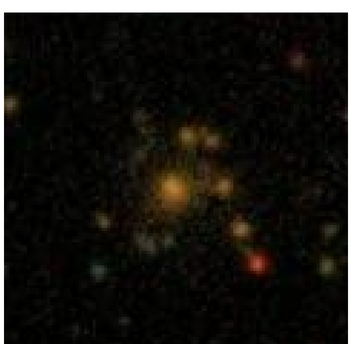
2 Systems Rejected by Follow-Up

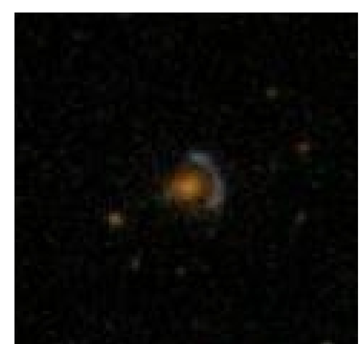
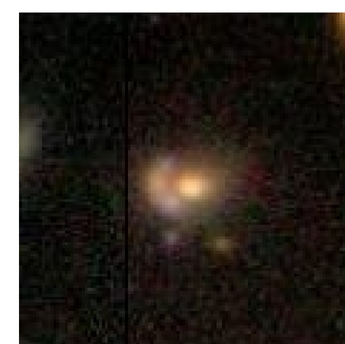
Buckley-Geer

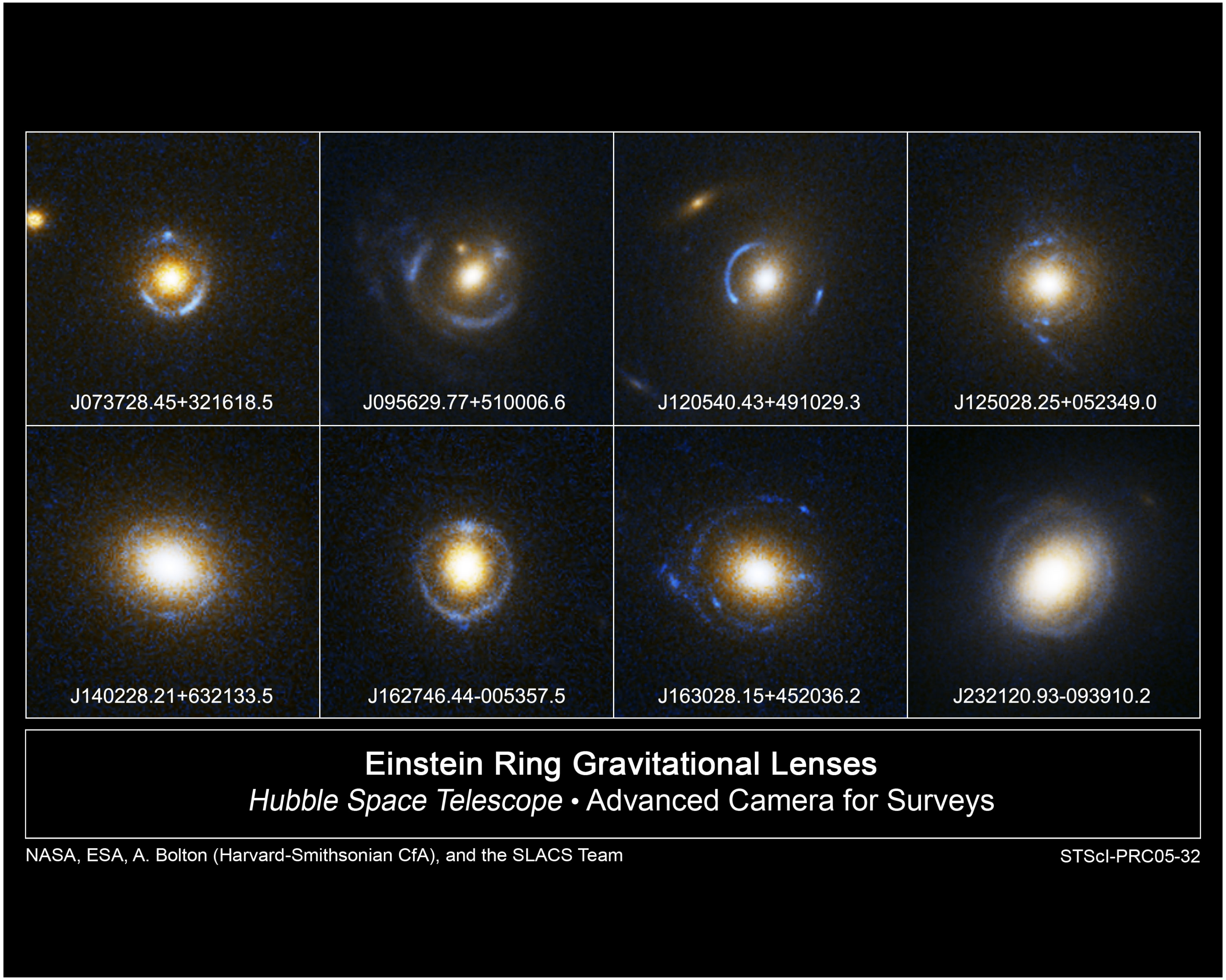





J073728.45+321618.5
J095629.77+510006.6
J120540.43+491029.3
J125028.25+052349.0
J140228.21+632133.5
J162746.44-005357.5
J163028.15+452036.2
J232120.93-093910.2
Einstein Ring Gravitational Lenses
Hubble Space Telescope • Advanced Camera for Surveys
NASA, ESA, A. Bolton (Harvard-Smithsonian CfA), and the SLACS Team
STScI-PRC05-32

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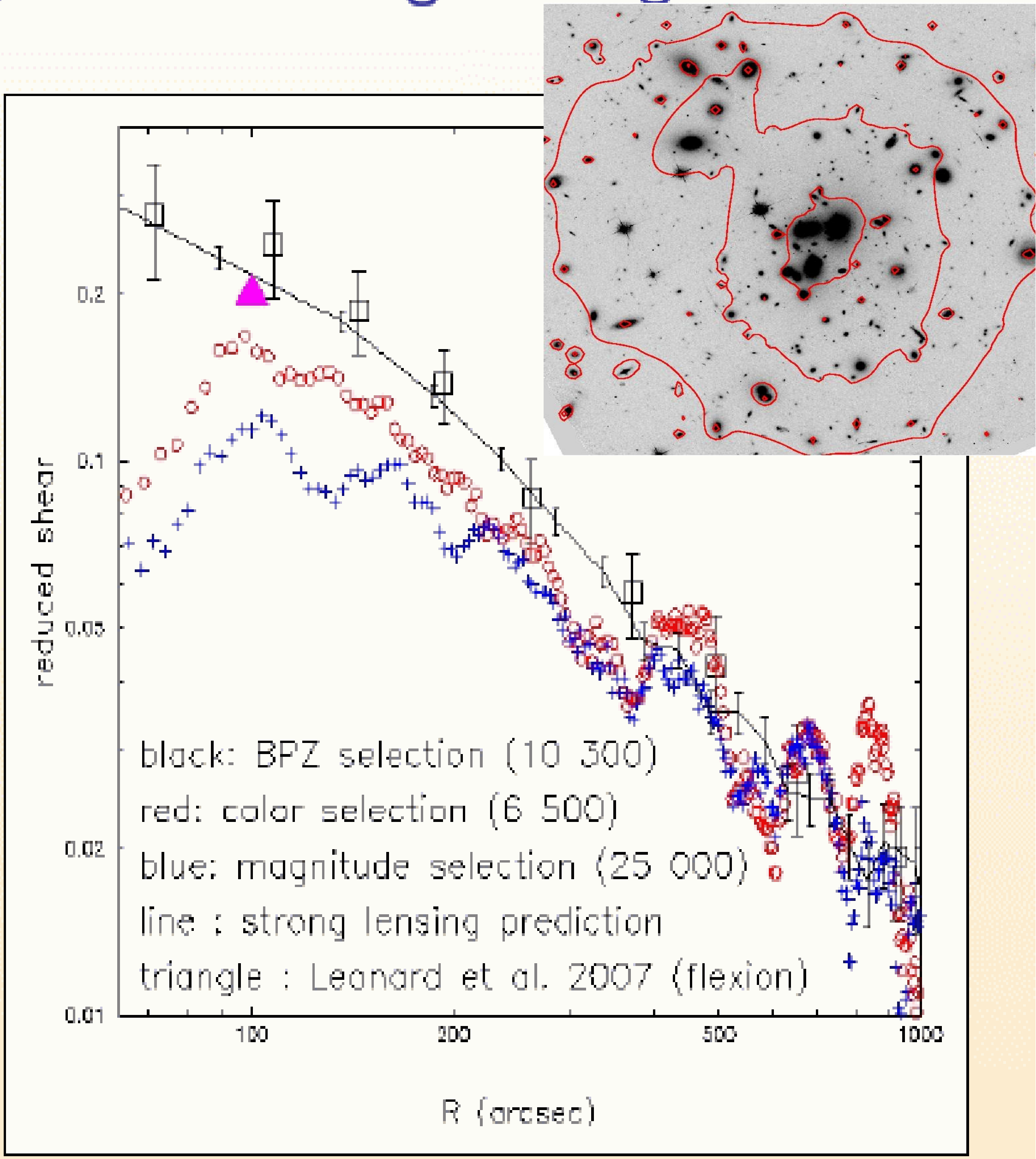
Weak Lensing: agree with Strong Lensing

- Wide Field multi-color data CFH12K (Czoske et al., 2002)
- Bayesian Photometric Redshifts (BPZ)
- Background galaxies selection is cruciale
- Strong and Weak lensing agree ($c_{200} \sim 7$)
- c_{200} High but Compatible with ΛCDM (Neto et al. 2007): possible but rare



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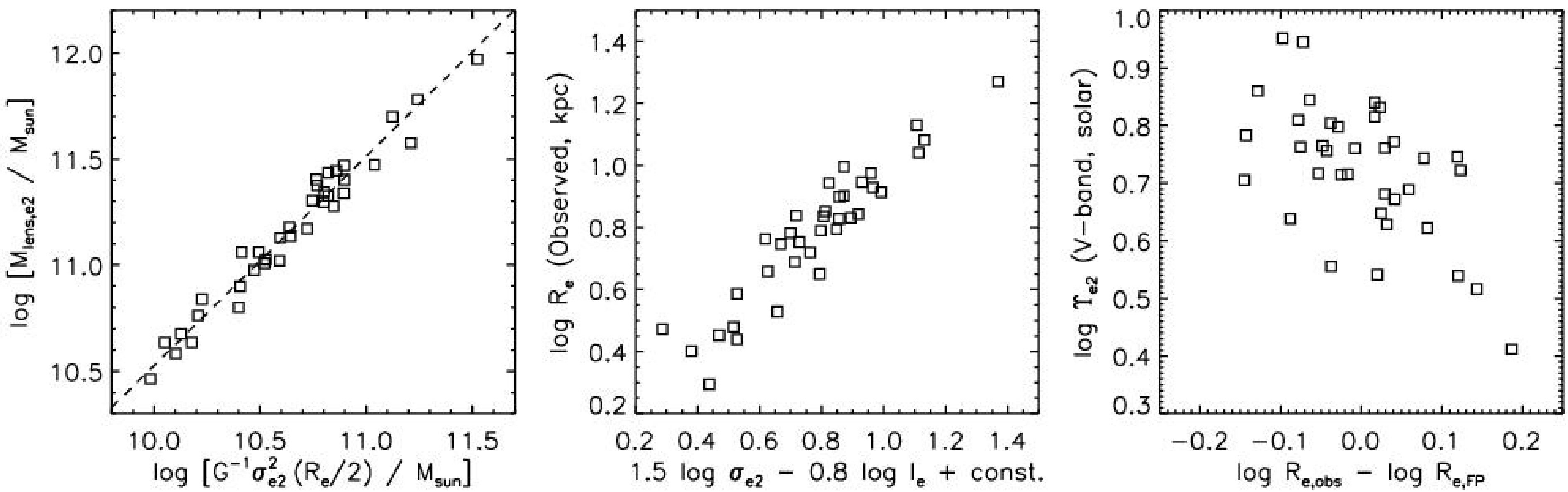
Treu

A more Fundamental Plane

$$\log R_e = a \log \sigma + b \log \Sigma_{lens} + d$$



- Intrinsic scatter of MFP is half that of the classic FP
- MFP has no "tilt", i.e. $M_{tot} \propto \sigma^2 R_e / G$
- Tilt of the classic FP $L \propto (\sigma^2 R_e/G)^{0.8}$ due to varying dark matter content?

Bolton et al. 2007

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Spitzer and IRAM Follow up

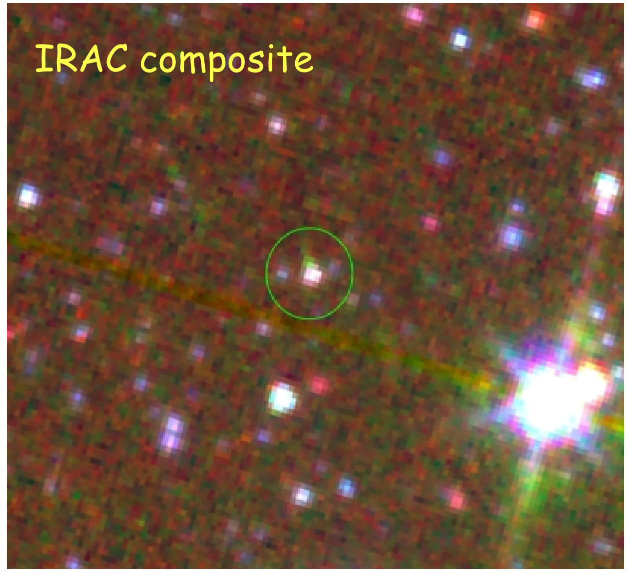
Ellis

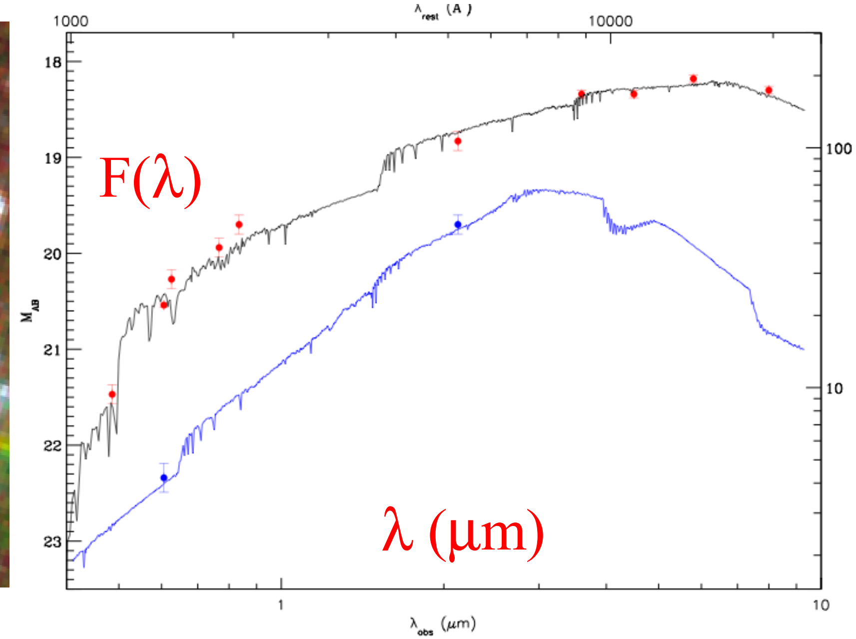
Stellar mass & SFR:

$M_K = -22.2\pm0.2$

$M_* \sim 8\times10^9 M_\odot$

SFR(24μm) $60 M_\odot$/yr

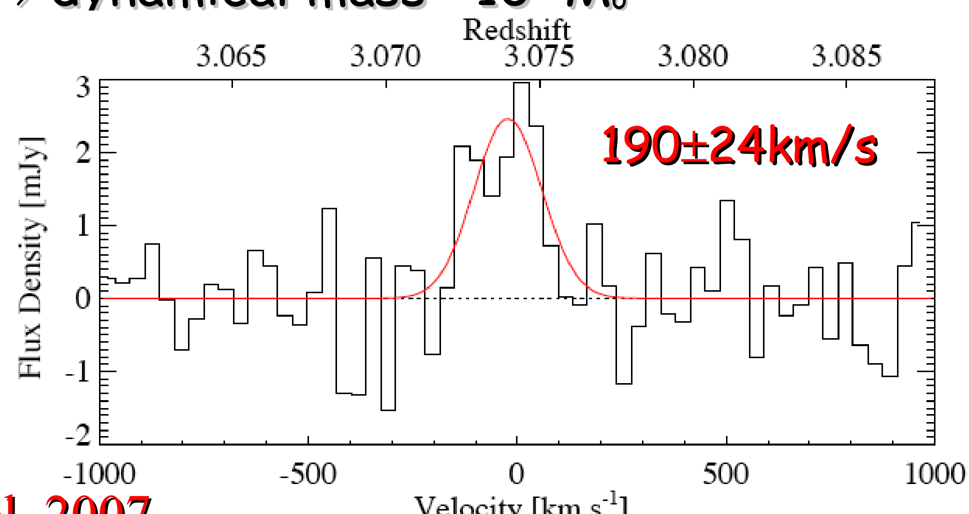


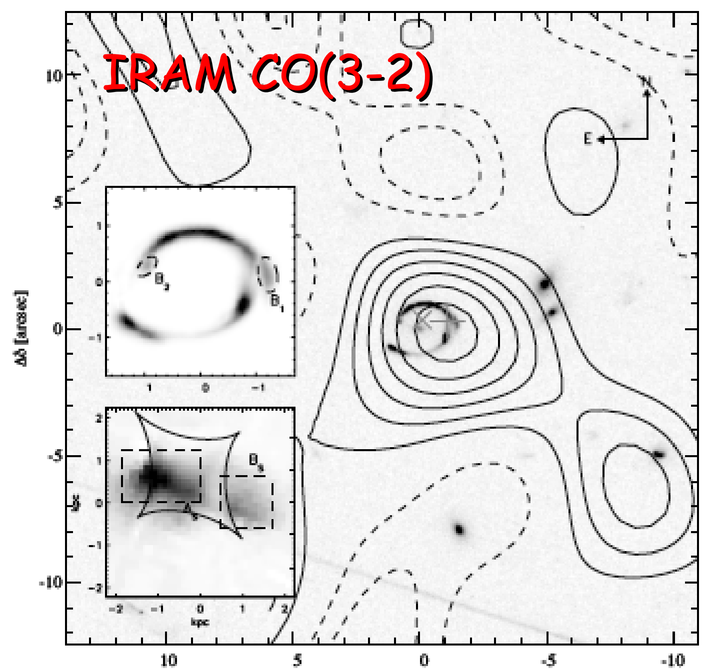


IRAM CO(3-2) data:

Luminosity → gas mass $\sim5\times10^8 M_\odot$

Line width → dynamical mass $\sim10^{10} M_\odot$





Coppin et al. 2007

Ellis

`Cosmic Eye' - Preview of ALMA science

What is gas content of early galaxies?

z~3.07 LGB pair lensed by

L^*_K z=0.73 galaxy + z=0.33 cluster

Cluster provides ~30% boost & induces

non-concentricity of arcs

Magnification = × 28 ± 3

Sources 1.5 kpc apart (< 1kpc in size)

<u>Intrinsic properties:</u>

L_K = 22.6 ± 0.2 (AB), M_K=-22.2+/-0.2 (~L_K*)

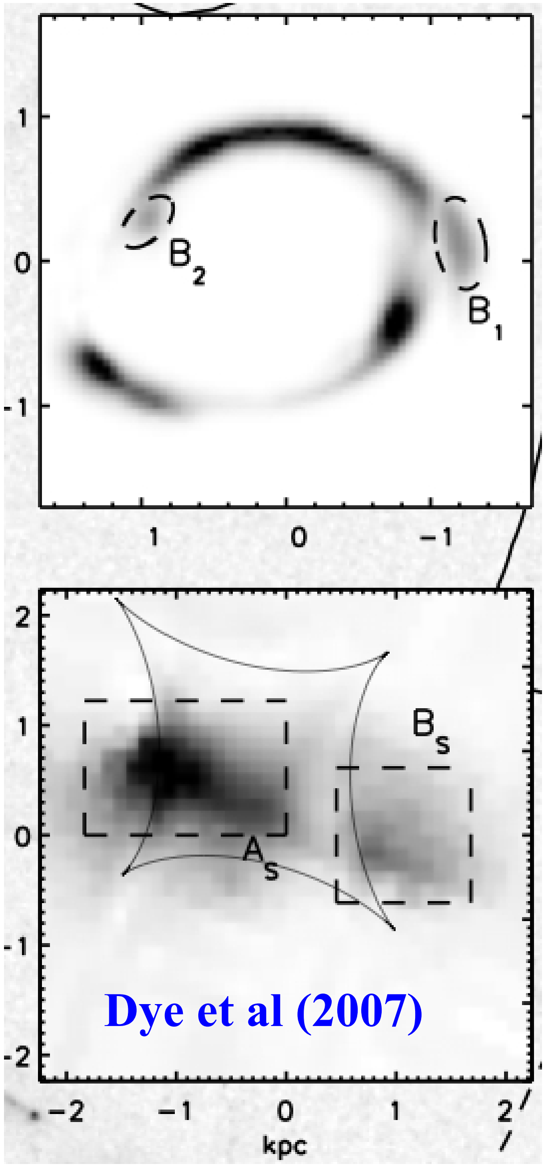
SFR ~ 100 $M_o yr^{-1}$

Masses: $1 \times 10^{10} M_o$ (dynamics)

$7 \times 10^{9} M_o$ (stellar)

$5 \times 10^{8} M_o$ (gas)

Timescale = Gas mass/SFR = 40Myr!



Dye et al (2007)

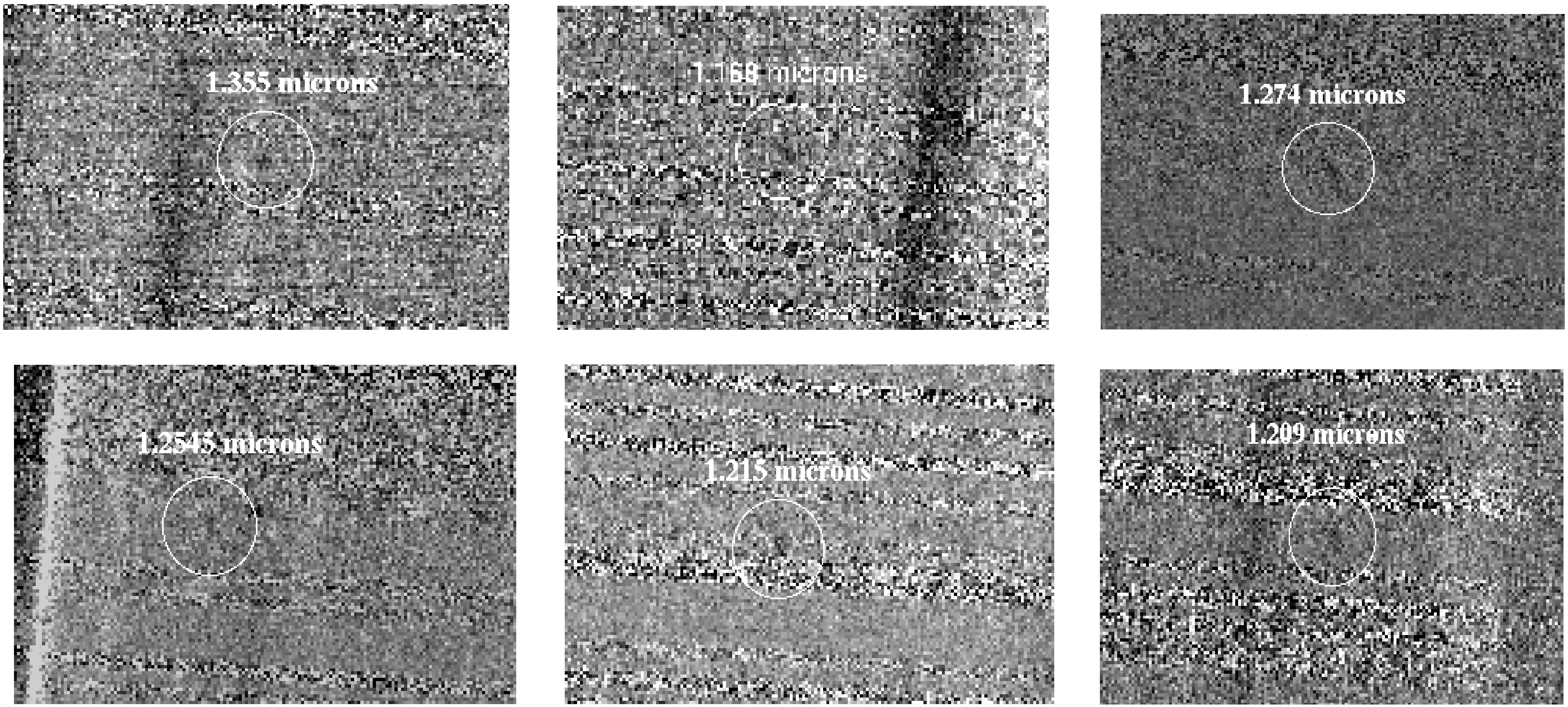
Gas-rich & similar (less vigorous) to sub-mm popn.

Smail et al 2007; Coppin et al 2007

Ellis

Candidate Lyα Emitters

$8.6 < z < 10.2$; L ~ 2 - 10. 10^{41} cgs; SFR ~ 0.2 - 1 M yr^{-1}



Recognize burden of proof that these are z~10 emitters is high

Each detection is > 5σ, seen in independent exposures/visits

- **Now believe >3/6 candidates likely to be 8<z<10 sources**

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Summary

Suyu

- Bayesian Source and Potential Reconstruction:

  iterative and perturbative potential correction scheme works for potential perturbations of ~5%

- *HST* observations of B1608+656:

  obtained a representative suite of PSF, dust, and lens galaxies' light models using ACS and NICMOS images

- Potential reconstruction of B1608+656:

  corrected initial potential SPLE1+D(isotropic) on a grid of pixels for each set of PSF, dust, lens galaxies' light models.

  Bayesian techniques can be used to compare objectively different PSF, dust, lens galaxy light, and lens potential model and used to quantify modeling (statistical) error.

  Mass sheet degeneracy is the strongest systematic error

  → H_0=72 ± 2(stat.) ± 4(syst.) km s^{-1} Mpc^{-1}

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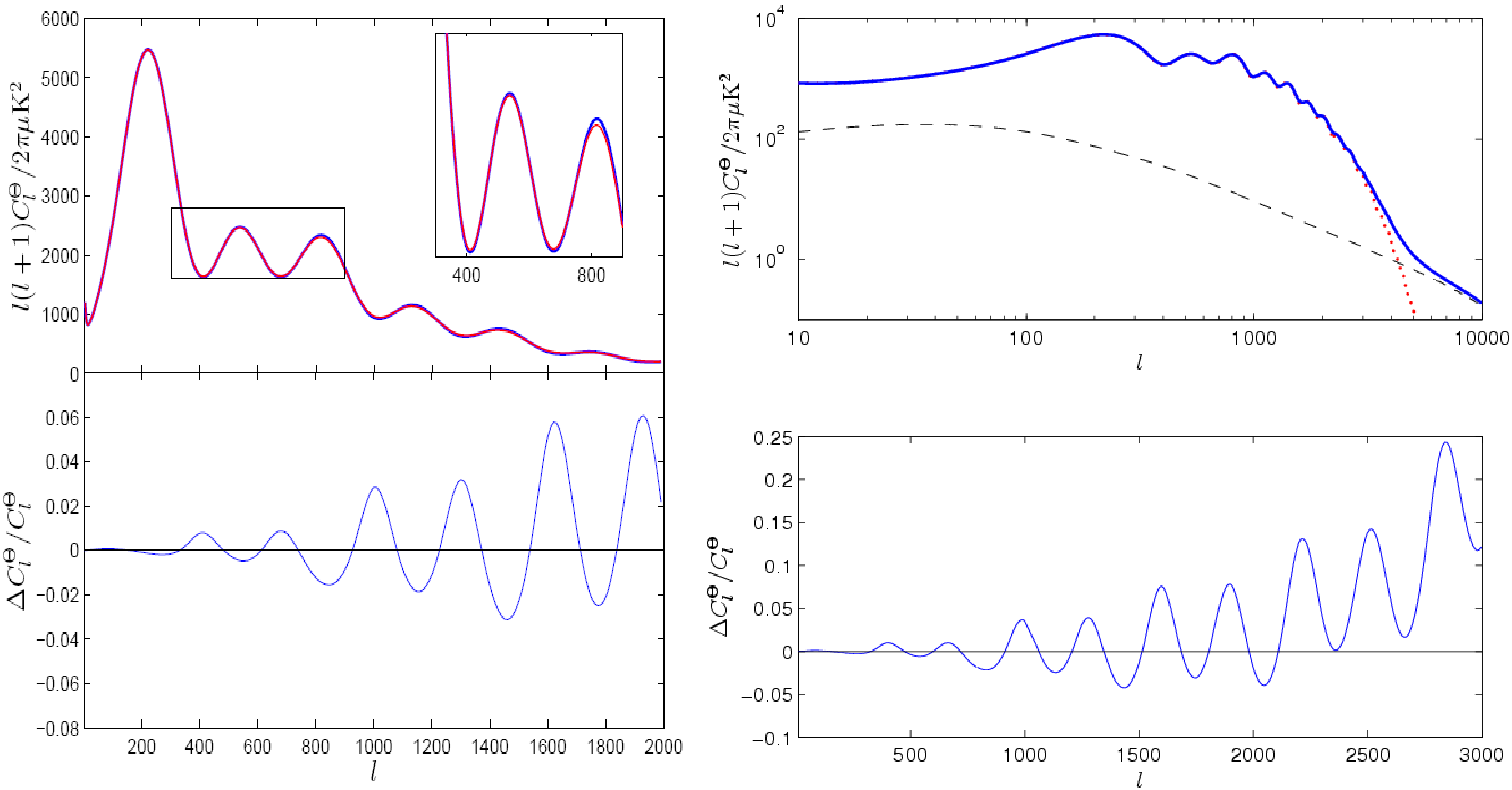
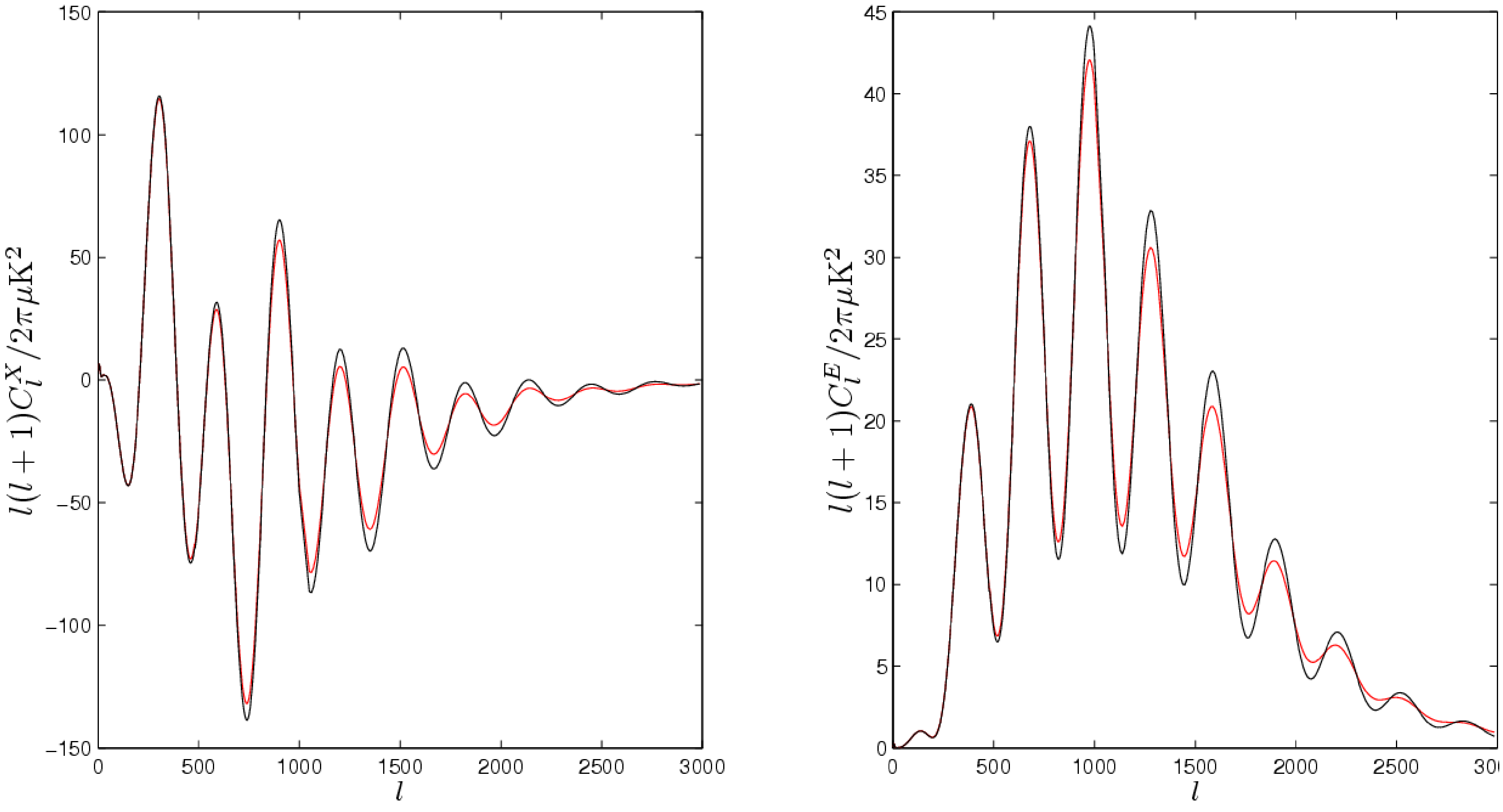
Lensing effect on CMB temperature power spectrum



CAMB's 0.1% calculation; http://camb.info : Challinor & Lewis 2005, astro-ph/0502425

Polarization lensing: C_X and C_E



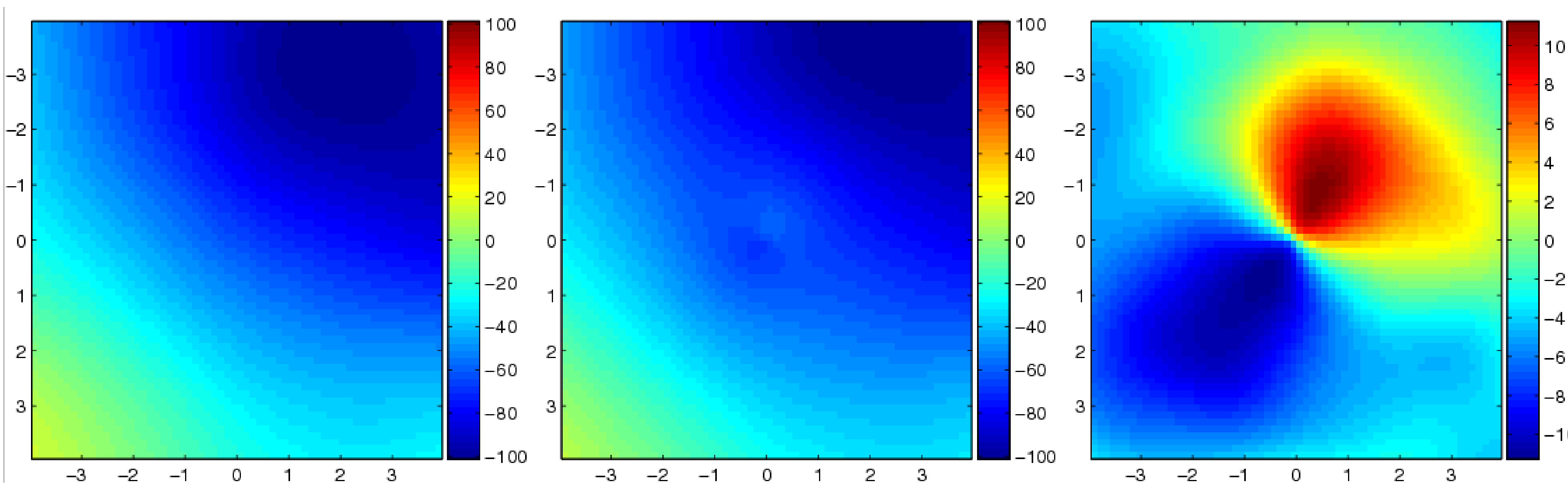
Lewis

RMS gradient ~ 13 μK / arcmin
deflection from cluster ~ 1 arcmin

Lensing signal ~ 10 μK

BUT: depends on CMB gradient behind a given cluster

Unlensed | Lensed | Difference



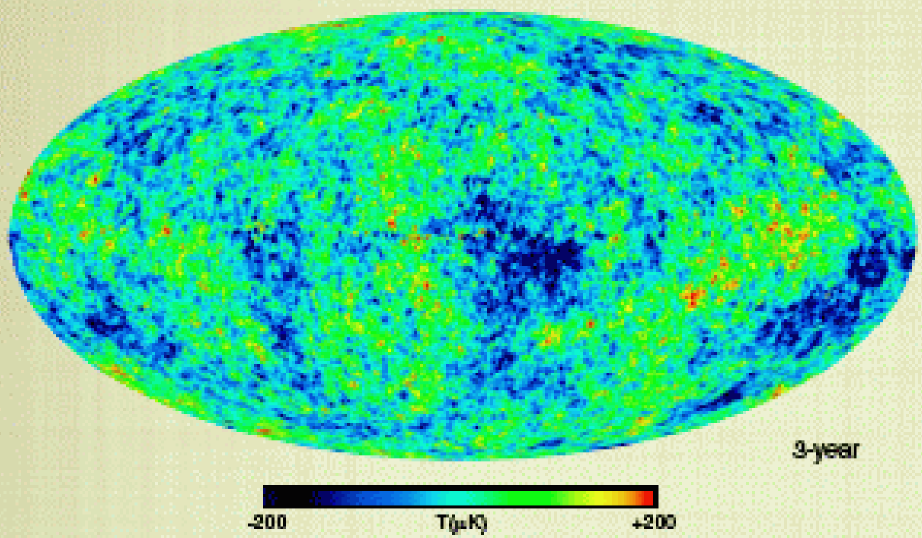
Unlensed CMB unknown, but statistics well understood (background CMB Gaussian) :

can compute likelihood of given lens (e.g. NFW parameters) essentially exactly

Dore

DATASETS

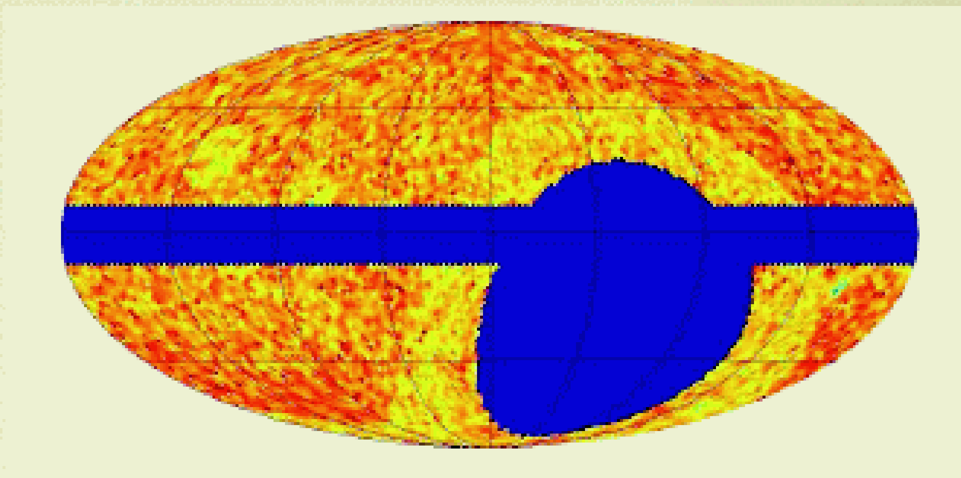
WMAP



- 3 yr public temperature maps
- 3 bands (Q, V and W) combined or not
- Use Kp0 mask to cover 79% of the sky (galactic emissions and pt sources)
- Take into account, for each DA:
  - beam window functions (circular)
  - exact beam patterns
- Exact inhomogeneous noise patterns

Hinshaw et al. 06

NVSS

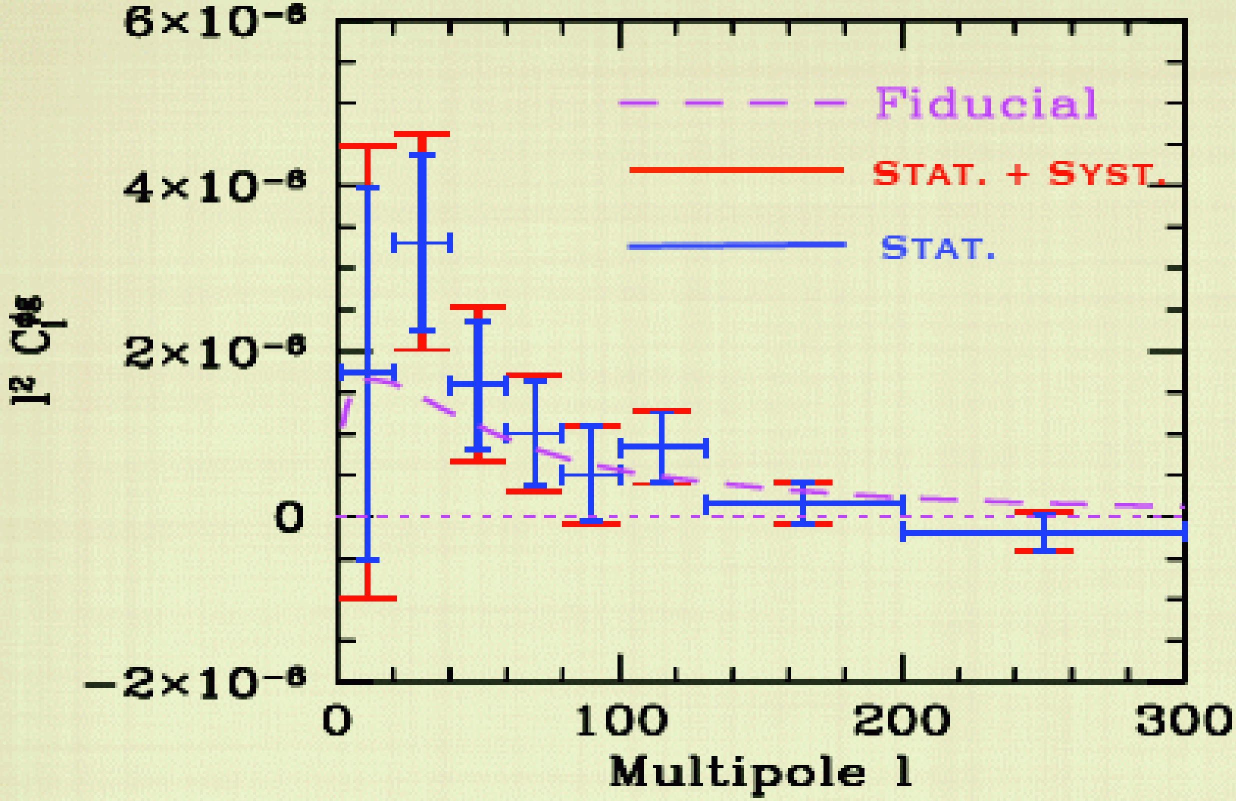


- NRAO VLA Sky Survey
- 1.4 GHz continuum survey 50% complete at 2.5mJy
- AGN powered radio galaxies, quasars, near star-forming galaxies
- Covers 82% of the sky
- After removing bright objects (>1Jy)and low galactic latitude ($|b|<10$), we ended up using 1.29 10^6 gal., ie 1.6 10^5 gal/ steradian
- Redshift distribution has a mean of 0.89 and peaks around 1.

Condon et al. 98

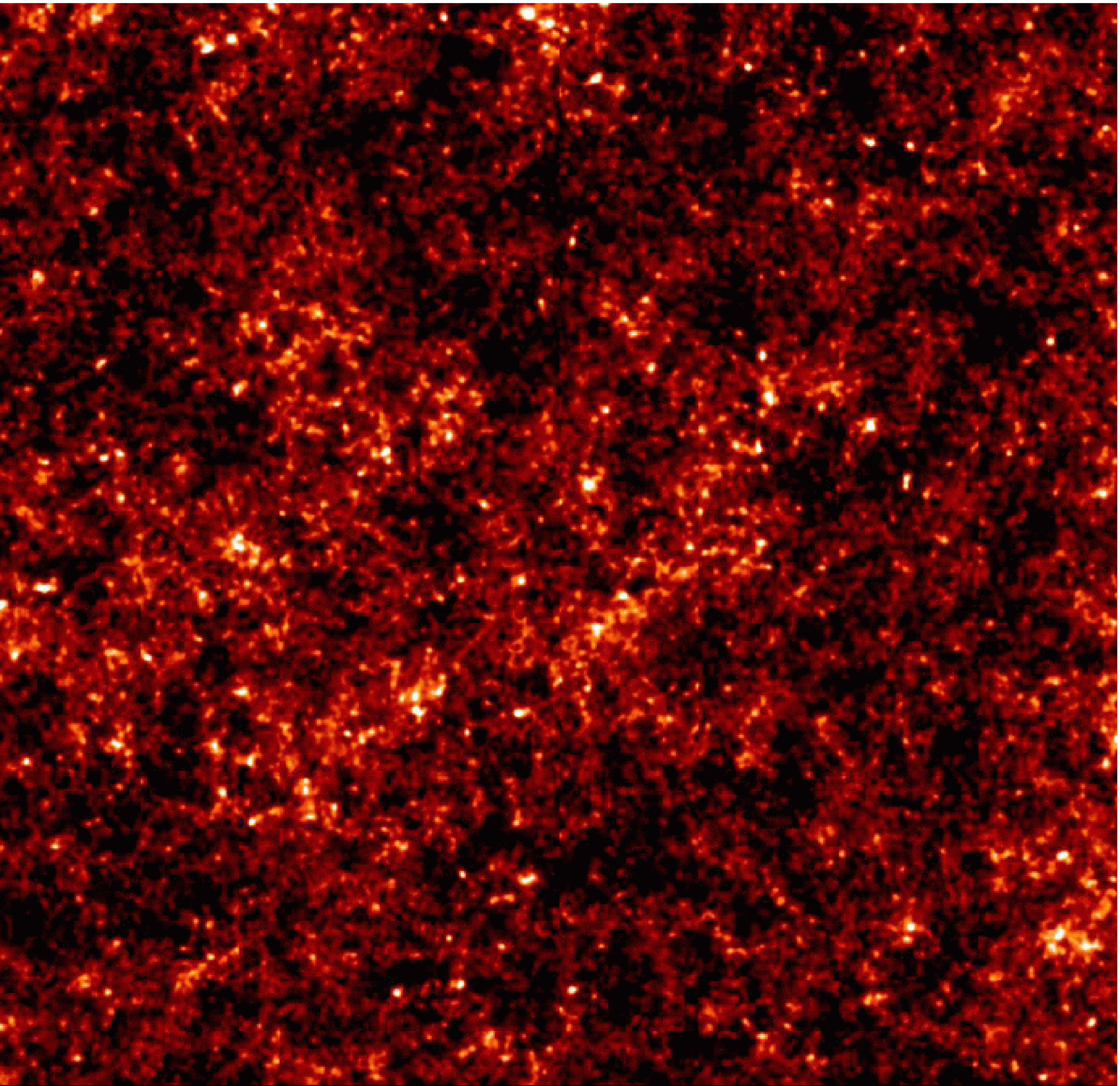
Final measurement

Dore



- Q, V and W combined
- All systematics are combined
- Results are robust wrt systematic effects
- Combined in one single band power:

$C = 1.15 \pm 0.34$, i.e. a 3.4σ signal detection



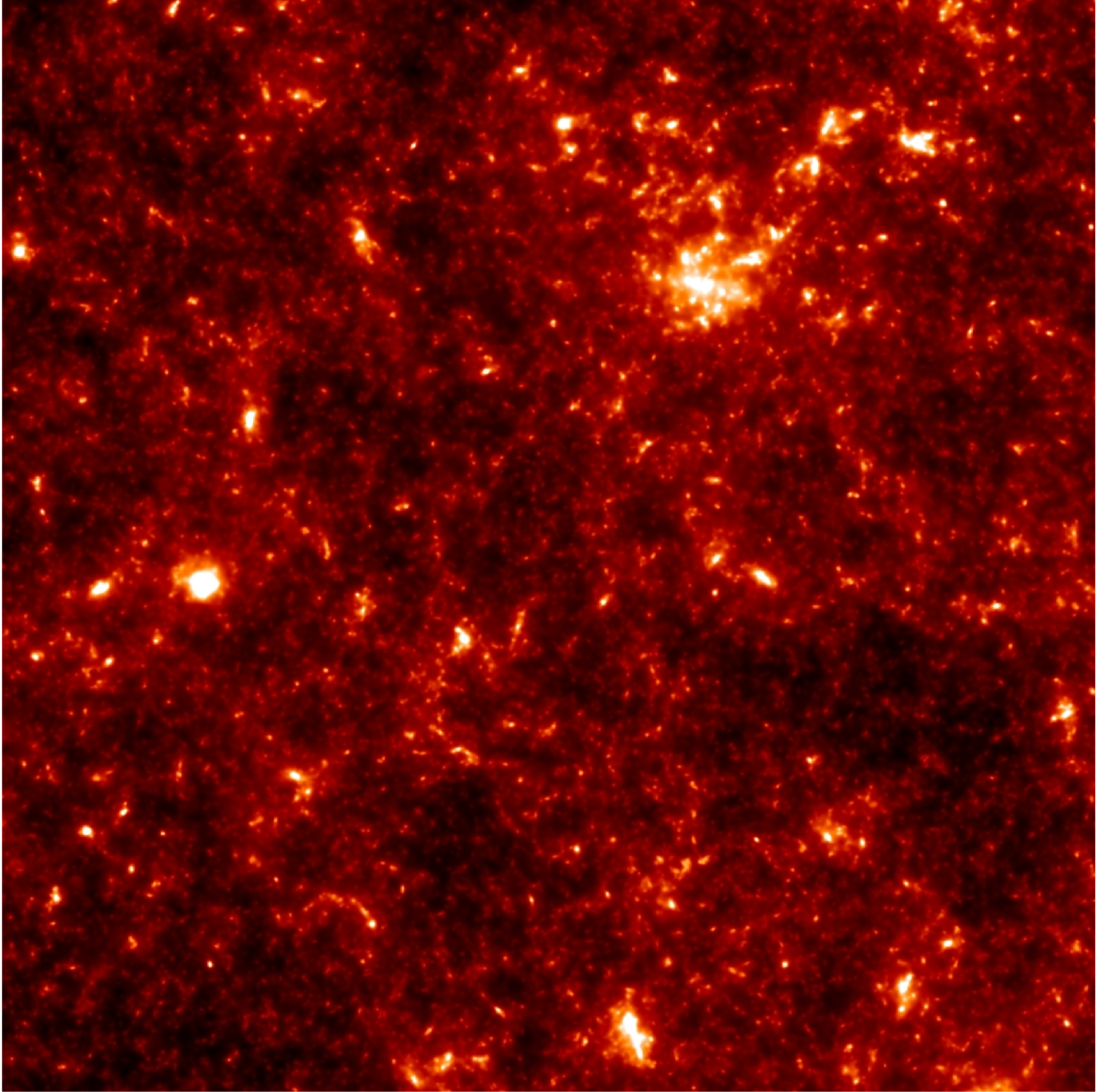
Hilbert, Metcalf

5° x 5°
as mapped by
`SKA'

$z_{source} \sim 12$

$\Delta\theta \sim 1'$

S/N ~ 4 per pix.
(cf S/N ~ 1.5
for a galaxy
survey with
100 gals/amin^2)



Hilbert, Metcalf

15' x 15'
as mapped by
`superSKA'





Domino GT

THANK YOU!

Yannick Mellier
Karim Benabed
Delphine Charbonneau