Dark Matter
(The Astrophysical Perspective)

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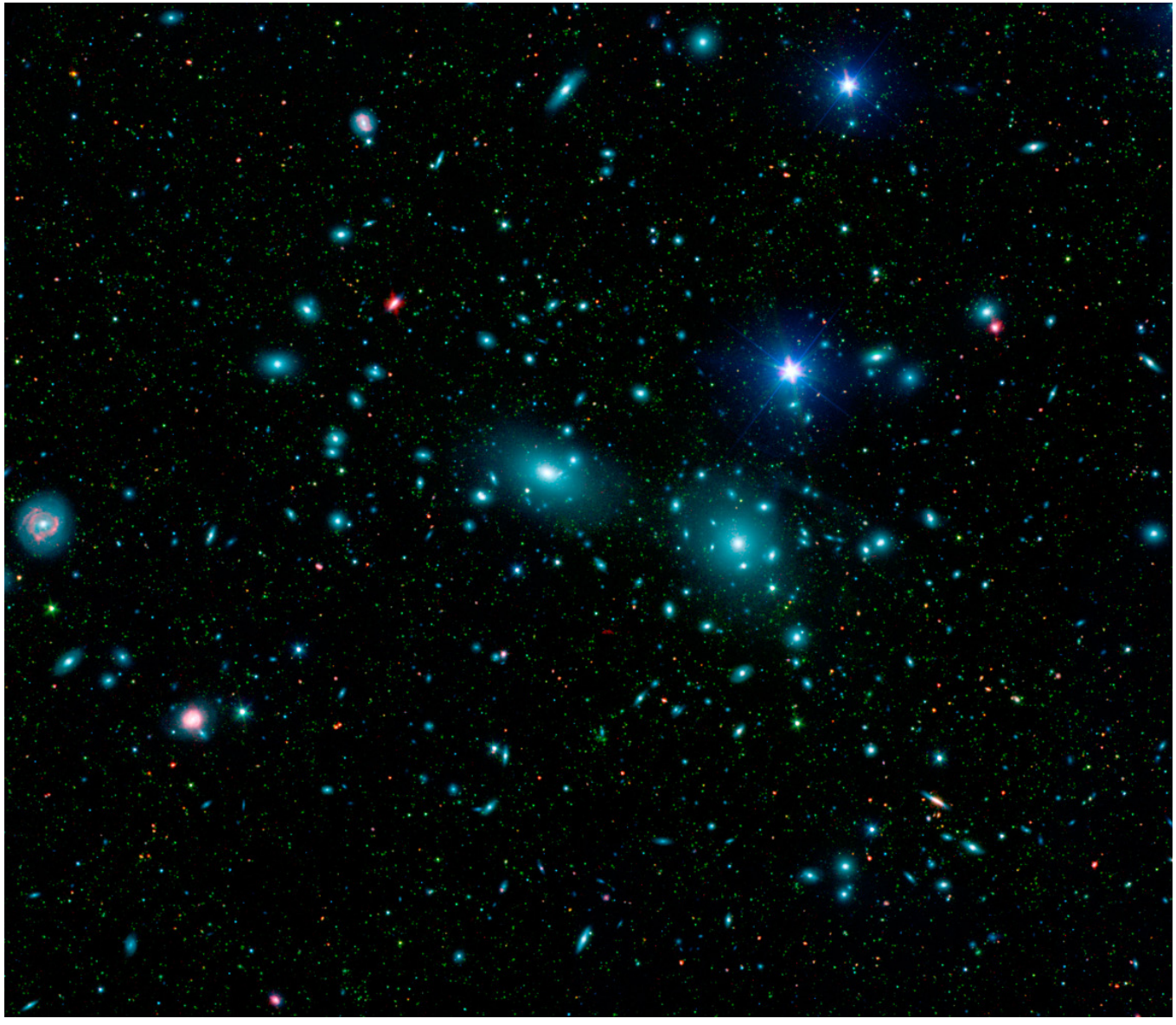
Dark Matter in Galaxy Clusters



Coma galaxy cluster

Dark Matter in Galaxy Clusters

galaxy cluster MACS J 1206, CLASH project

virial theorem:

$$\frac{GM}{R} \approx 3\sigma_v^2$$

Dark Matter in Galaxy Clusters

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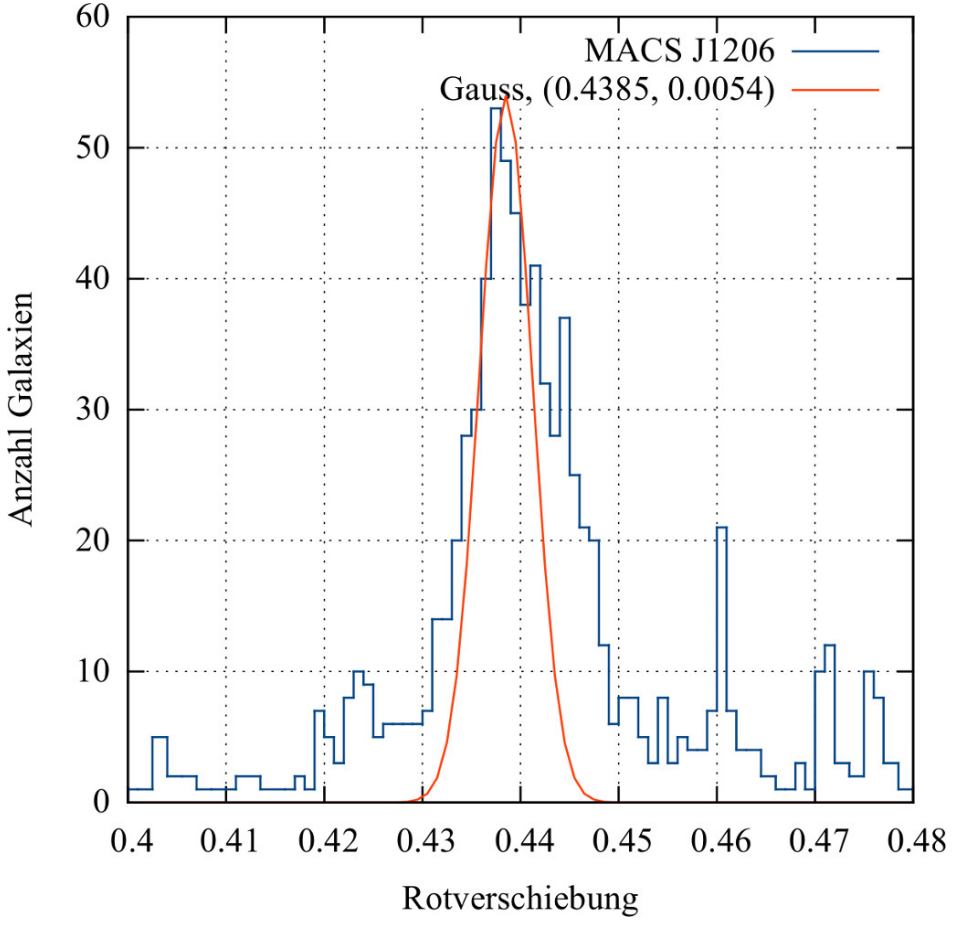
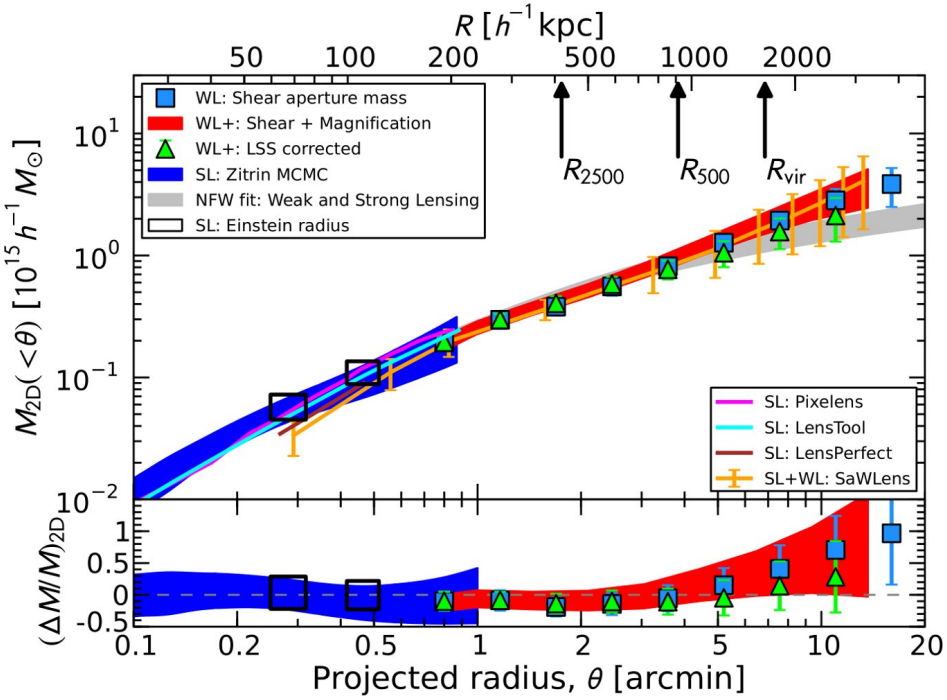
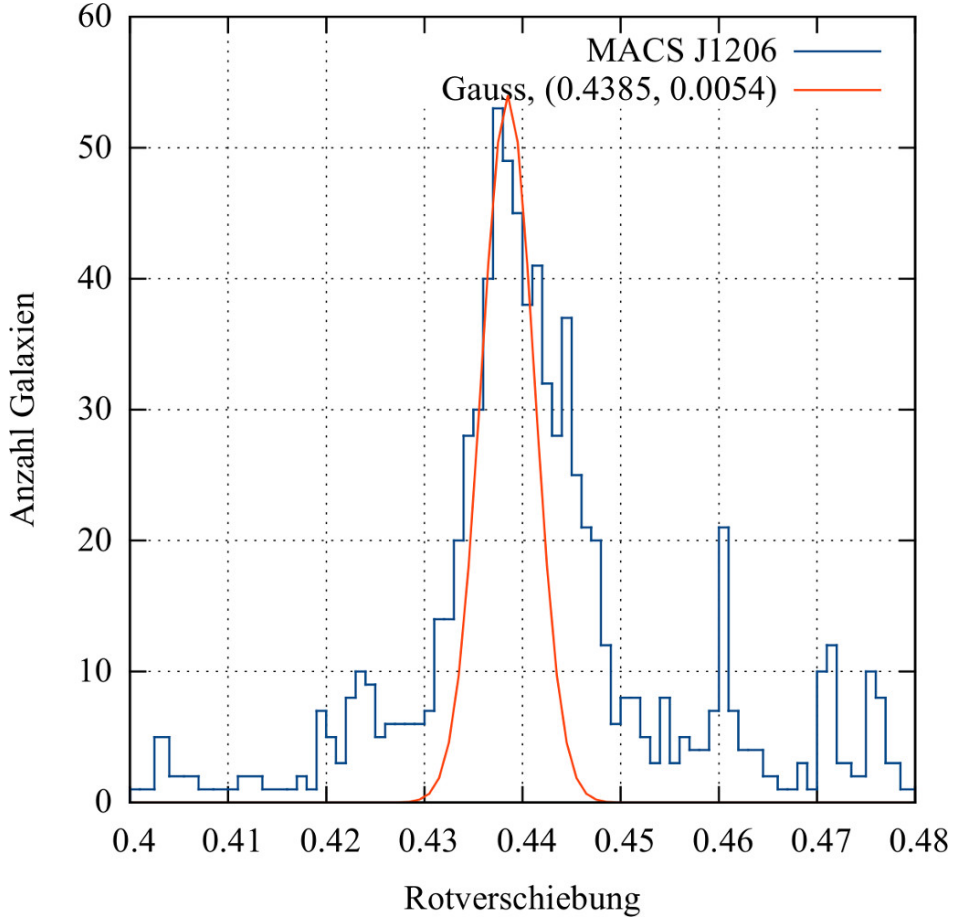


velocity dispersion, Rosati et al.

Dark Matter in Galaxy Clusters

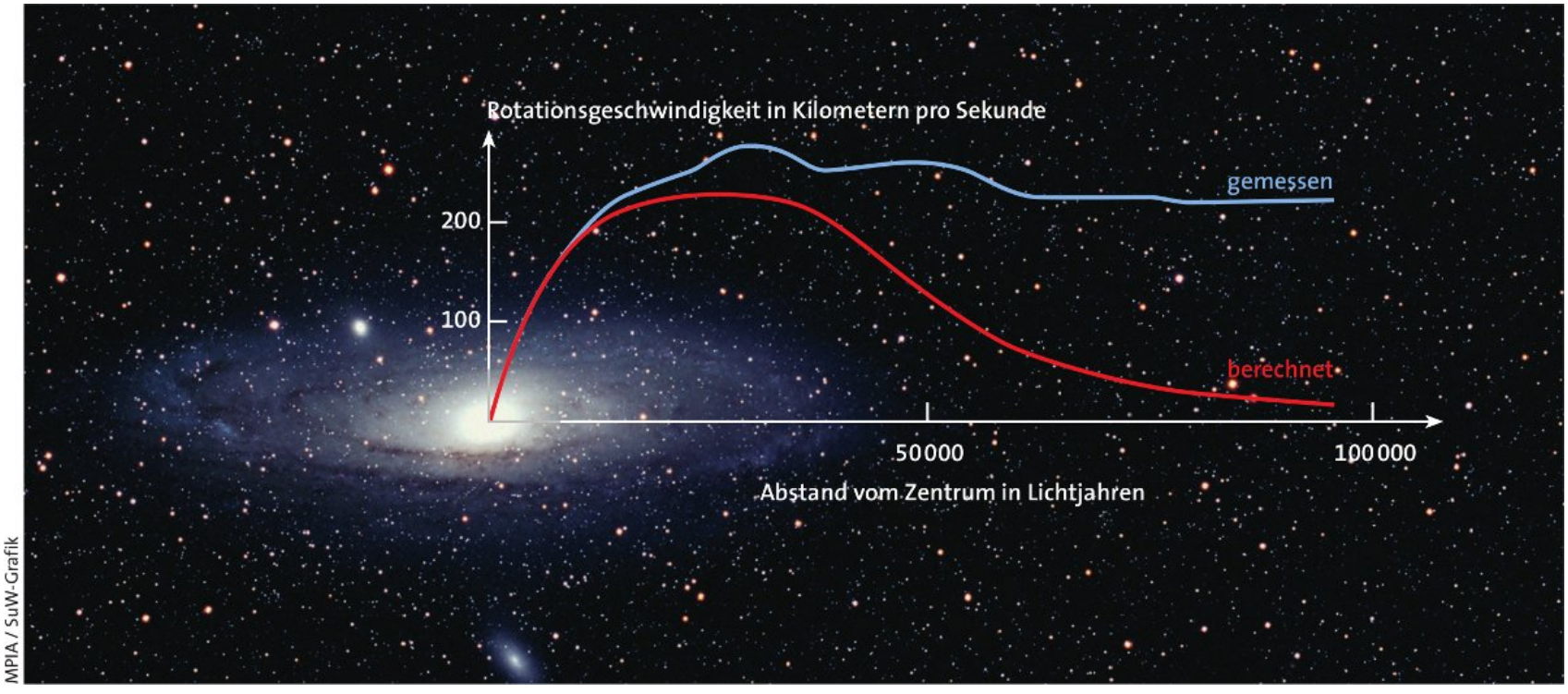


mass profile, CLASH project



velocity dispersion, Rosati et al.

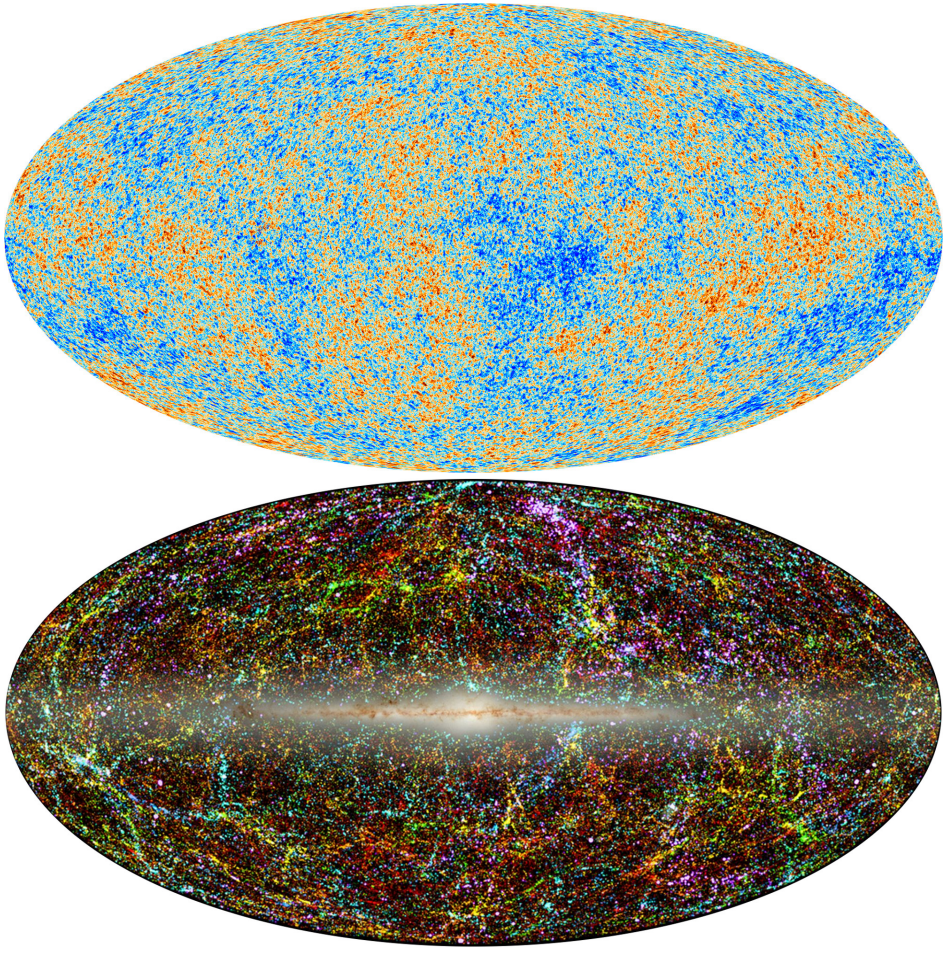
Dark Matter in Galaxies



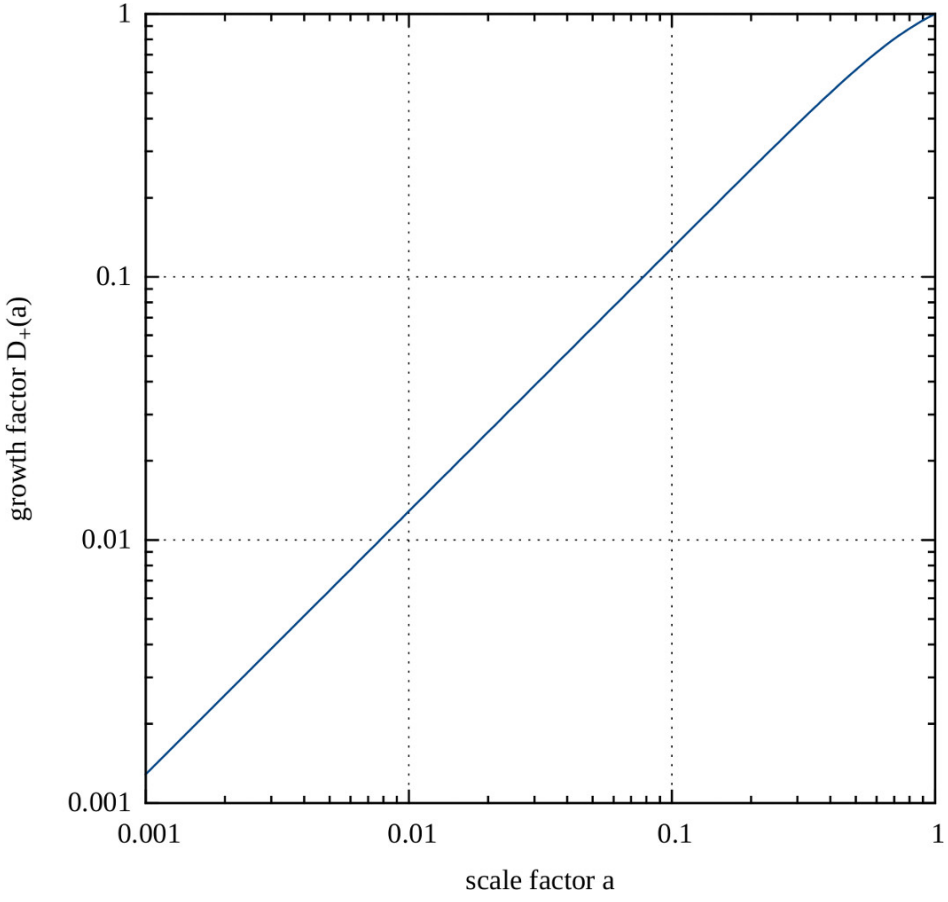
rotation curve, Andromeda galaxy

$$\frac{GM(r)}{r} = v_{\mathrm{rot}}^2$$

Dark Matter in the Universe

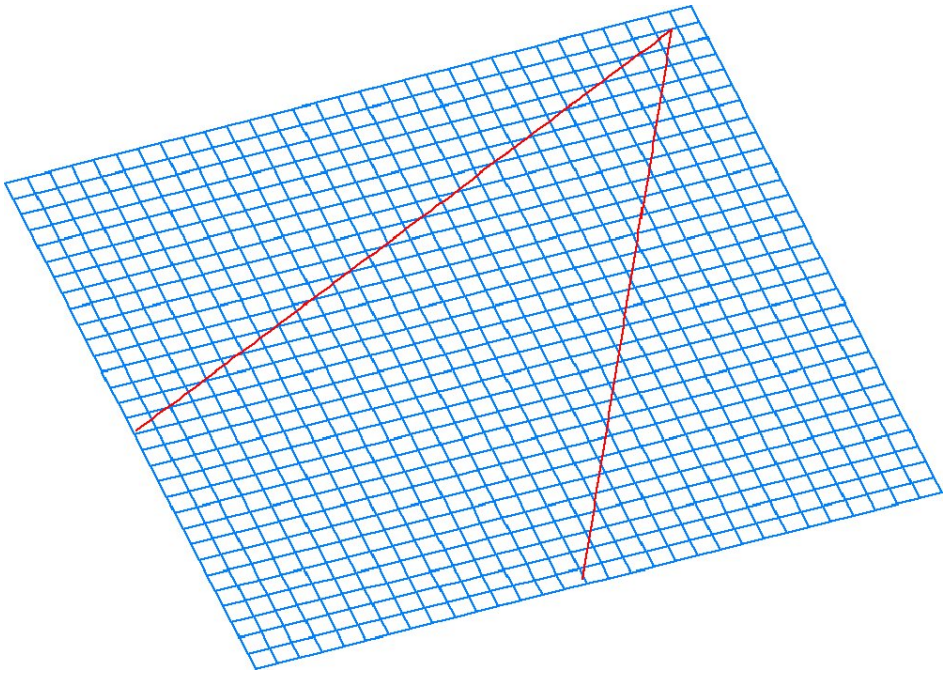


top: Planck CMB map, bottom: 2-micron all-sky survey

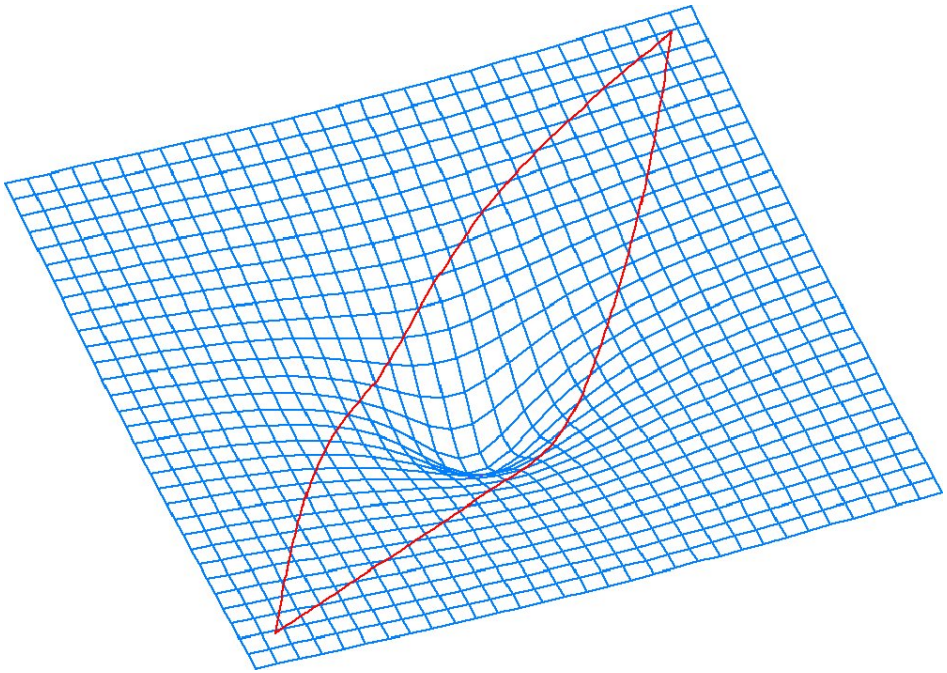


growth of cosmic structures

Light Deflection by Mass



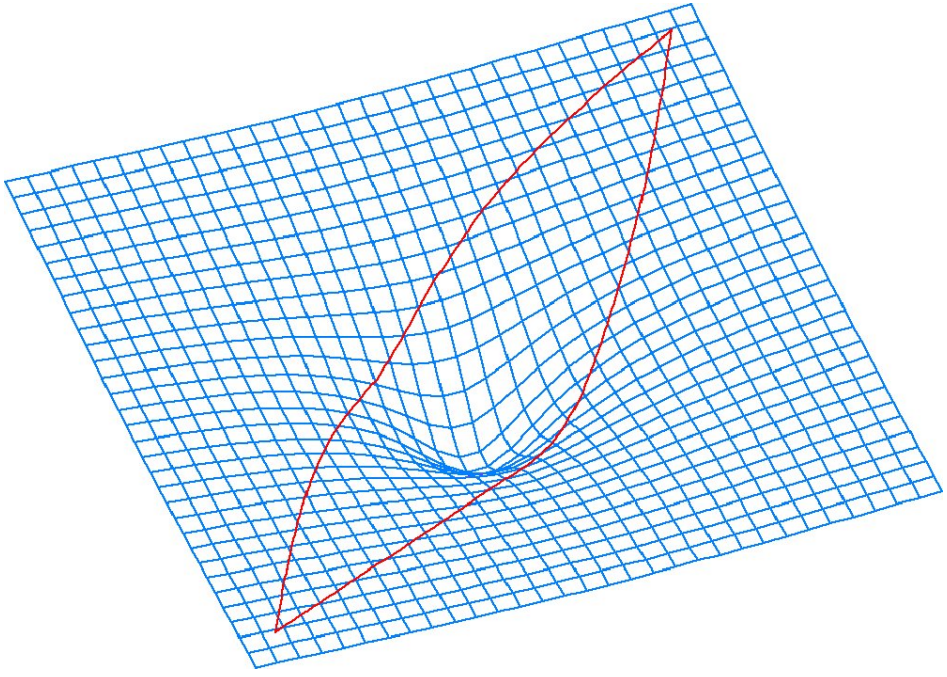
Light Deflection by Mass



index of refraction:

$$n = 1 - \frac{2\Phi}{c^2}$$

Light Deflection by Mass



galaxy cluster MACS J 1206, CLASH project

Mass Mapping in Galaxy Clusters

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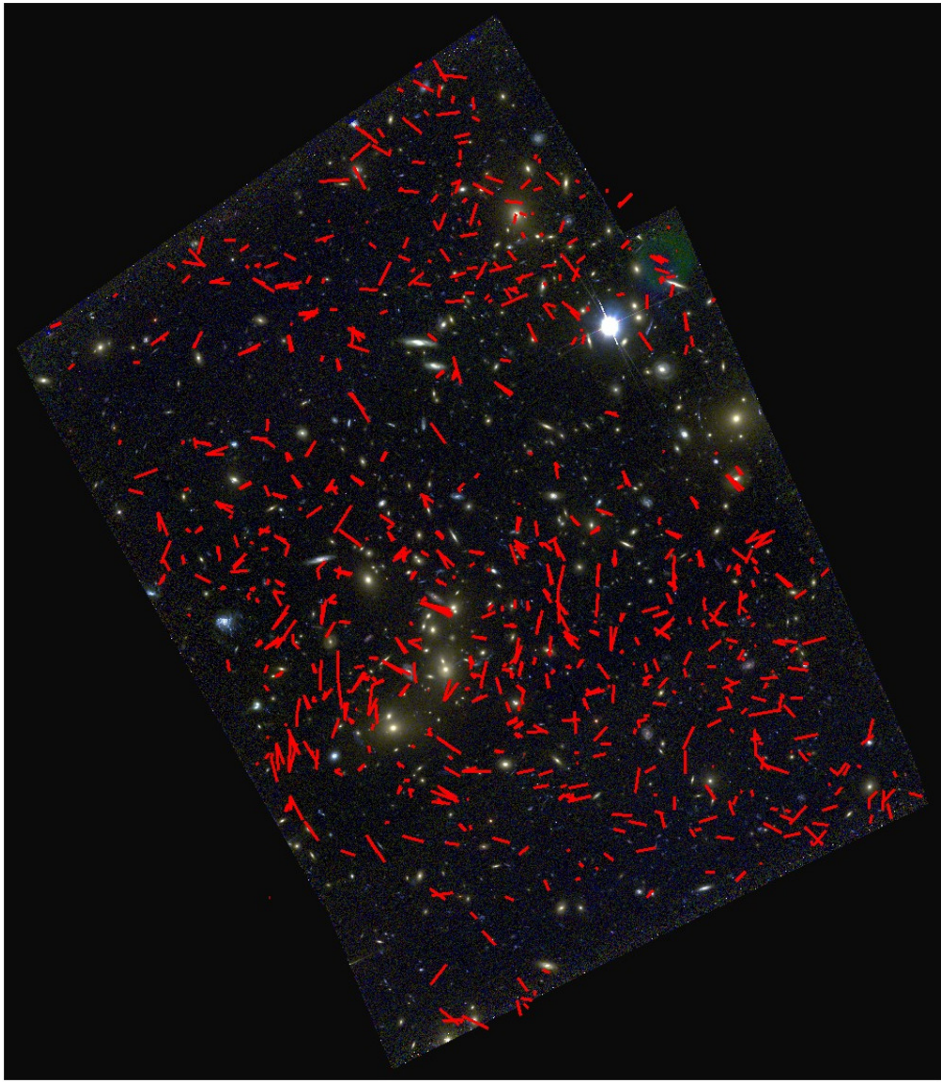
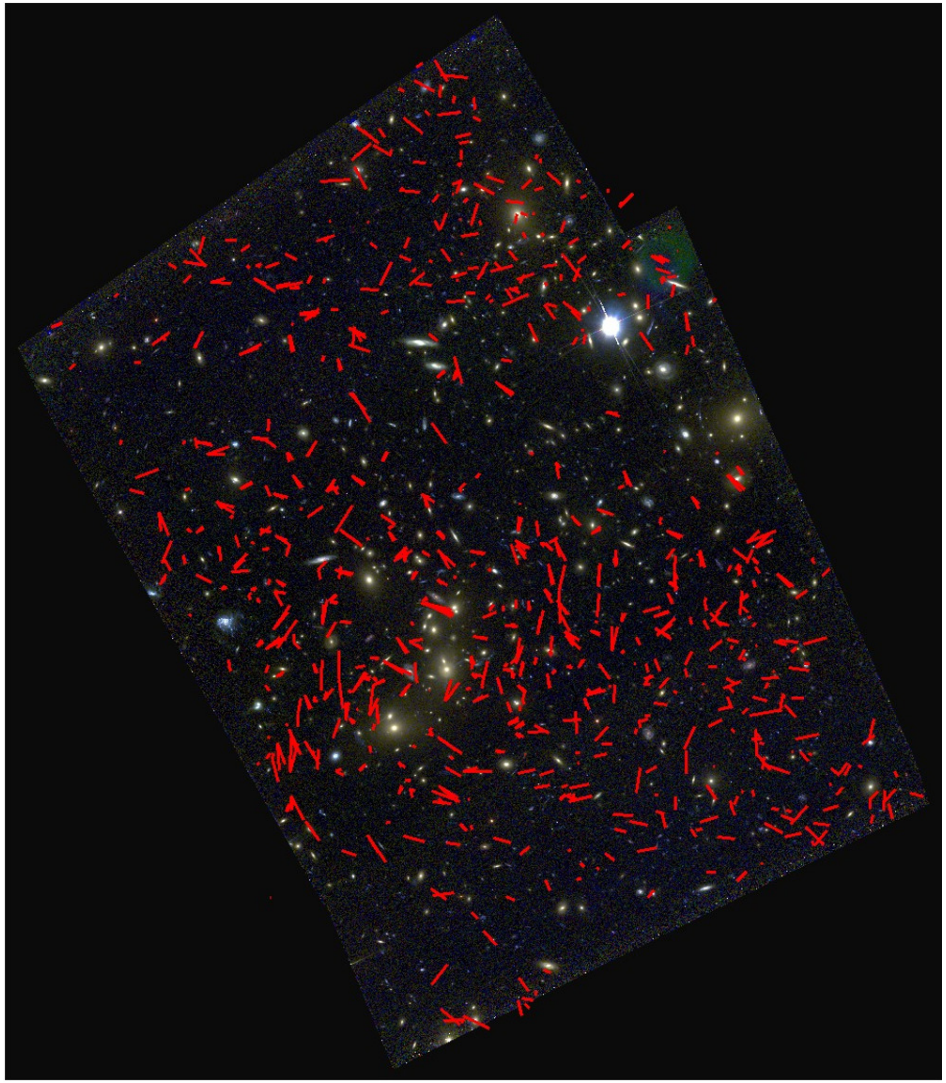
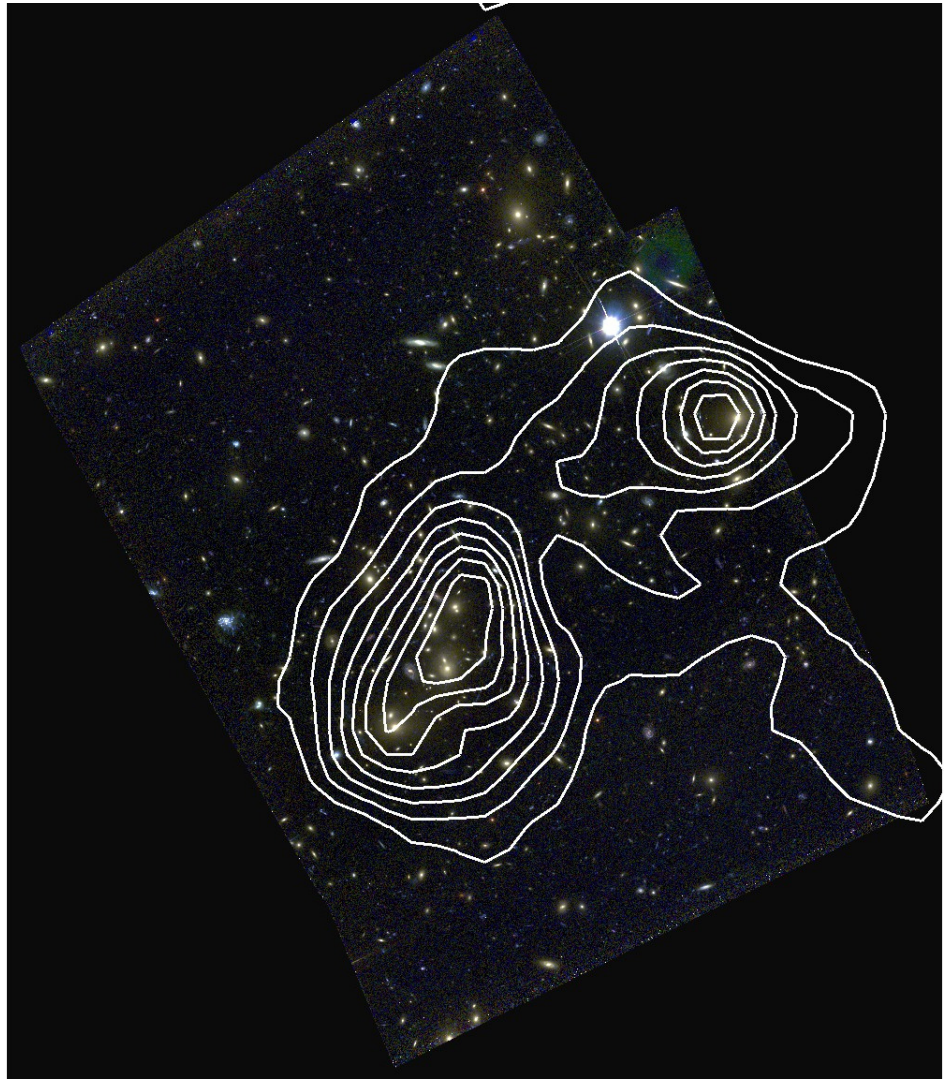


- ellipticities trace the tidal field (shear)
- shear is converted to matter density

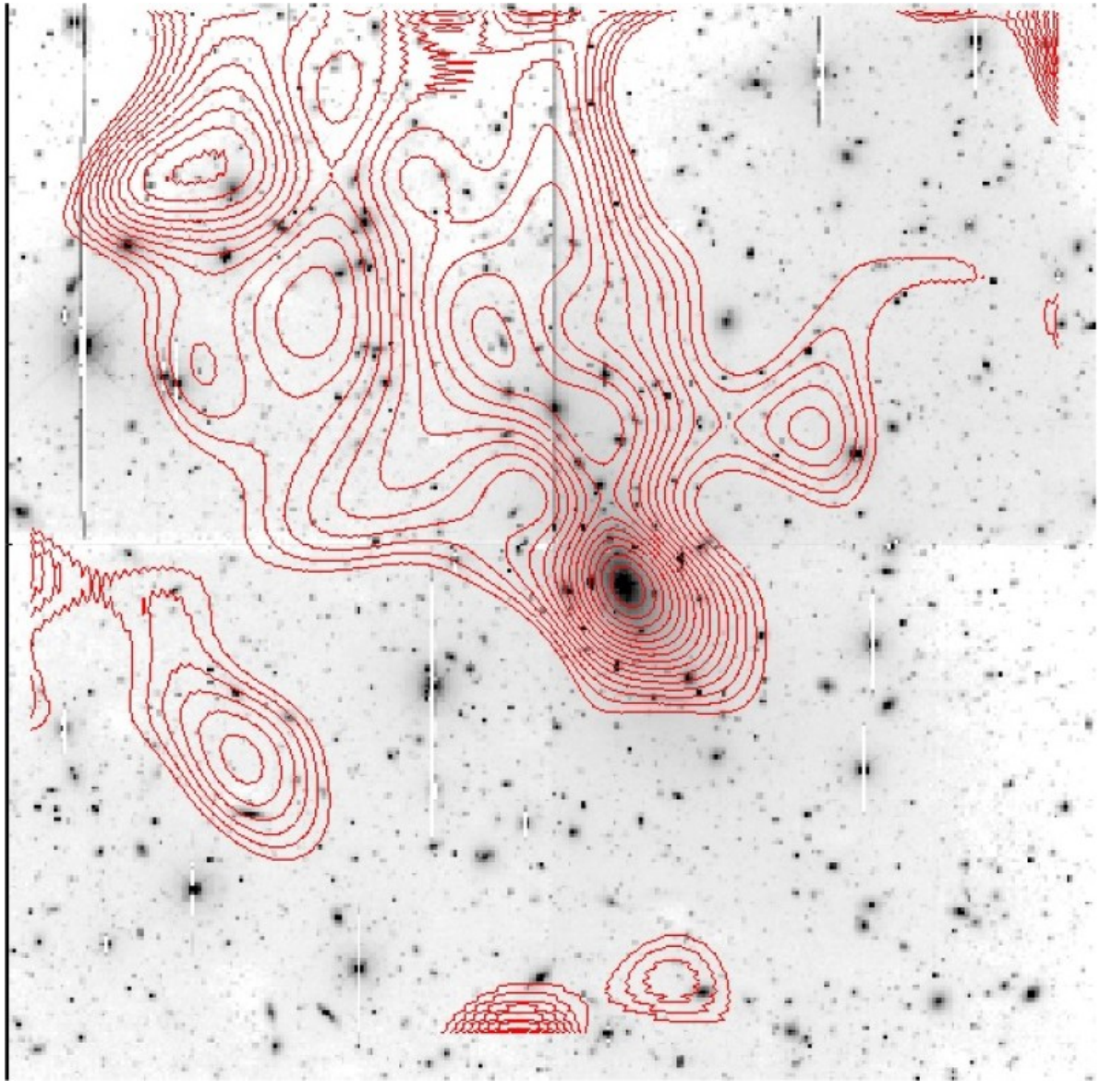
Mass Mapping in Galaxy Clusters





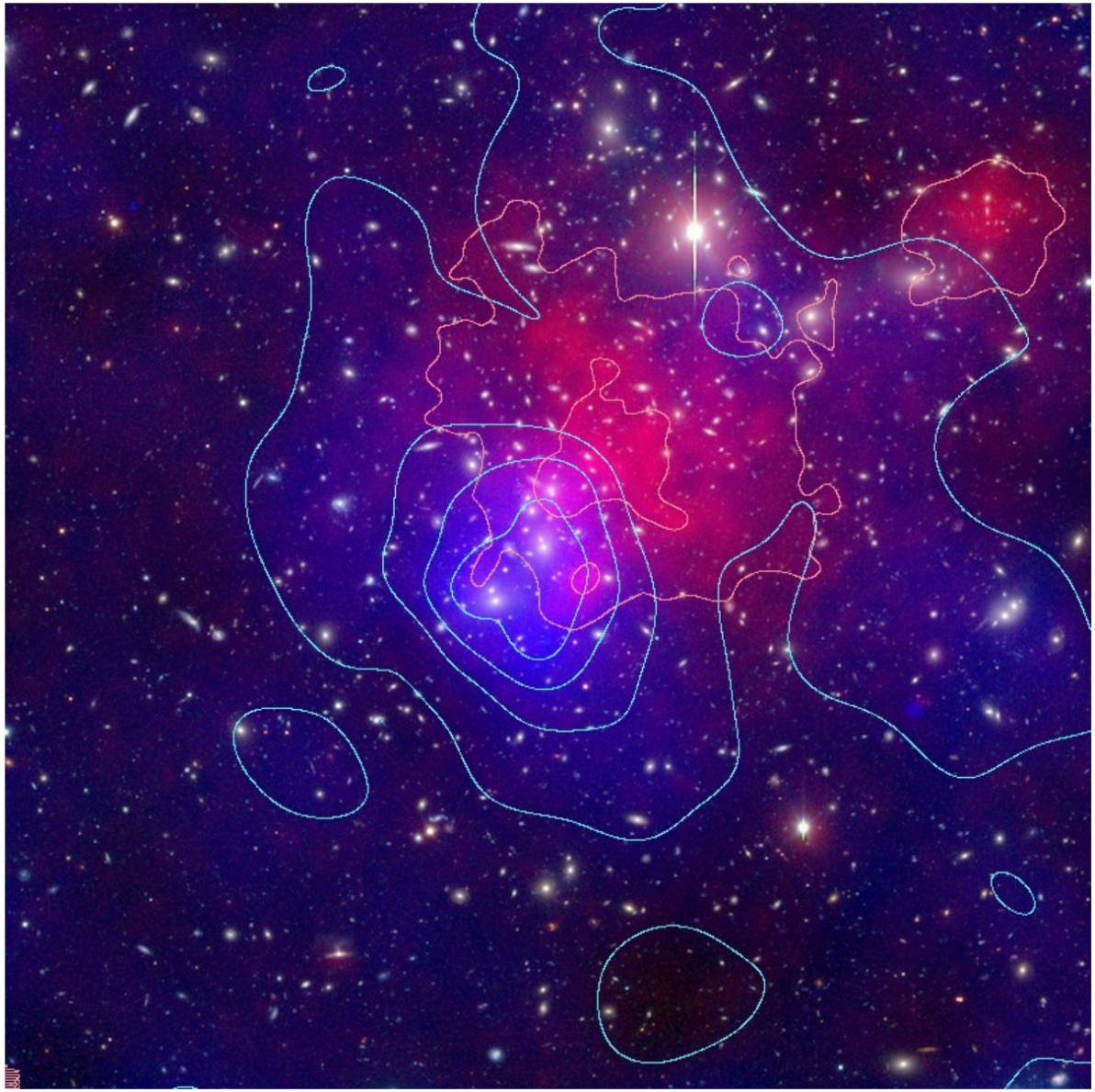
galaxy cluster Abell 2744, Merten et al.

Mass Mapping in Galaxy Clusters



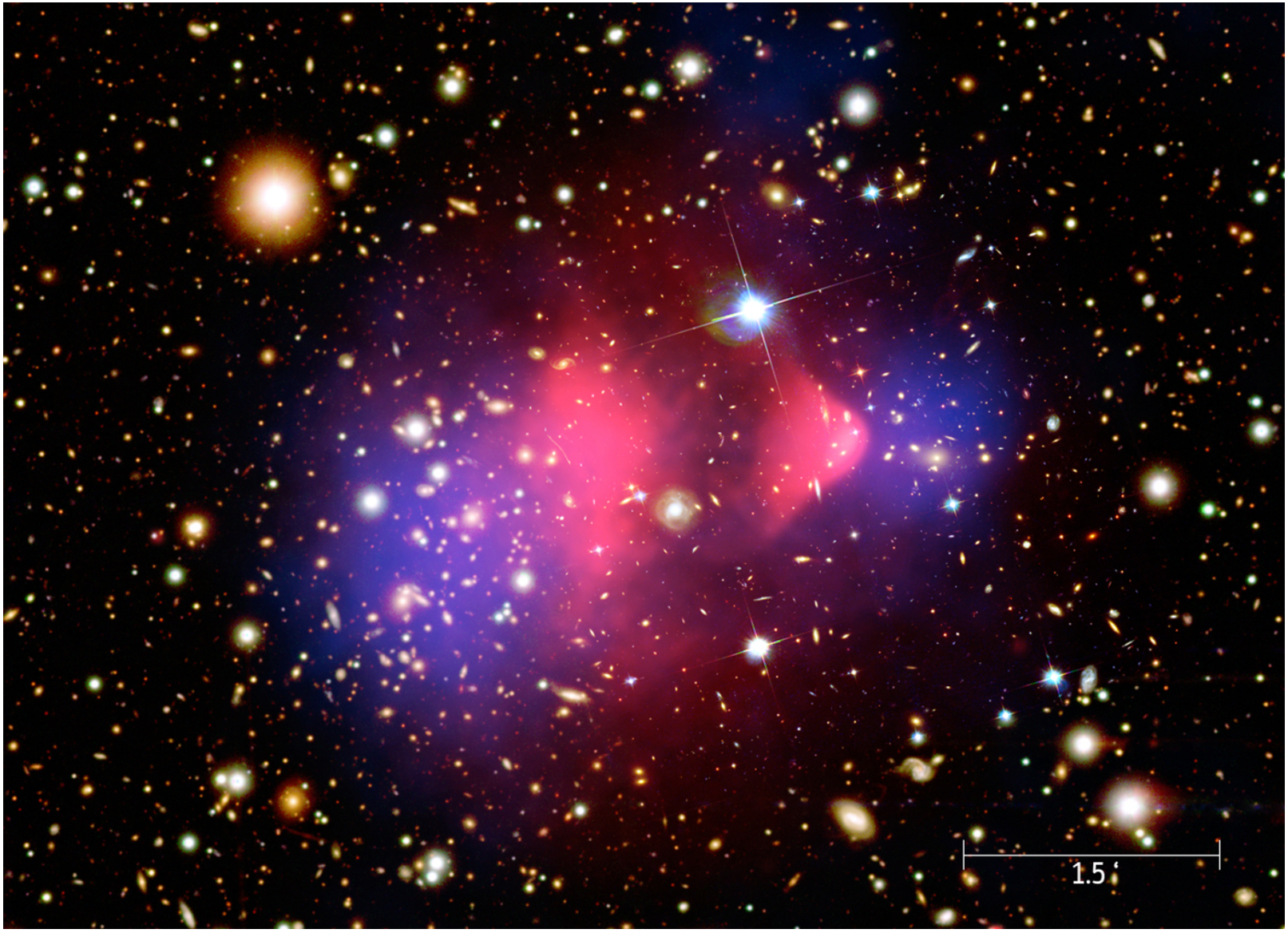
galaxy cluster Abell 2029, Ménard et al.

Mass Mapping in Galaxy Clusters



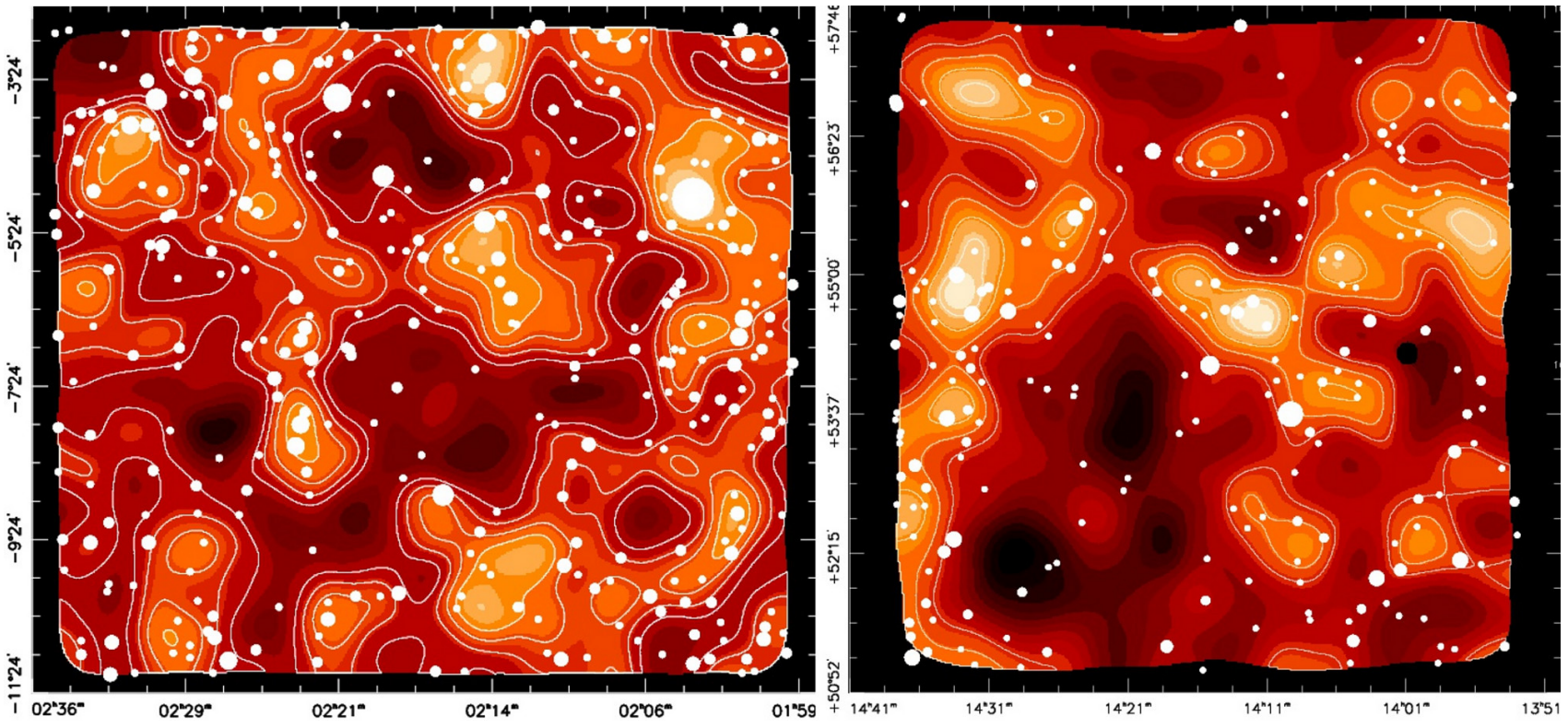
galaxy cluster Abell 2744, Merten et al.

Mass Mapping in Galaxy Clusters



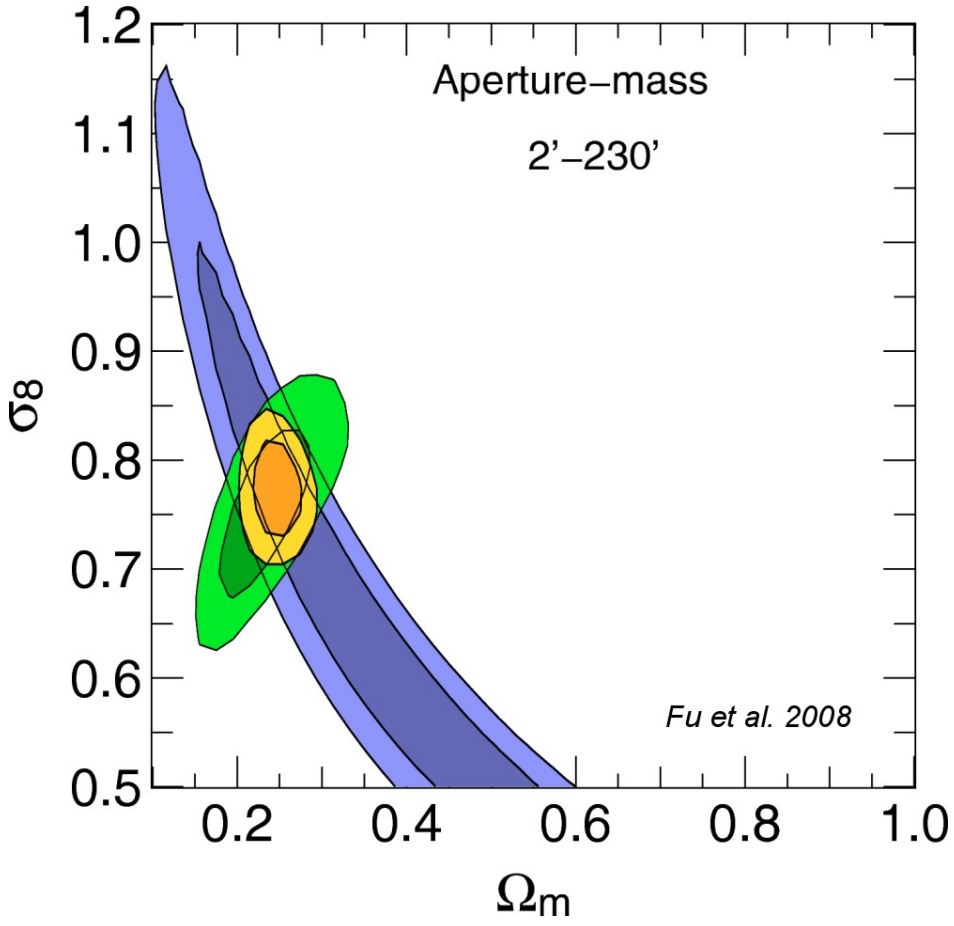
galaxy cluster 1E 0657–558, Bradač et al.

Mass Mapping in the Universe



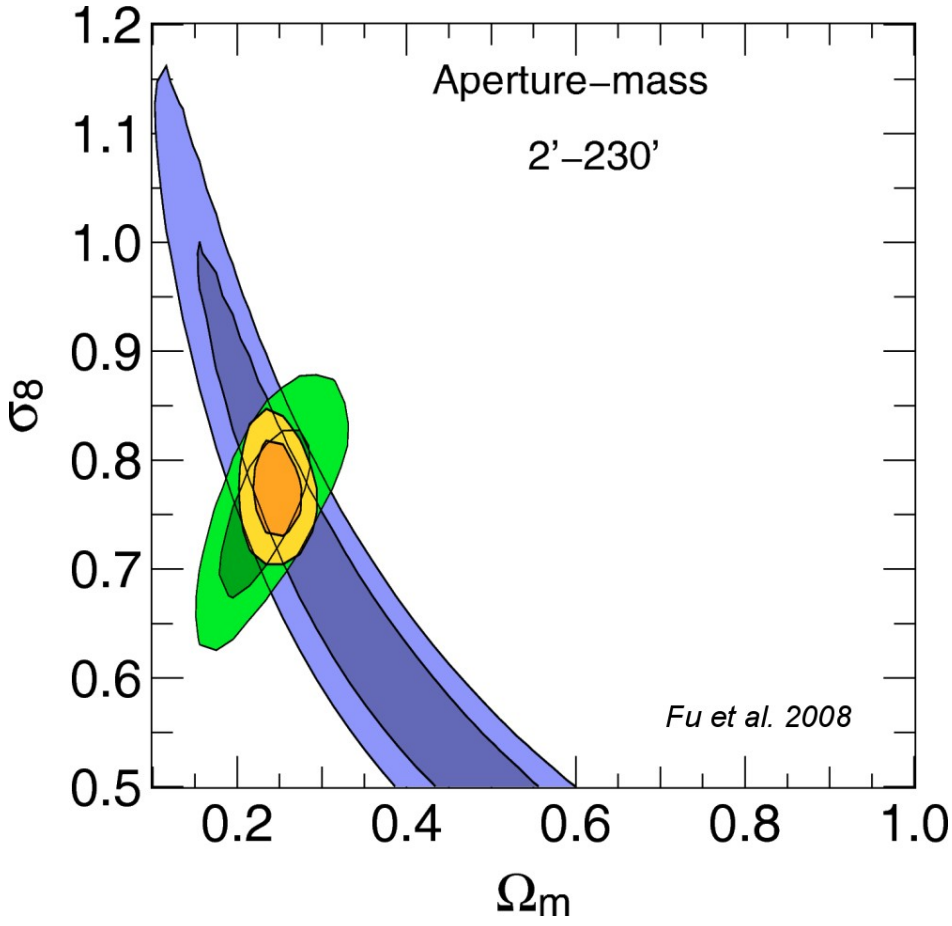
CFHTLS, van Waerbeke et al.

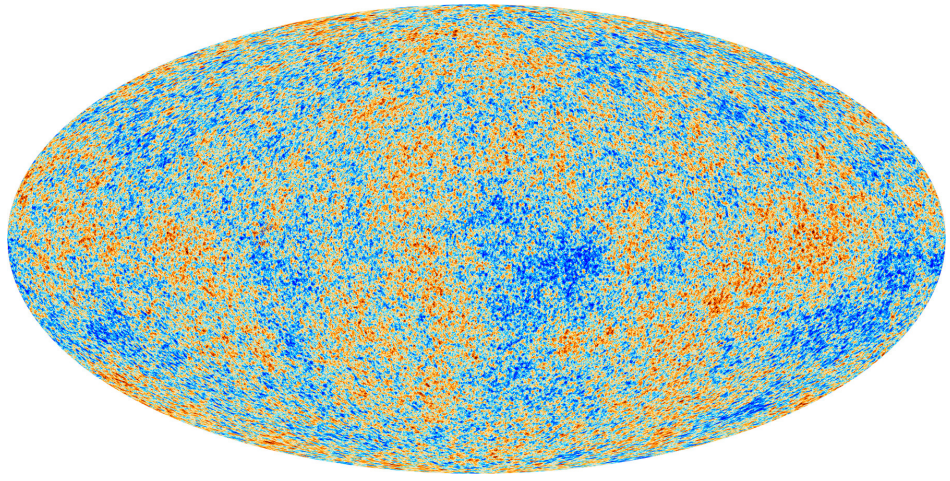
Mass Mapping in the Universe



CFHTLS, Fu et al.

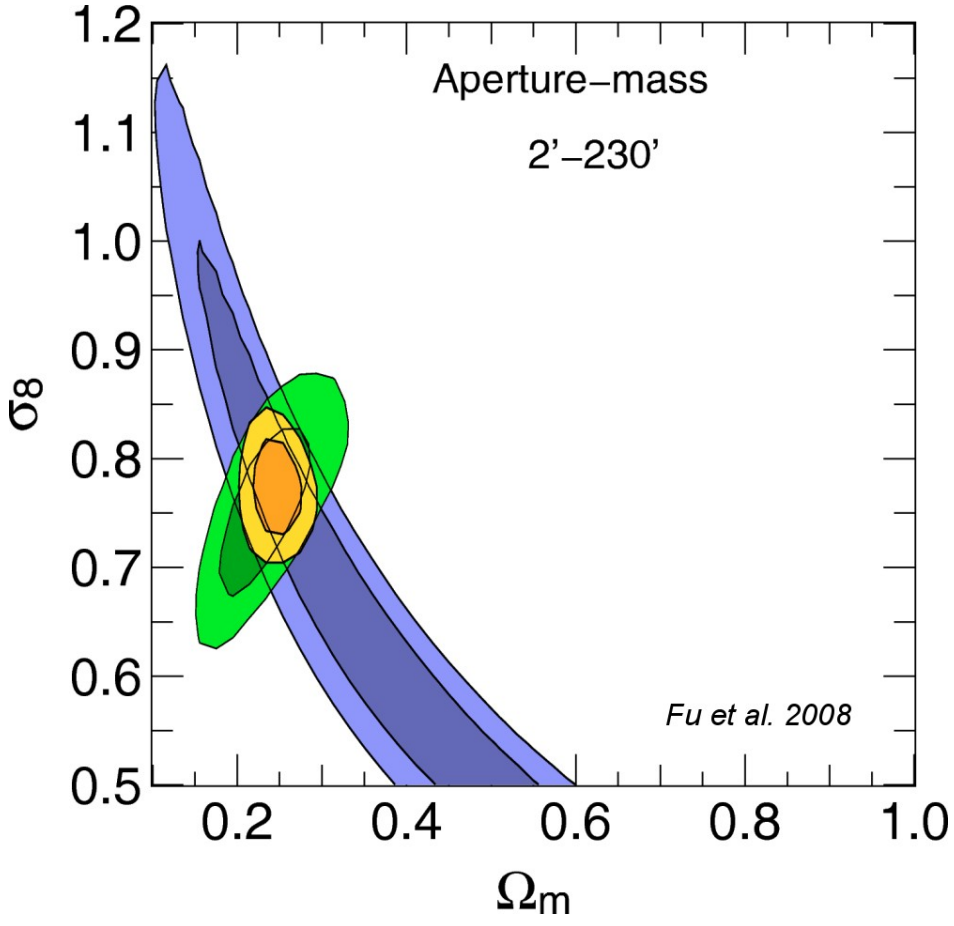
Mass Mapping in the Universe



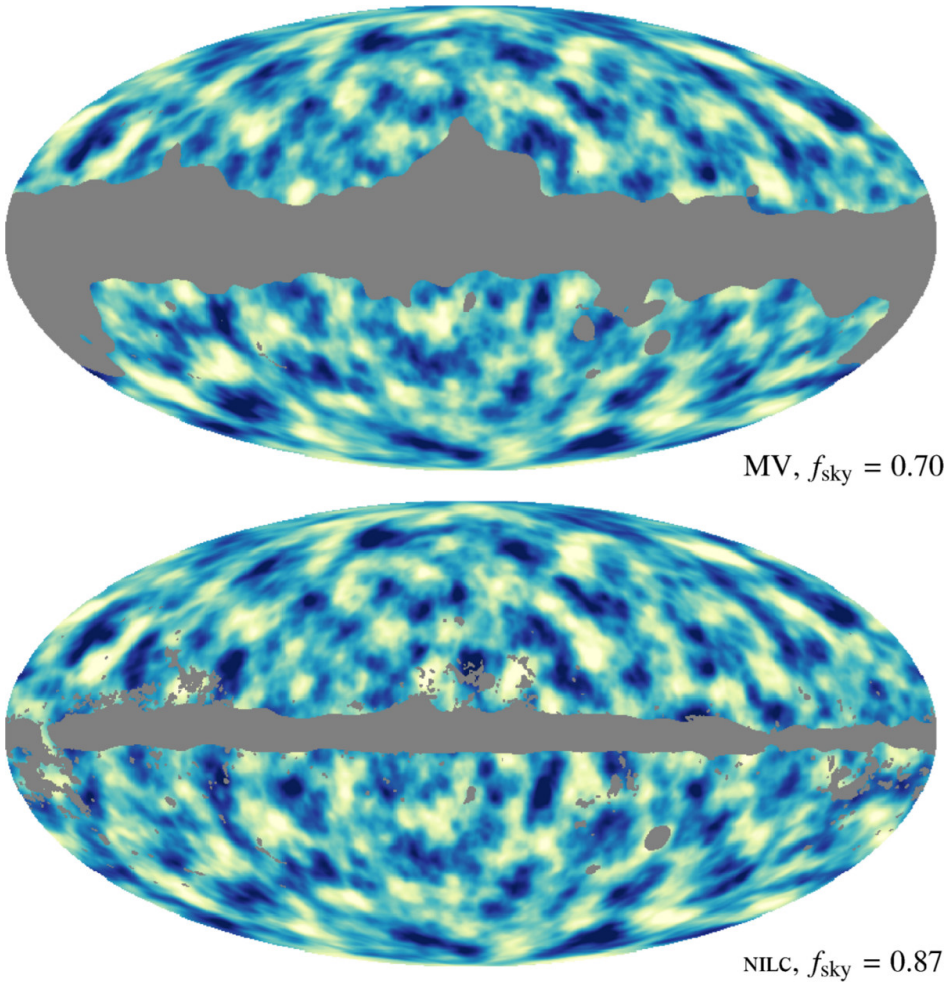


CFHTLS, Fu et al.

Mass Mapping in the Universe

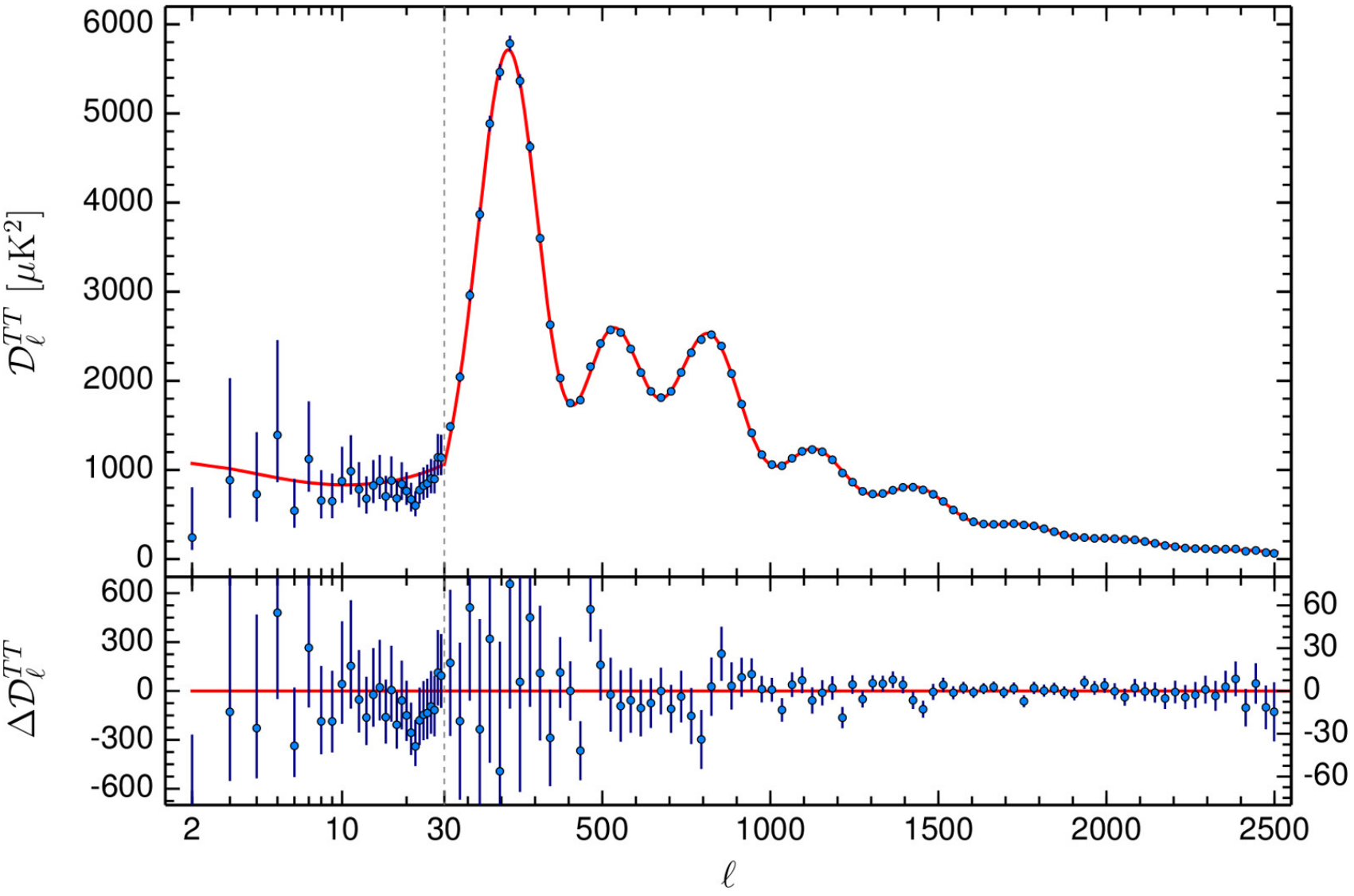


CFHTLS, Fu et al.



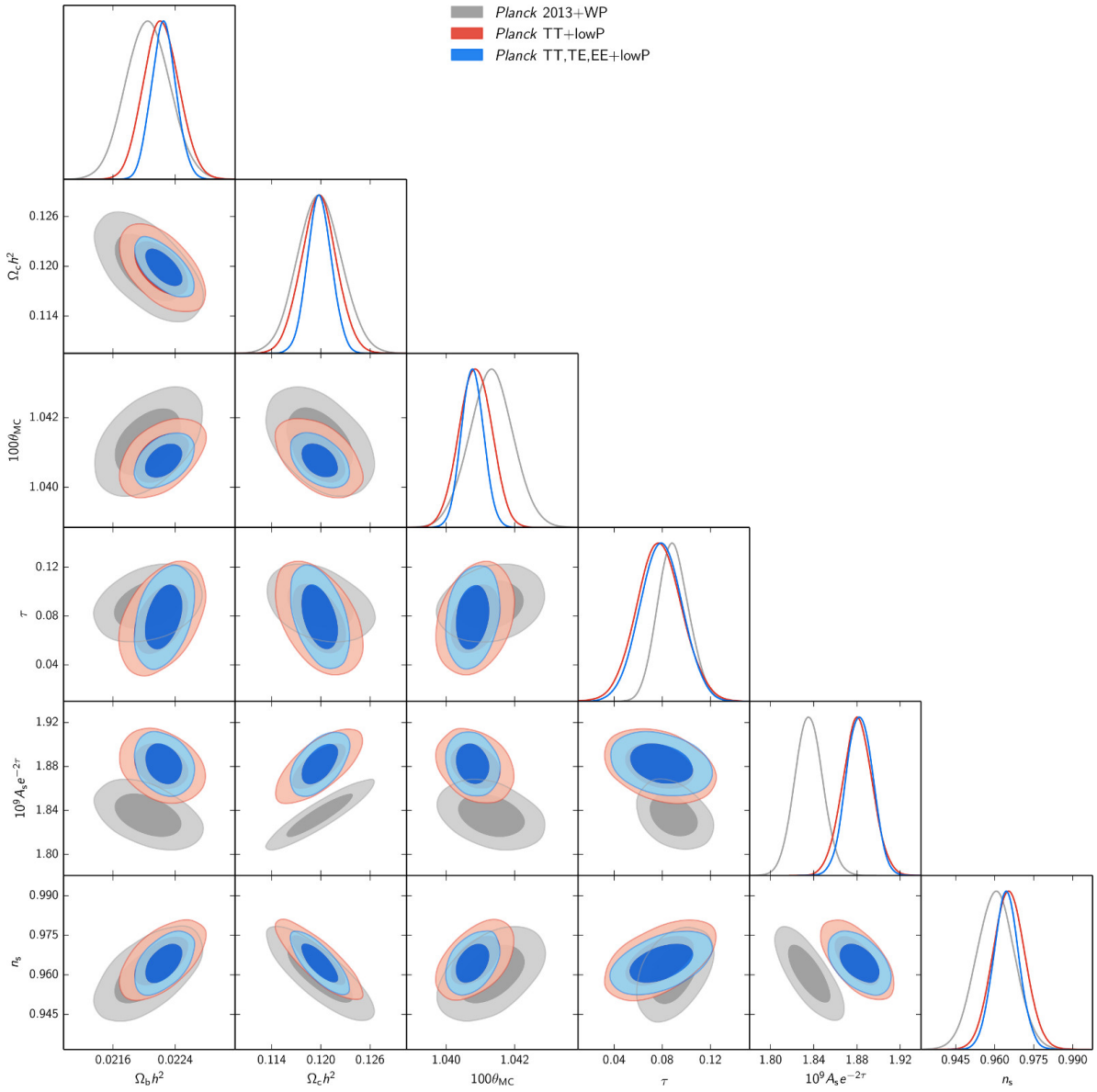
CMB lensing, Planck consortium

Quantifying Mass in the Universe



CMB power spectrum, Planck consortium

Quantifying Mass in the Universe



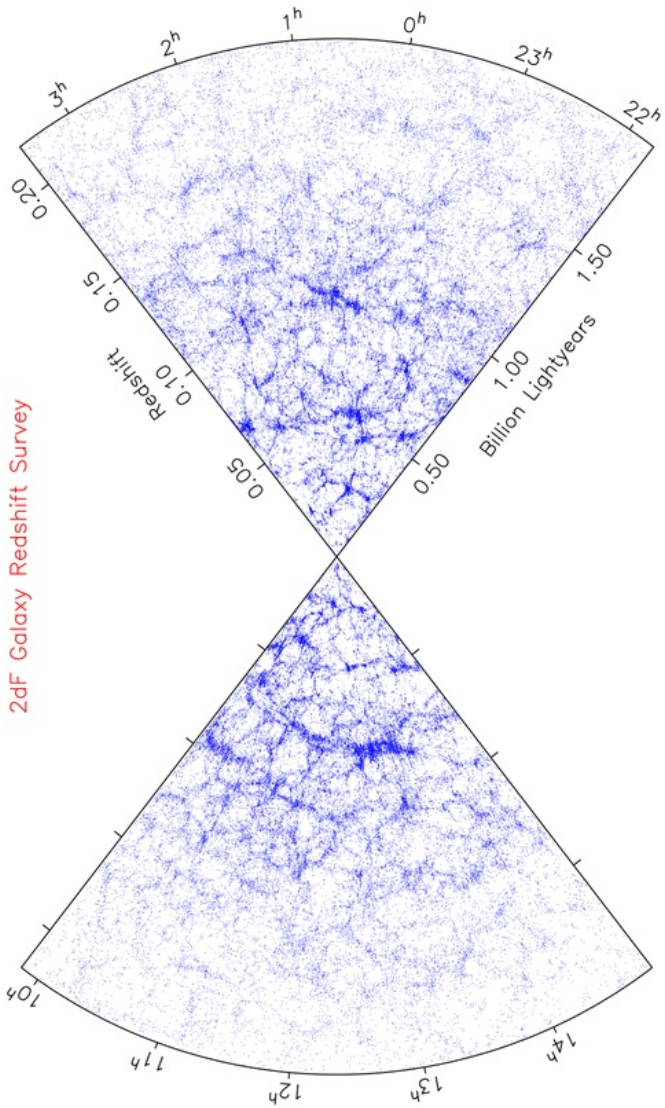
cosmological parameters, Planck consortium

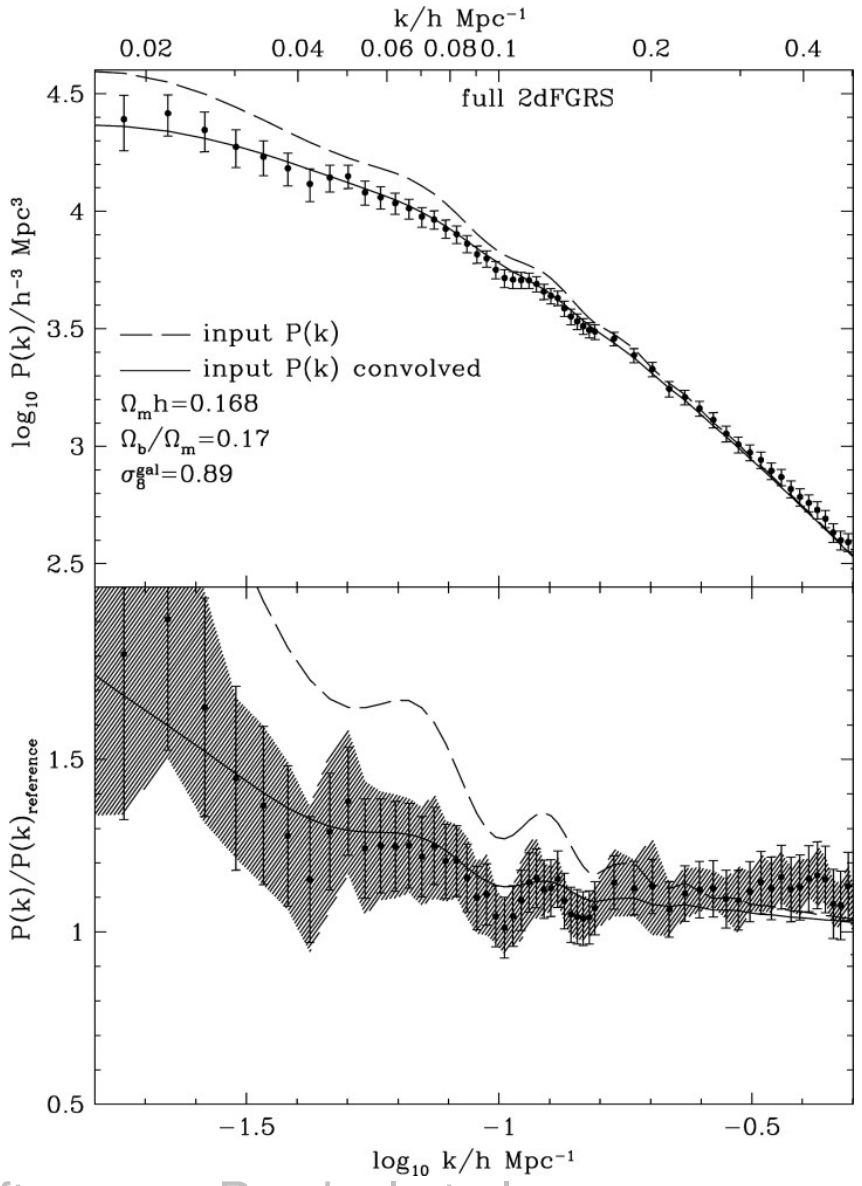
Quantifying Mass in the Universe

Parameter	PlanckTT+lowP 68 % limits	PlanckTT,TE,EE+lowP 68 % limits
$\Omega_b h^2$	0.02222 ± 0.00023	0.02225 ± 0.00016
$\Omega_c h^2$	0.1197 ± 0.0022	0.1198 ± 0.0015
$100\theta_{MC}$	1.04085 ± 0.00047	1.04077 ± 0.00032
τ	0.078 ± 0.019	0.079 ± 0.017
$\ln(10^{10} A_s)$	3.089 ± 0.036	3.094 ± 0.034
n_s	0.9655 ± 0.0062	0.9645 ± 0.0049
H_0	67.31 ± 0.96	67.27 ± 0.66
Ω_Λ	0.685 ± 0.013	0.6844 ± 0.0091
Ω_m	0.315 ± 0.013	0.3156 ± 0.0091
$\Omega_m h^2$	0.1426 ± 0.0020	0.1427 ± 0.0014
$\Omega_m h^3$	0.09597 ± 0.00045	0.09601 ± 0.00029
σ_8	0.829 ± 0.014	0.831 ± 0.013
$\sigma_8 \Omega_m^{0.5}$	0.466 ± 0.013	0.4668 ± 0.0098
$\sigma_8 \Omega_m^{0.25}$	0.621 ± 0.013	0.623 ± 0.011
z_{re}	$9.9^{+1.8}_{-1.6}$	$10.0^{+1.7}_{-1.5}$
$10^9 A_s$	$2.198^{+0.076}_{-0.085}$	2.207 ± 0.074
$10^9 A_s e^{-2\tau}$	1.880 ± 0.014	1.882 ± 0.012
Age/Gyr	13.813 ± 0.038	13.813 ± 0.026
z_*	1090.09 ± 0.42	1090.06 ± 0.30
r_*	144.61 ± 0.49	144.57 ± 0.32
$100\theta_*$	1.04105 ± 0.00046	1.04096 ± 0.00032
z_{drag}	1059.57 ± 0.46	1059.65 ± 0.31
r_{drag}	147.33 ± 0.49	147.27 ± 0.31
k_D	0.14050 ± 0.00052	0.14059 ± 0.00032
z_{eq}	3393 ± 49	3395 ± 33
k_{eq}	0.01035 ± 0.00015	0.01036 ± 0.00010
$100\theta_{s,eq}$	0.4502 ± 0.0047	0.4499 ± 0.0032
f_{2000}^{143}	29.9 ± 2.9	29.5 ± 2.7
$f_{2000}^{143\times217}$	32.4 ± 2.1	32.2 ± 1.9
f_{2000}^{217}	106.0 ± 2.0	105.8 ± 1.9

cosmological parameters, Planck consortium

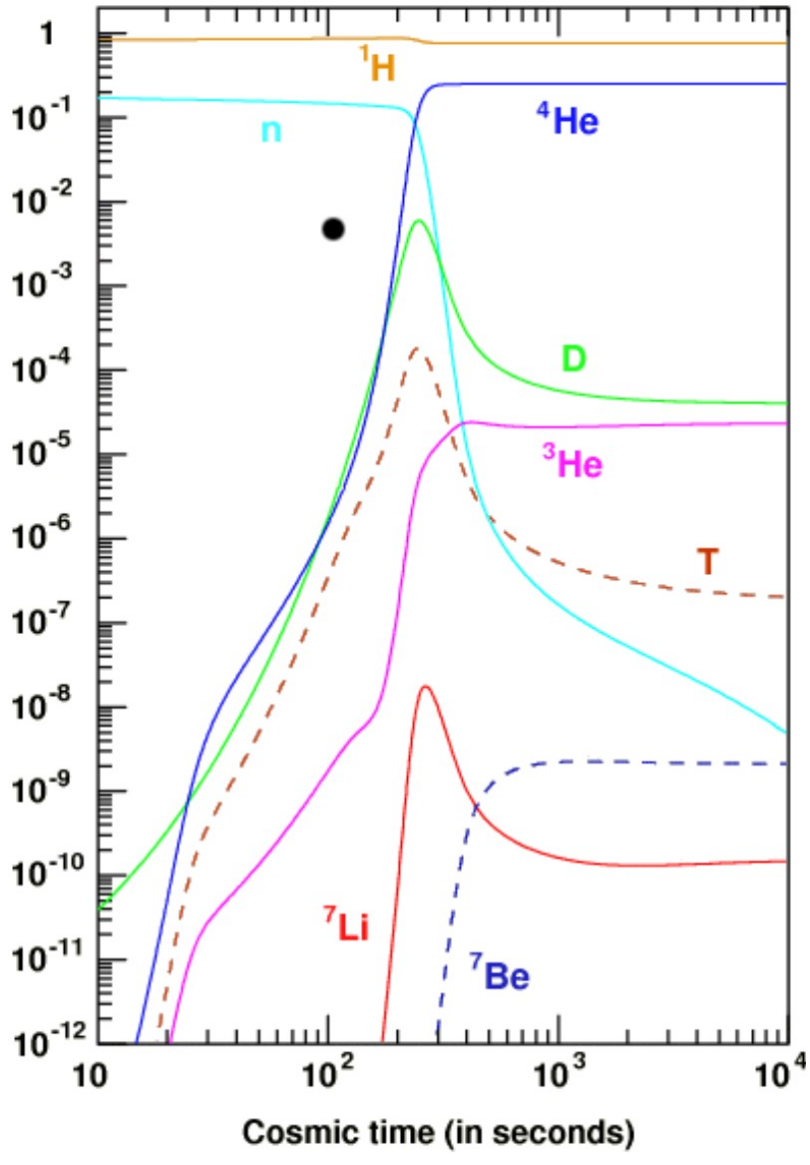
Quantifying Mass in the Universe

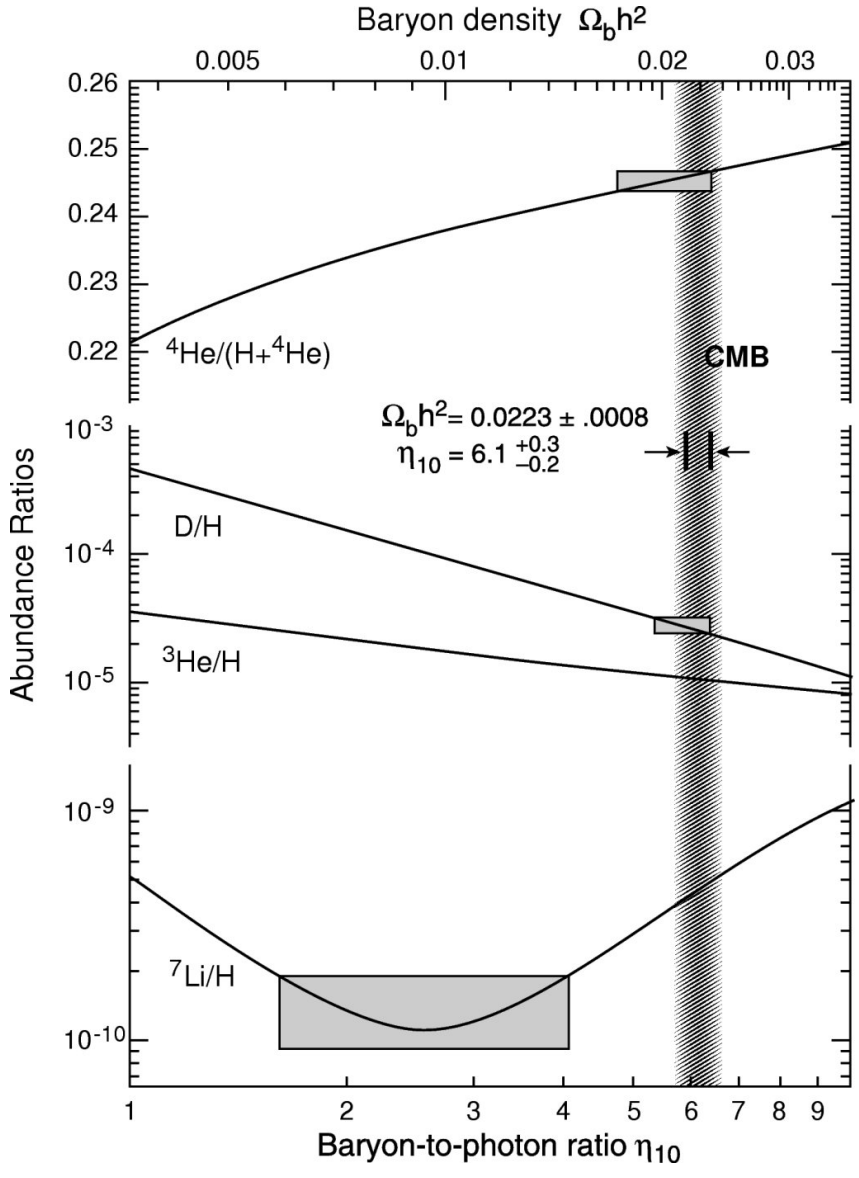




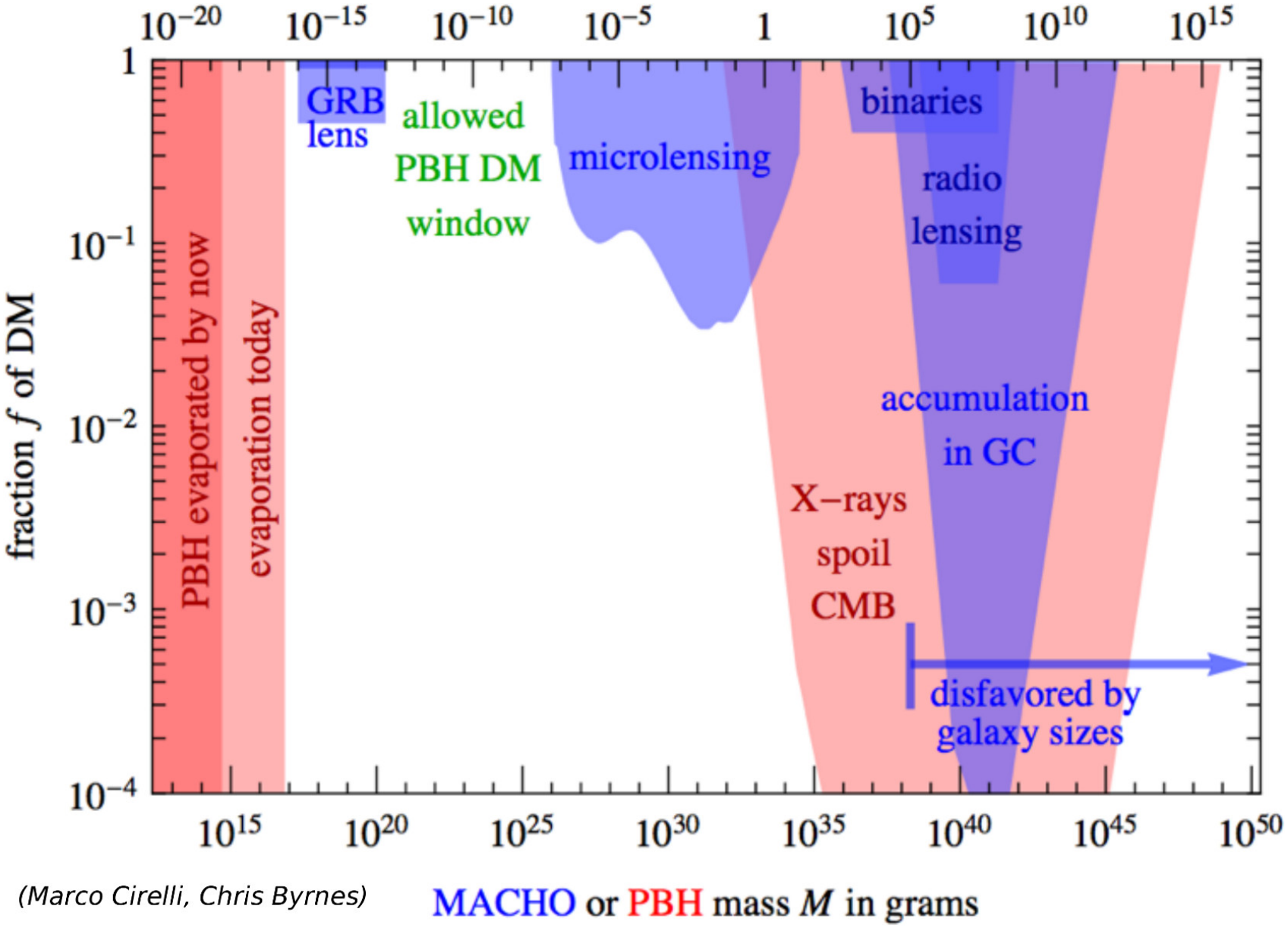
2-degree field galaxy redshift survey, Percival et al.

The Baryonic Contribution





Primordial Black Holes?



(Marco Cirelli, Chris Byrnes)