Joint second- and third-order shear statistics and cosmological constraints with CFHTLS

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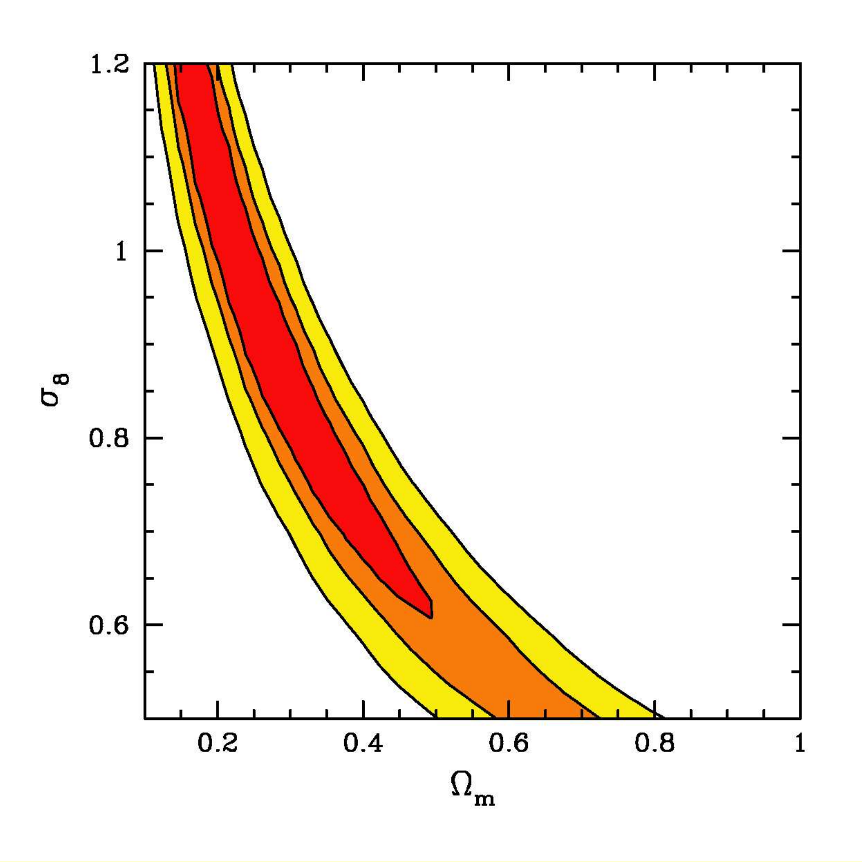
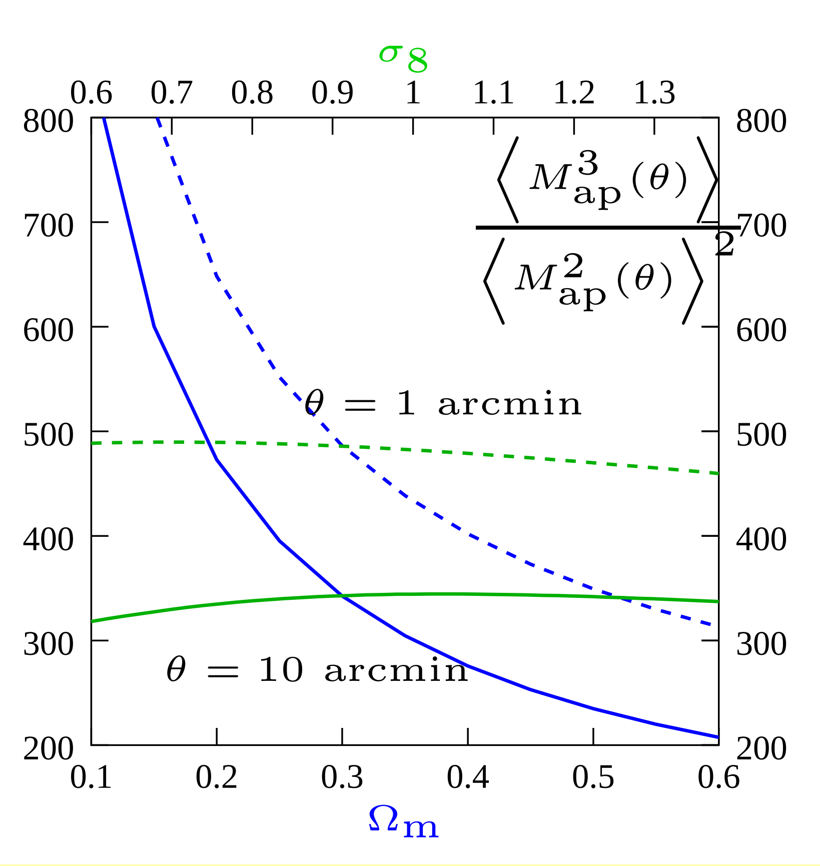
Recent results of (second-order) cosmic shear measurements

		$\sigma_8\ (\Omega_\mathrm{m} = 0.3)$
VIRMOS-DESCART	van Waerbeke et al. 2005	0.83 ± 0.07
CFHTLS wide	Hoekstra et al. 2006	0.85 ± 0.06
CFHTLS deep	Semboloni et al. 2006	0.9 ± 0.34
GEMS	Heymans et al. 2005	0.68 ± 0.13
GEMS/GOODS	Schrabback et al. 2006	0.52 ± 0.2
GaBoDS	Hetterscheidt et al. 2006	0.8 ± 0.1
CTIO	Jarvis et al. 2006	0.81 ± 0.15 (+ SN, CMB)

Motivation for 3^{rd}-order shear statistics

- Together with 2^{nd} order: lift parameter near-degeneracies, e.g.: $s_3(\theta) = \frac{\langle\kappa^3(\theta)\rangle}{\langle\kappa^2(\theta)\rangle^2}$ independent of σ_8 [Bernardeau, van Waerbeke, Mellier 1997]

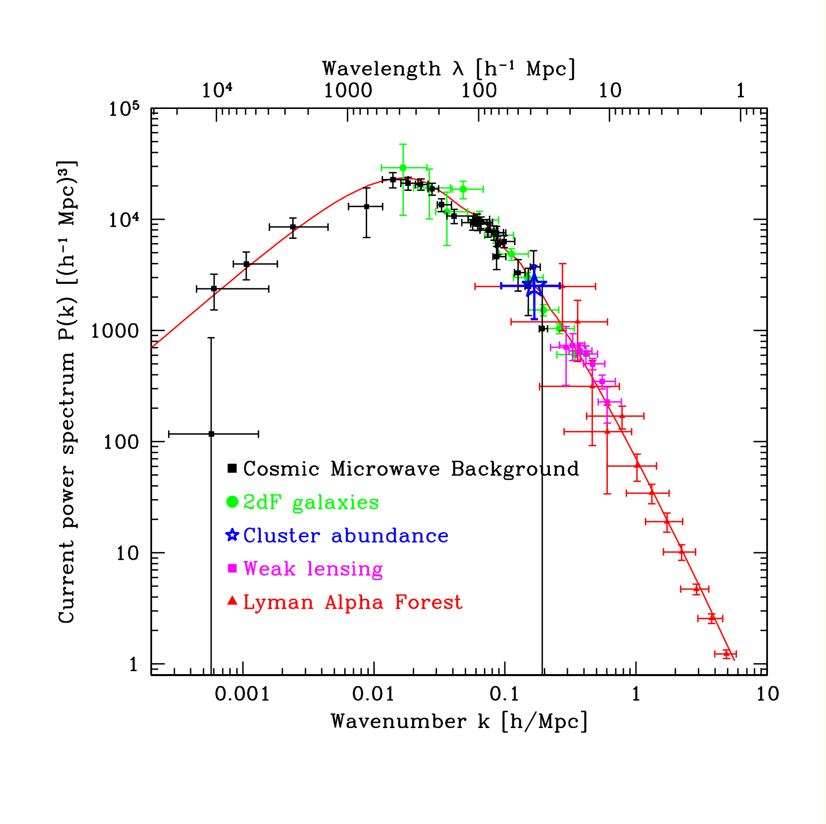




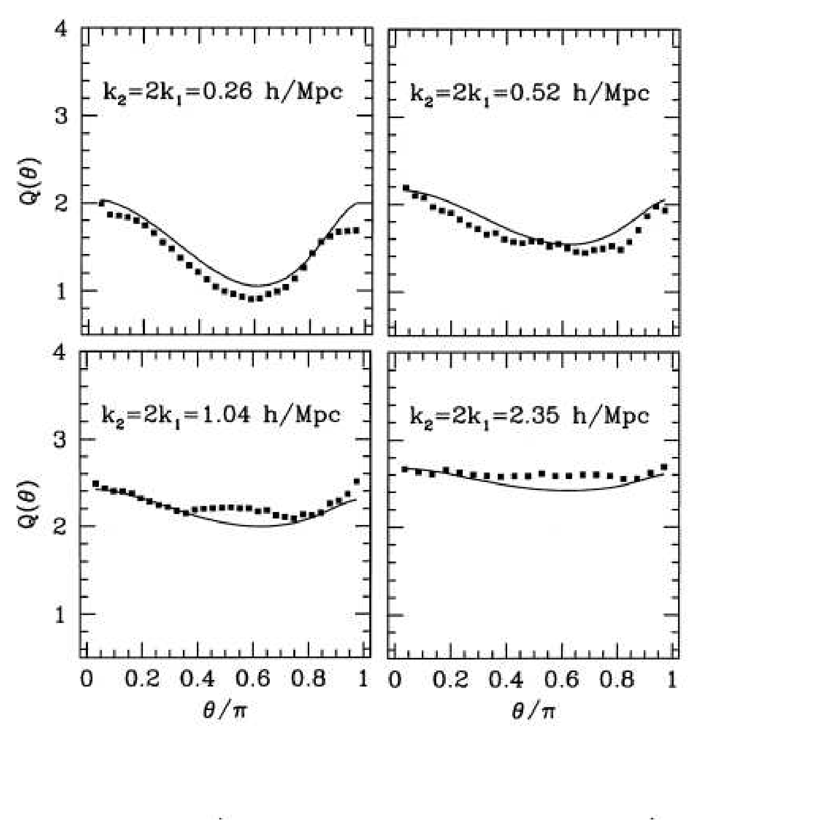
[CFHTLS wide]

- Dark matter power spectrum and bispectrum contain complementary information about cosmology.
- Probe Non-Gaussianity of the LSS on small scales, ($\lesssim 10'$), non-linear gravitional collapse, mode-coupling of the LSS, virialization of halos in hierarchical structure formation

power spectrum

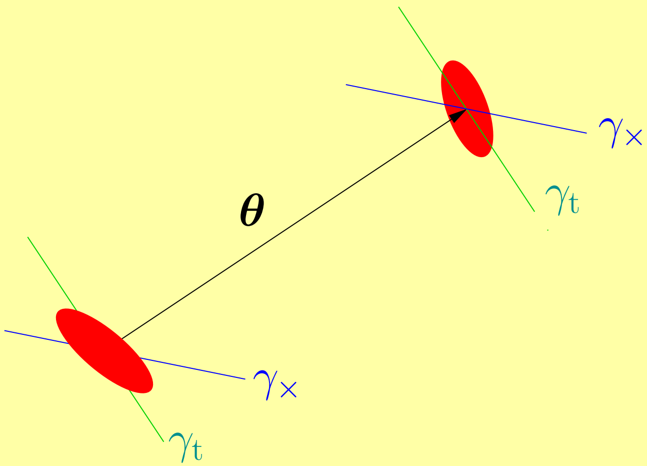


bispectrum



Weak lensing observables

Two-point correlation function



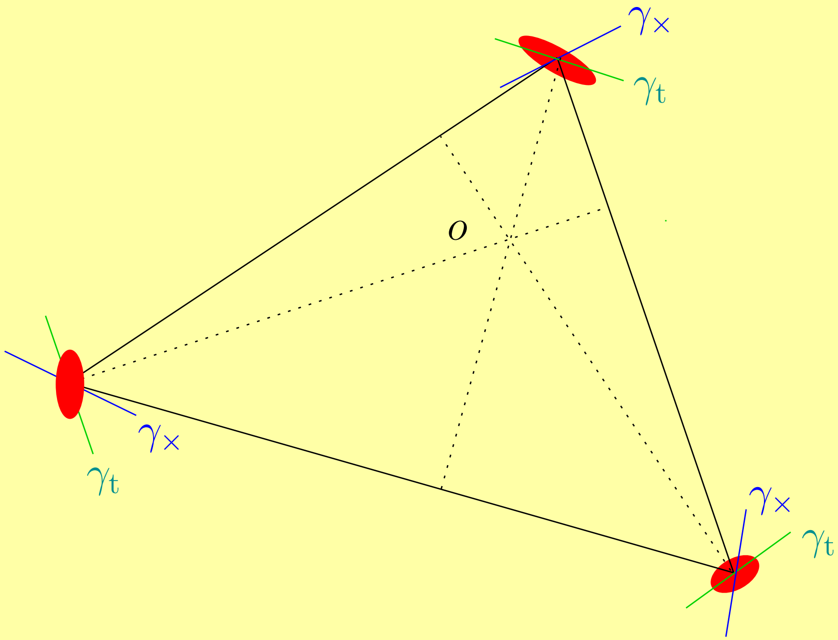
$$\langle \gamma_{\rm t} \gamma_{\rm t} \rangle$$

$$\langle \gamma_\times \gamma_\times \rangle$$

$$\left.\begin{array}{l} \langle \gamma_{\rm t} \gamma_\times \rangle \\ \langle \gamma_\times \gamma_{\rm t} \rangle \end{array}\right\} = 0 \quad \text{because of parity}$$

2PCF $\quad \xi_\pm(\theta) \equiv \langle \gamma_{\rm t} \gamma_{\rm t} \rangle \pm \langle \gamma_\times \gamma_\times \rangle \, ,$ $\quad$ two components

Three-point correlation function

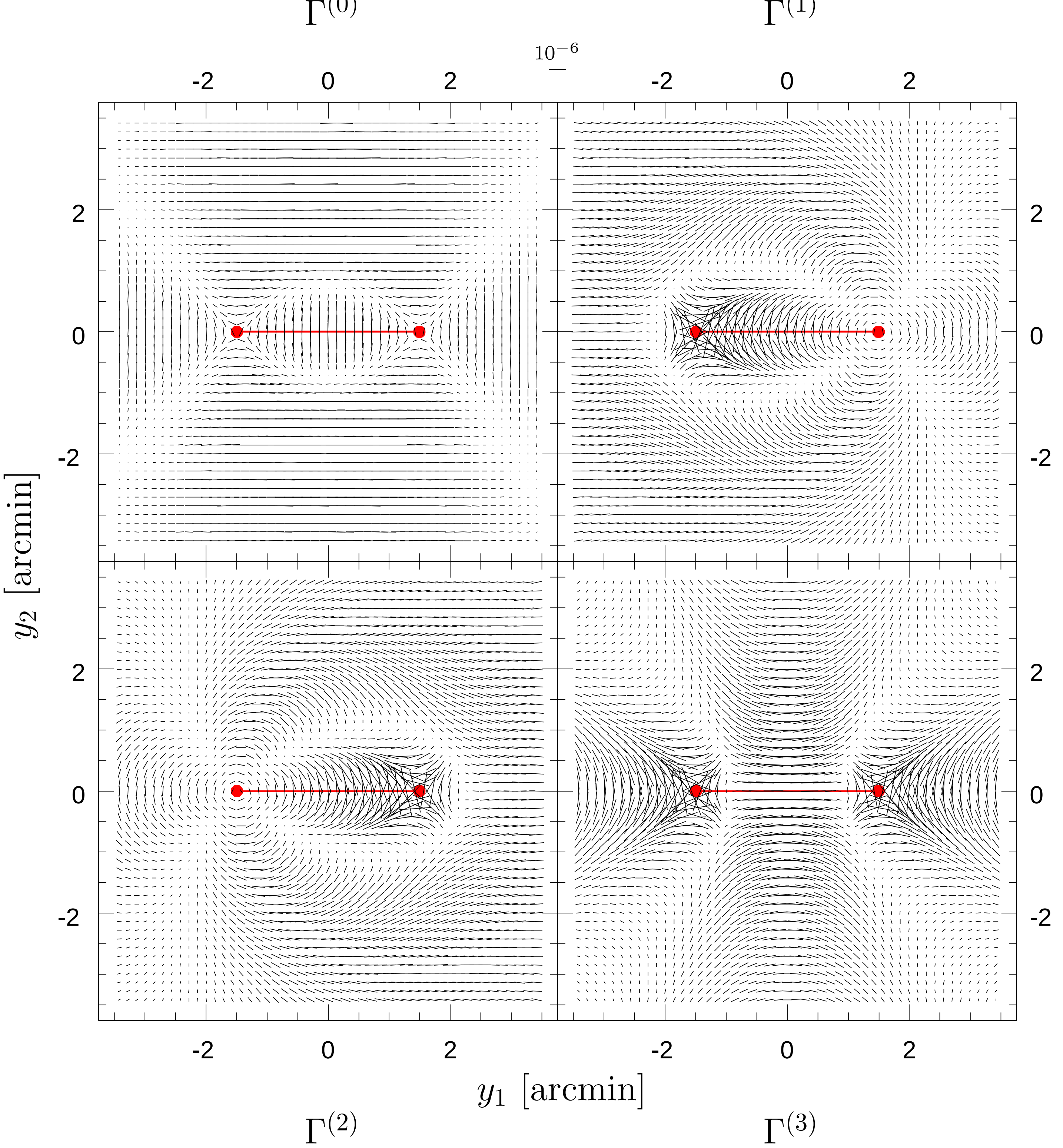


8 components:

$$\langle\gamma_\mathrm{t}\gamma_\mathrm{t}\gamma_\mathrm{t}\rangle \quad \langle\gamma_\mathrm{t}\gamma_\mathrm{t}\gamma_\times\rangle$$
$$\langle\gamma_\mathrm{t}\gamma_\times\gamma_\times\rangle \quad \langle\gamma_\mathrm{t}\gamma_\times\gamma_\mathrm{t}\rangle$$
$$\langle\gamma_\times\gamma_\mathrm{t}\gamma_\times\rangle \quad \langle\gamma_\times\gamma_\mathrm{t}\gamma_\mathrm{t}\rangle$$
$$\langle\gamma_\times\gamma_\times\gamma_\mathrm{t}\rangle \quad \langle\gamma_\times\gamma_\times\gamma_\times\rangle$$

"Natural components" $\Gamma^{(0)}, \Gamma^{(1)}, \Gamma^{(2)}, \Gamma^{(3)} \in \mathbb{C}$ = linear combinations of the $\langle\gamma_\mu\gamma_\nu\gamma_\lambda\rangle$ [Schneider & Lombardi 2003]

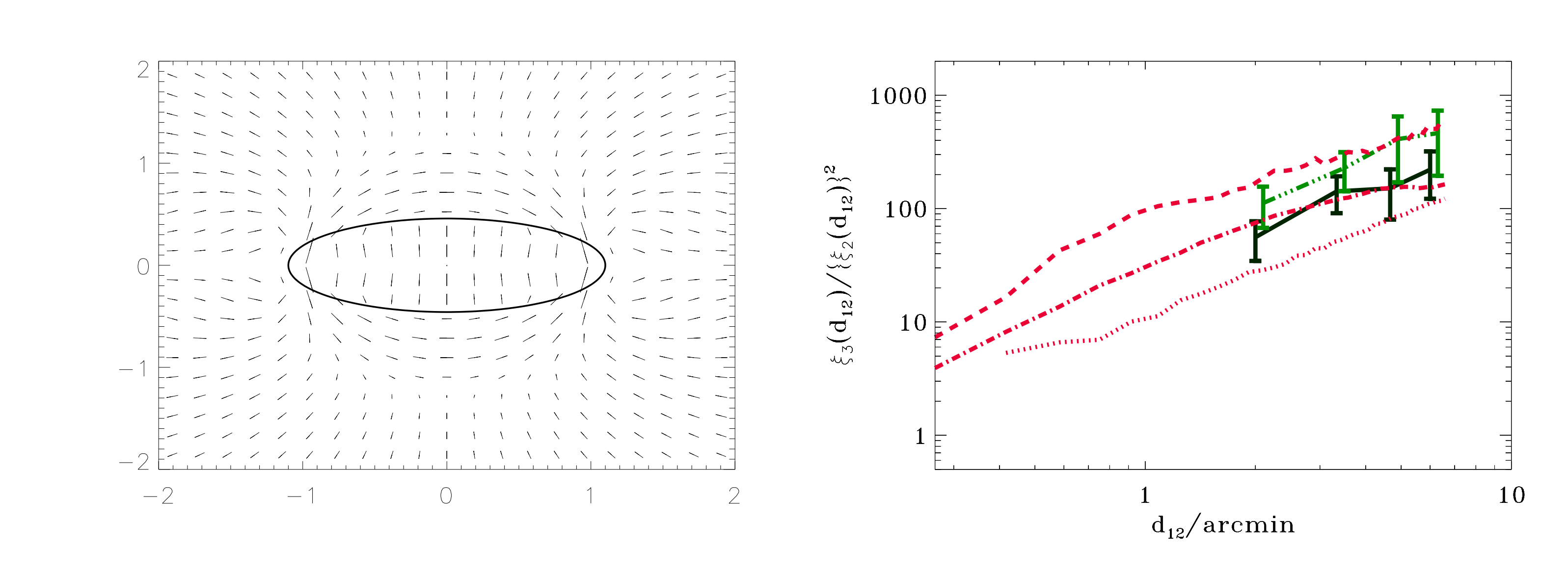
3PCF has 8 (non-vanishing) components, depends on 3 quantities and is not a scalar ☹



Γ^(0)
Γ^(1)
10^−6
-2
0
2
y_2 [arcmin]
y_1 [arcmin]
Γ^(2)
Γ^(3)

Flavours of 3^{rd}-order statistics

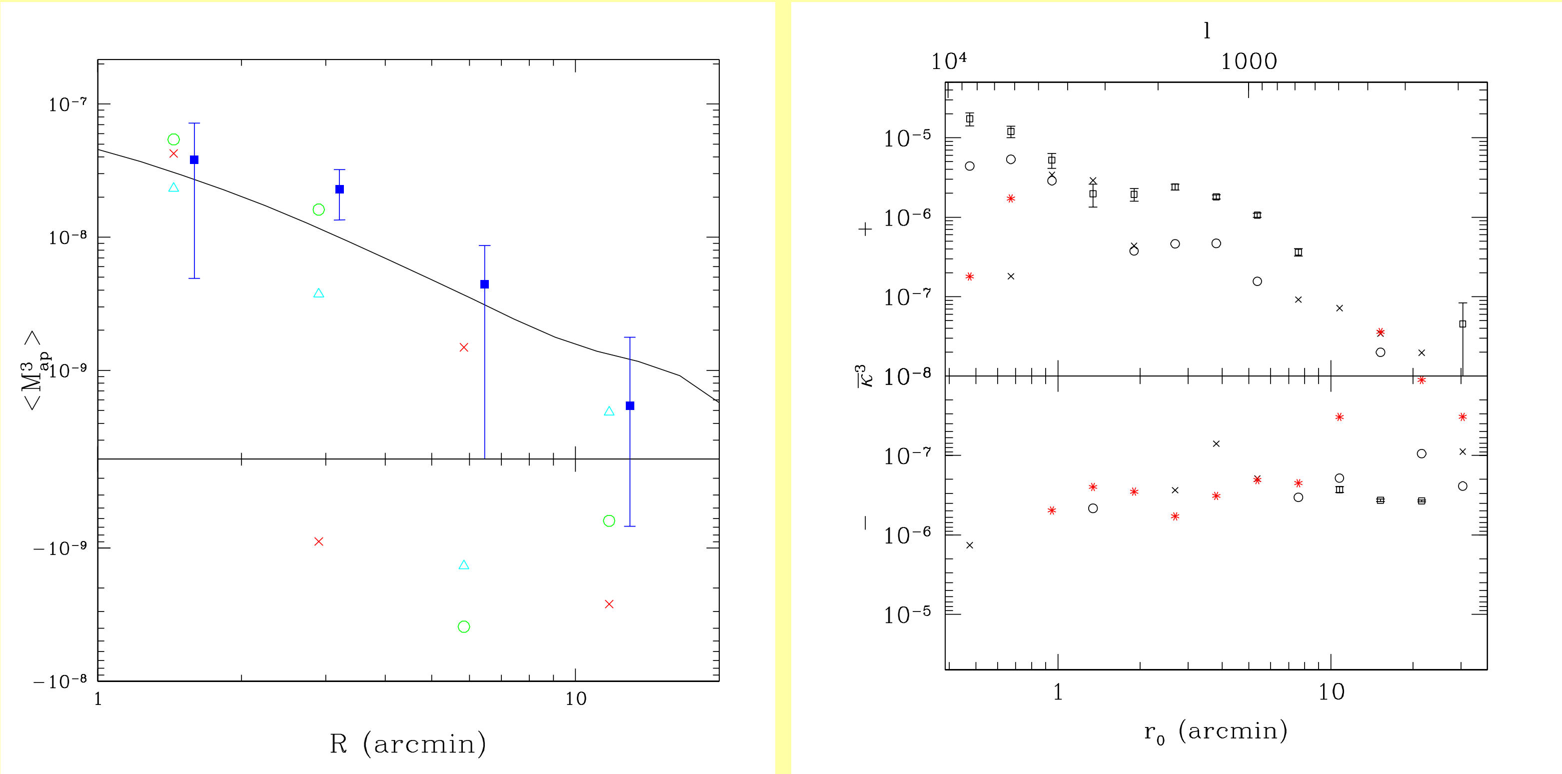
- projected 3PCF, integrated over elliptical region
  [Bernardeau, van Waerbeke & Mellier 2002, 2003]



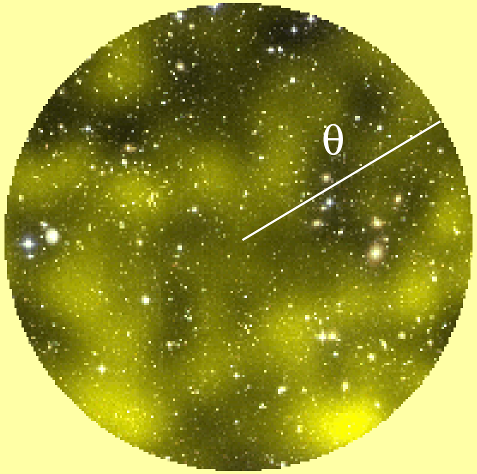
[VIRMOS-DESCART]

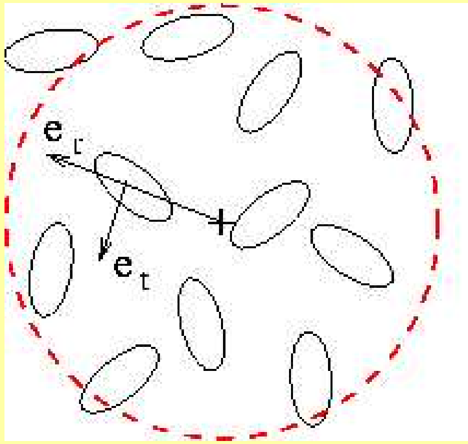
Flavours of 3^{rd}-order statistics

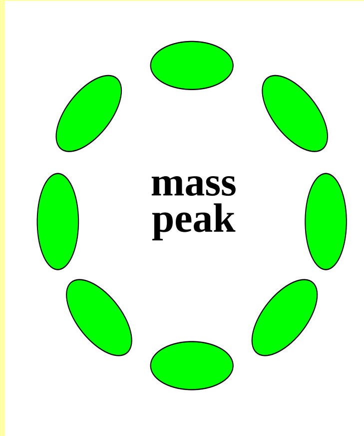
- projected 3PCF, integrated over elliptical region [Bernardeau, van Waerbeke & Mellier 2002, 2003]
- Aperture-mass $\langle M_{\mathrm{ap}}^3 \rangle$: CTIO [Jarvis et al. 2004] and VIRMOS-DESCART [Pen et al. 2003]



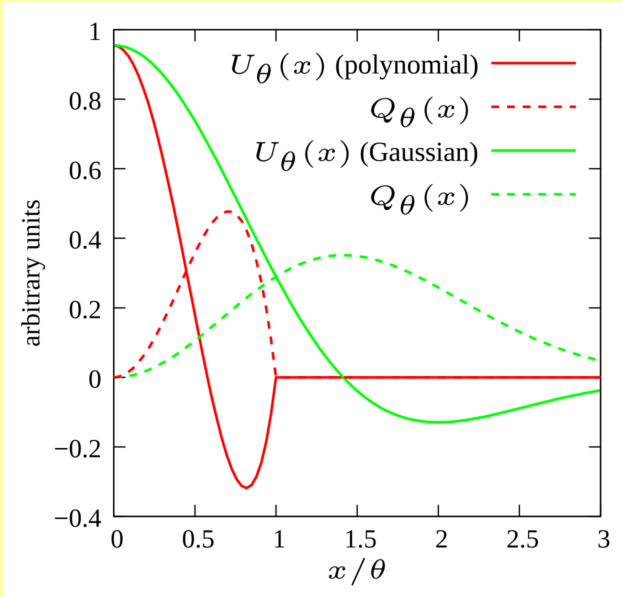
Aperture-Mass Statistics







Mass overdensity κ ⟷ Tangential shear in aperture $\gamma_{\rm t}$

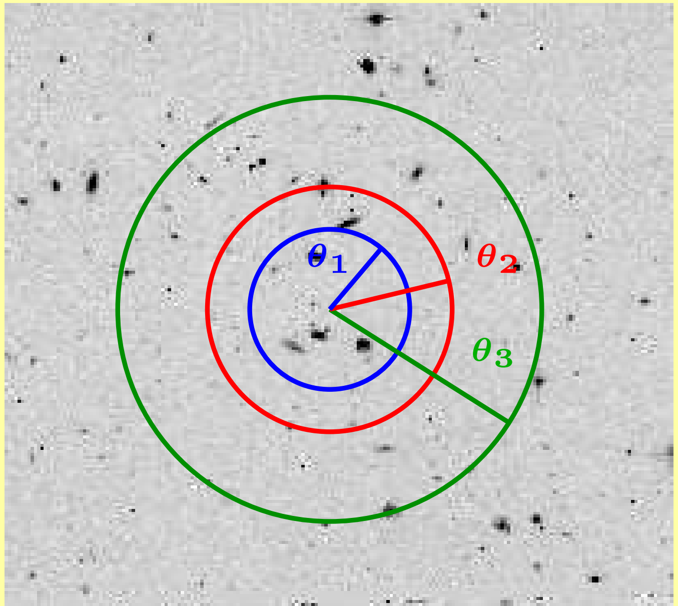


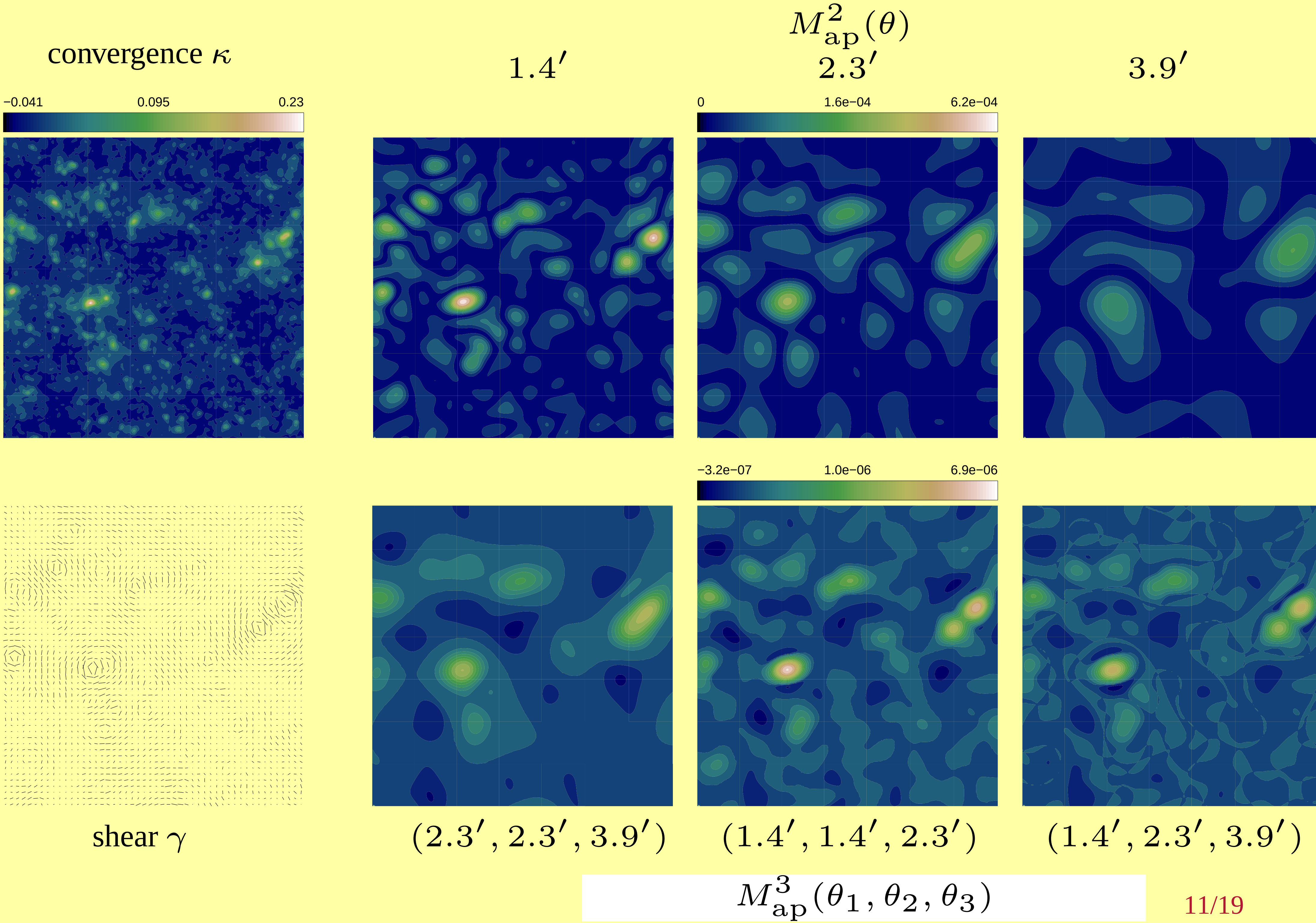
$$M_{\rm ap}(\theta) = \int {\rm d}^2x\, U_\theta(x)\kappa(\vec{x})$$

$$= \int {\rm d}^2x\, Q_\theta(x)\gamma_{\rm t}(\vec{x})$$

Second- and third-order statistics

- variance $\langle M_{\rm ap}^2(\theta)\rangle$ probes power spectrum $P_\kappa(\ell)$ at a scale $\ell \propto 1/\theta$
- skewness $\langle M_{\rm ap}(\theta_1)M_{\rm ap}(\theta_2)M_{\rm ap}(\theta_3)\rangle$ probes bispectrum $B_\kappa(\ell_1 \propto 1/\theta_1,\ \ell_2 \propto 1/\theta_2,\ \ell_3 \propto 1/\theta_3)$, cross-correlation or mode coupling of the large-scale structure on different scales [Schneider, MK & Lombardi 2005]





convergence κ
$M_{\rm ap}^2(\theta)$
$1.4'$
$2.3'$
$3.9'$
−0.041
0.095
0.23
0
1.6e−04
6.2e−04
−3.2e−07
1.0e−06
6.9e−06
shear γ
$(2.3', 2.3', 3.9')$
$(1.4', 1.4', 2.3')$
$(1.4', 2.3', 3.9')$
$M_{\rm ap}^3(\theta_1, \theta_2, \theta_3)$

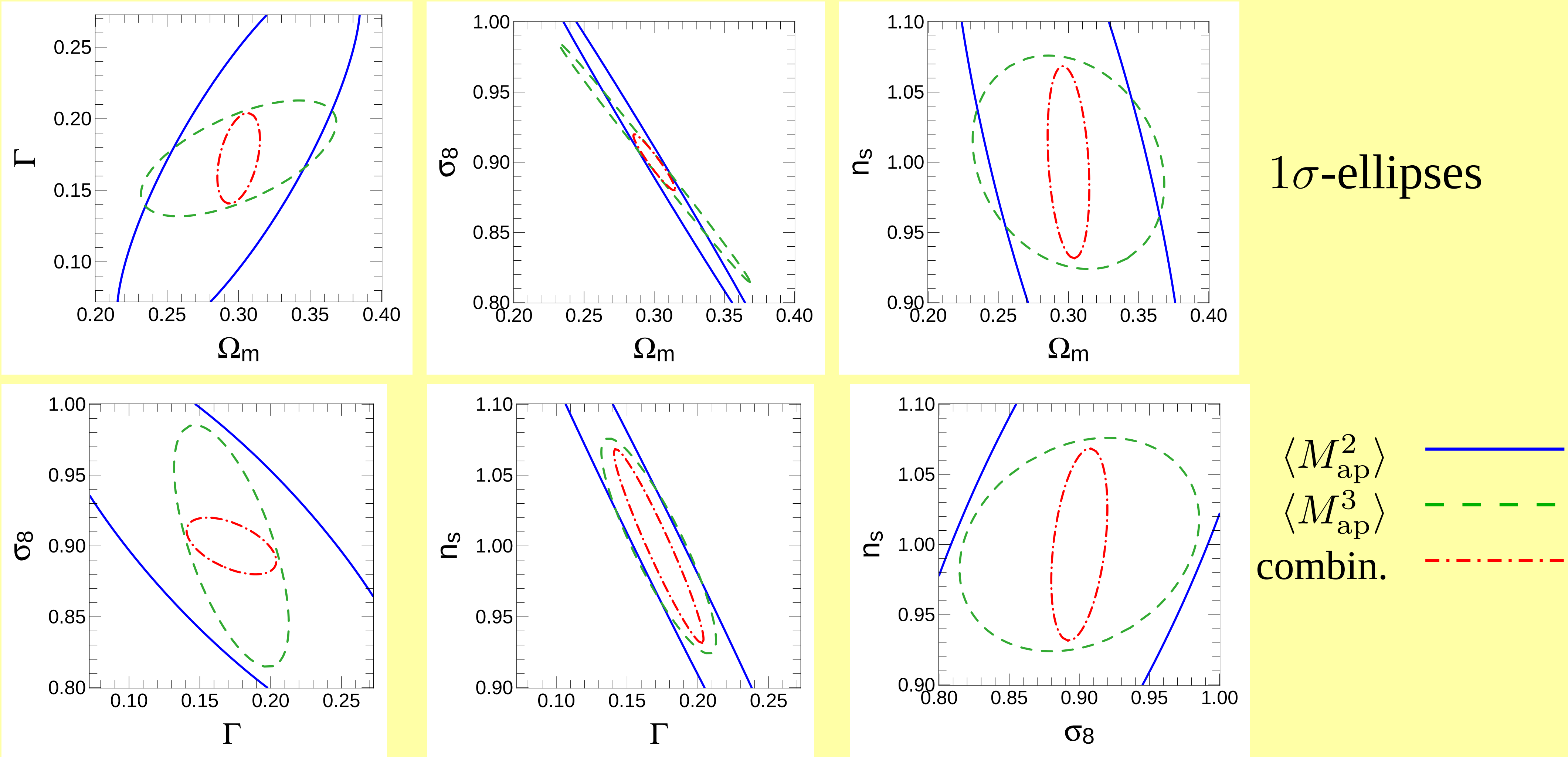
Why $M_{\rm ap}$?

- $\langle M_{\rm ap}^3 \rangle$ is a scalar
- separates E- & B-modes
- one can obtain $\langle M_{\rm ap}^2 \rangle, \langle M_{\rm ap}^3 \rangle$ from 2pcf, 3pcf *or* directly from galaxy field [work in progress]
- localized filter $\longrightarrow$ simple relation to power spectrum/bispectrum
- no information loss if $\langle M_{\rm ap}^3 \rangle$ is used instead of 3pcf [work in progress]

Predictions for CFHTLS wide

- Ray-tracing simulations [T. Hamana]
- All galaxies at redshift $z_0 = 0.977$, $\bar{n} = 25/\mathrm{arcmin}^2$
- Shear signal for aperture radii θ between 1 and 15 arc minutes
- Error budget: shape noise, (non-Gaussian) cosmic variance, cross-correlation between $\langle M_{\mathrm{ap}}^2 \rangle$ and $\langle M_{\mathrm{ap}}^3 \rangle$ [MK & Schneider 2005]
- Fisher matrix for 1σ errors

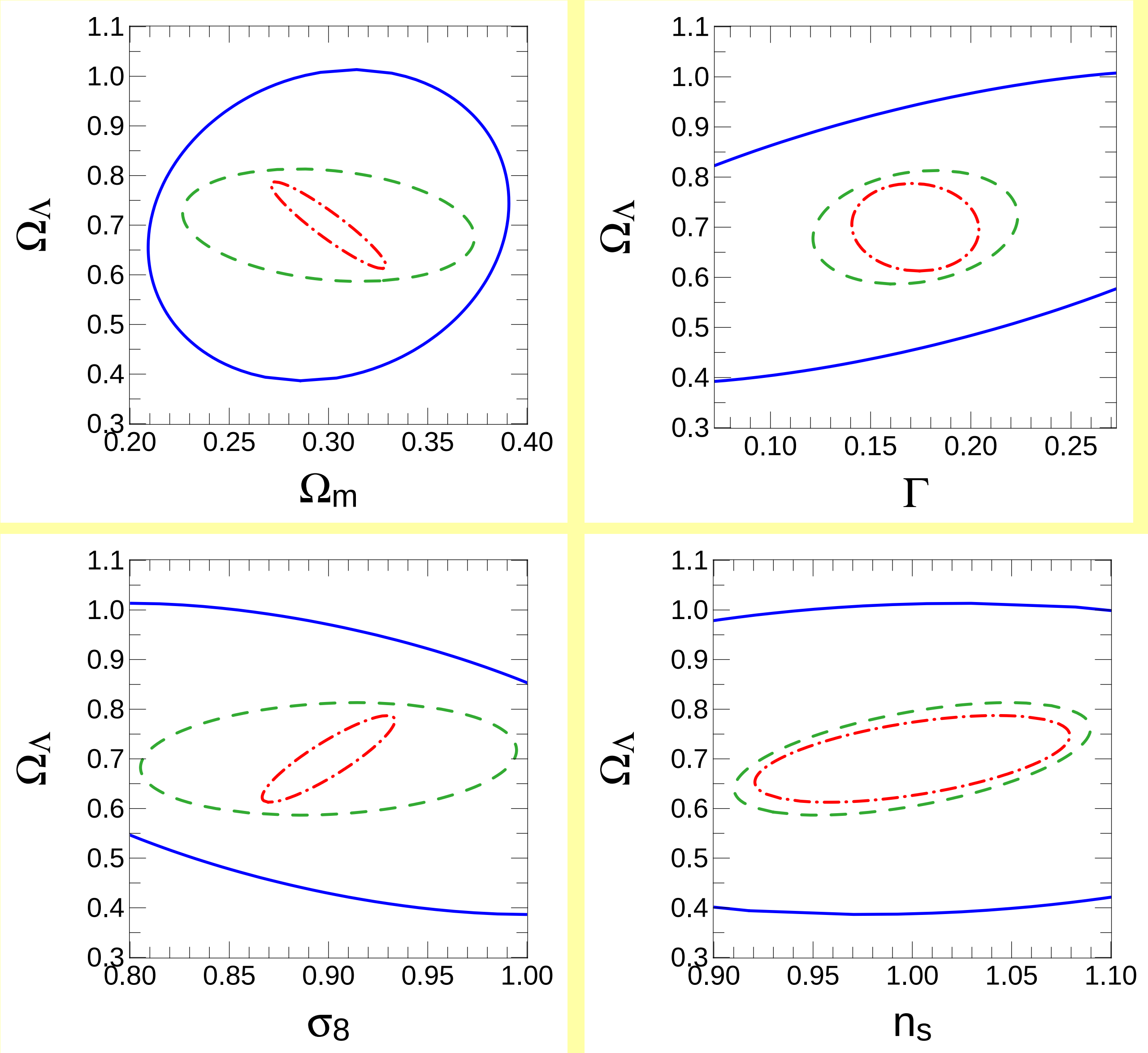
Parameter constraints



Fisher matrix with 5 parameters assuming flat CDM cosmology

$\sigma(z_0) = 0.01$

Dark energy constraints



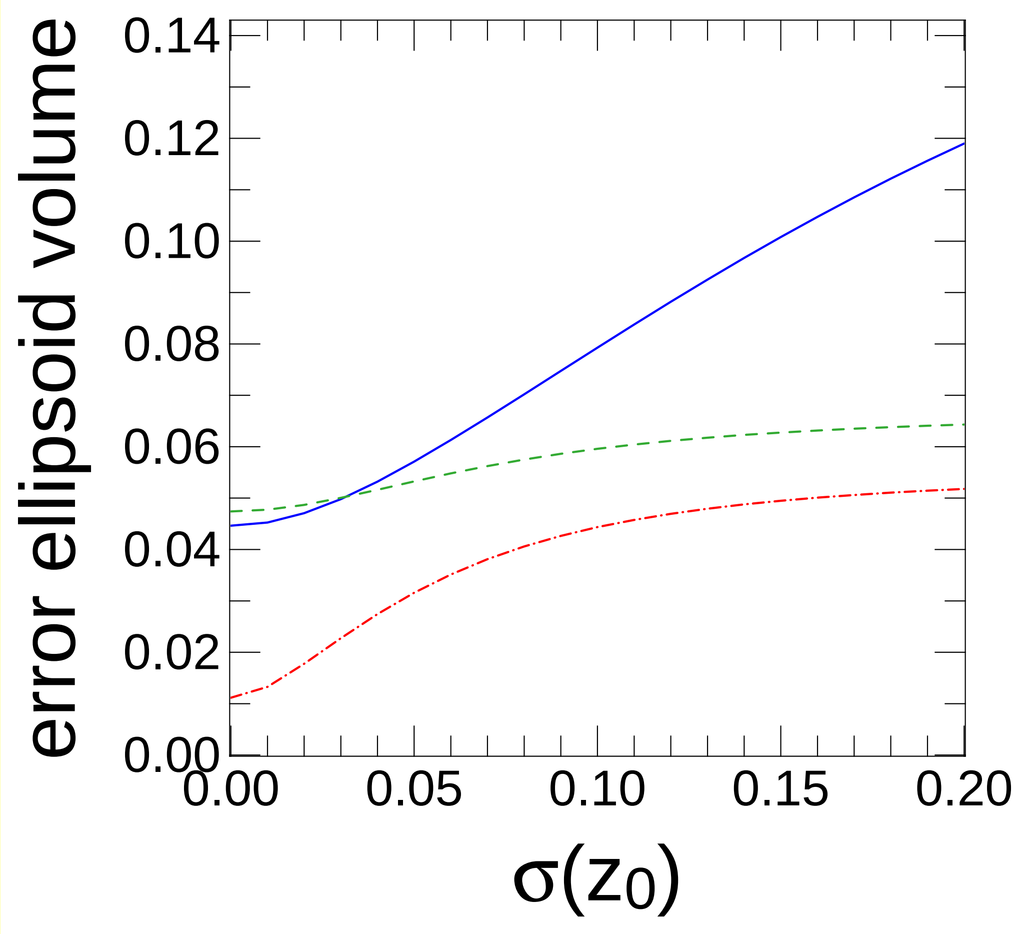
1σ-ellipses

$\langle M_{\rm ap}^2 \rangle$

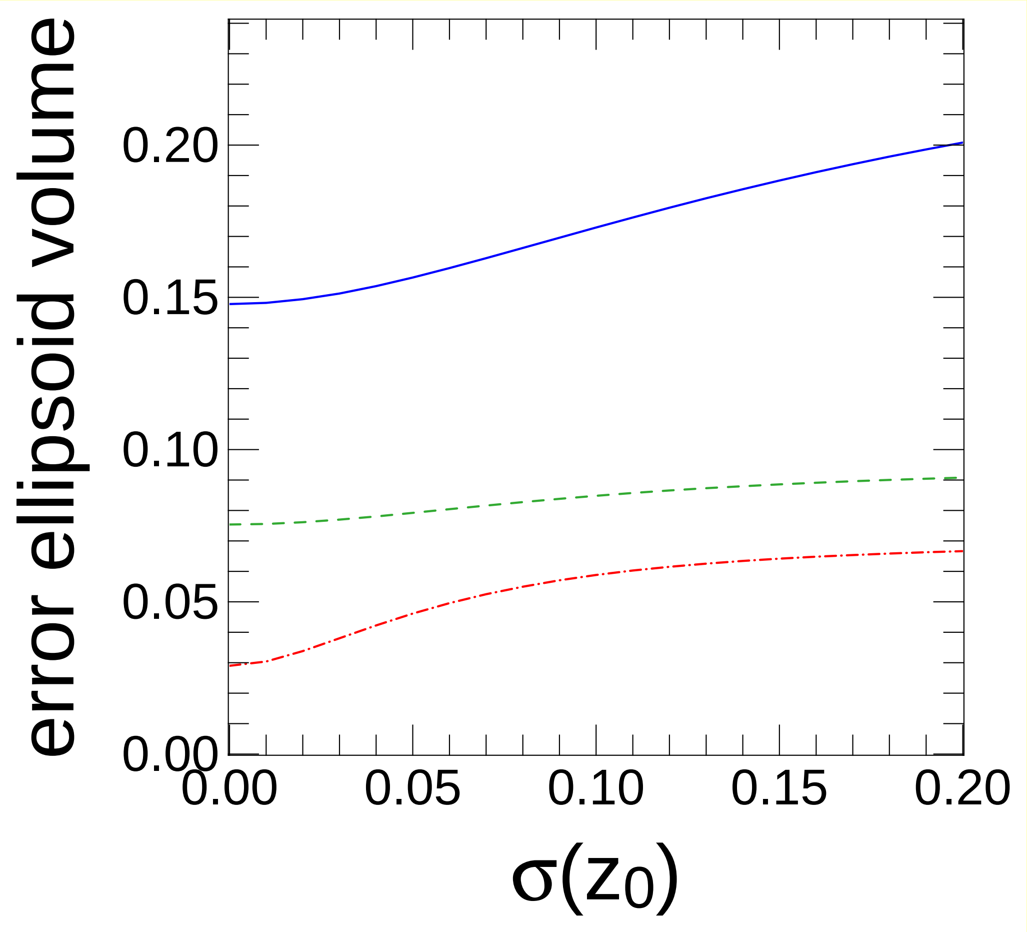
$\langle M_{\rm ap}^3 \rangle$

combin.

Redshift uncertainty



$(\Omega_\mathrm{m}, \Gamma, \sigma_8)$, flat



$(\Omega_\mathrm{m}, \Omega_\Lambda, \Gamma, \sigma_8)$

Parameter constraints summary

Flat ΛCDM

	$\Omega_{\rm m}$	Γ	σ_8	$n_{\rm s}$
$\langle M_{\rm ap}^2 \rangle$	0.085	0.13	0.141	0.27
$\langle M_{\rm ap}^3 \rangle$	0.068	0.04	0.085	0.076
combination	0.015	0.032	0.02	0.068

General ΛCDM

	$\Omega_{\rm m}$	Ω_Λ	Γ	σ_8	$n_{\rm s}$
$\langle M_{\rm ap}^2 \rangle$	0.091	0.31	0.21	0.2	0.27
$\langle M_{\rm ap}^3 \rangle$	0.074	0.11	0.051	0.095	0.09
combination	0.029	0.087	0.032	0.033	0.079

Figurs are marginalized 1σ-errors, $\sigma(z_0) = 0.01$

Summary and Outlook

- Third-order cosmic shear statistic has been detected and is expected to be measured with high significance in CFHTLS
- Joint $\langle M_{\rm ap}^2 \rangle$ and $\langle M_{\rm ap}^3 \rangle$ observations can improve parameter constraints by a factor of $3-6$ (with flat prior)
- For tight constraints on dark energy tomography needed [Takada & Jain 2004]
- Source redshifts have to be known accurately
- Need better models of non-linear structure formation!

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