# Euclid Science Drivers and Requirements: Weak Lensing

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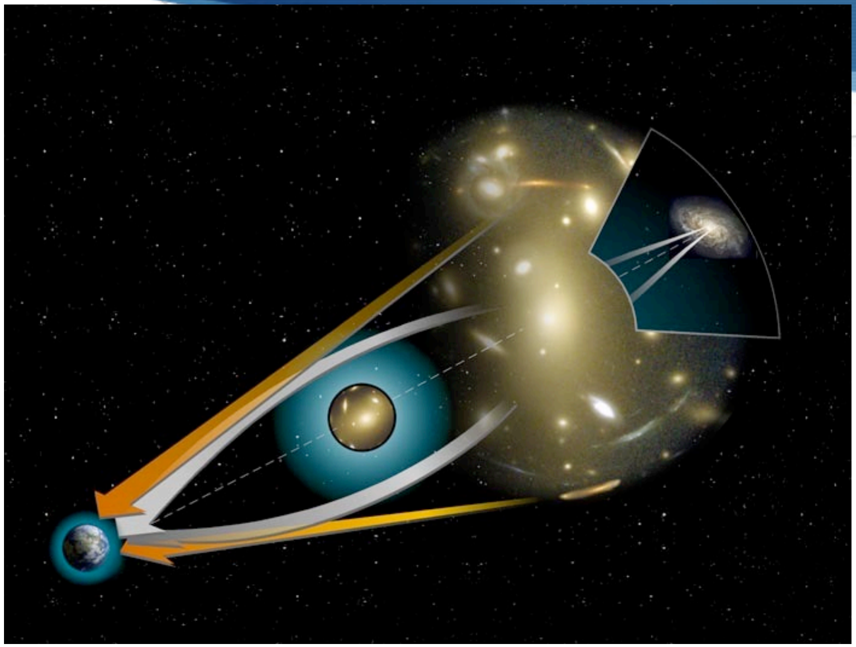
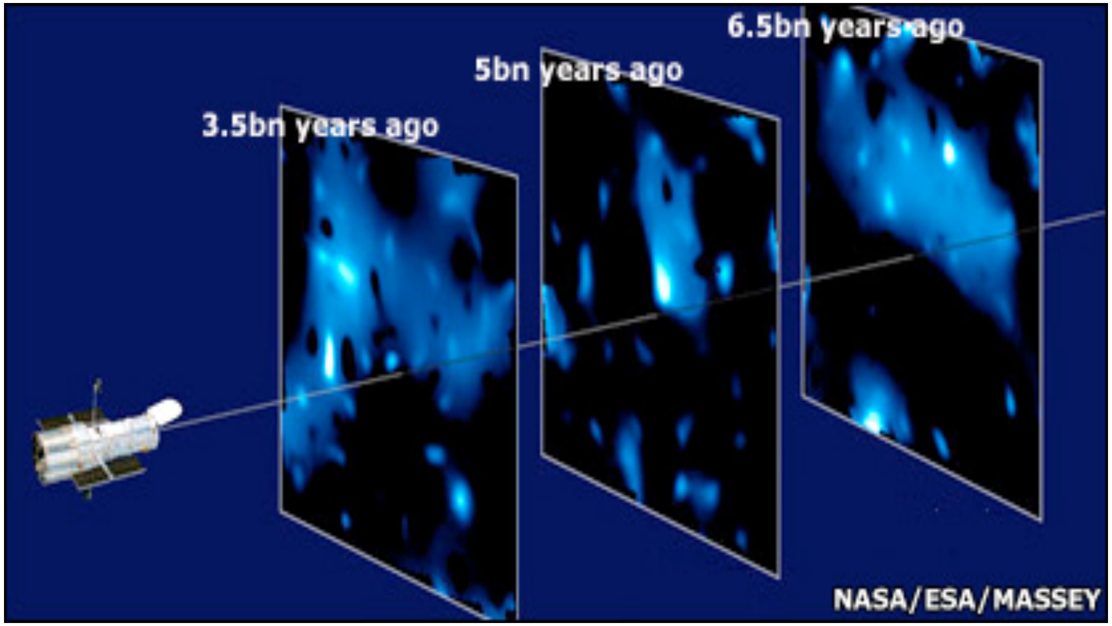
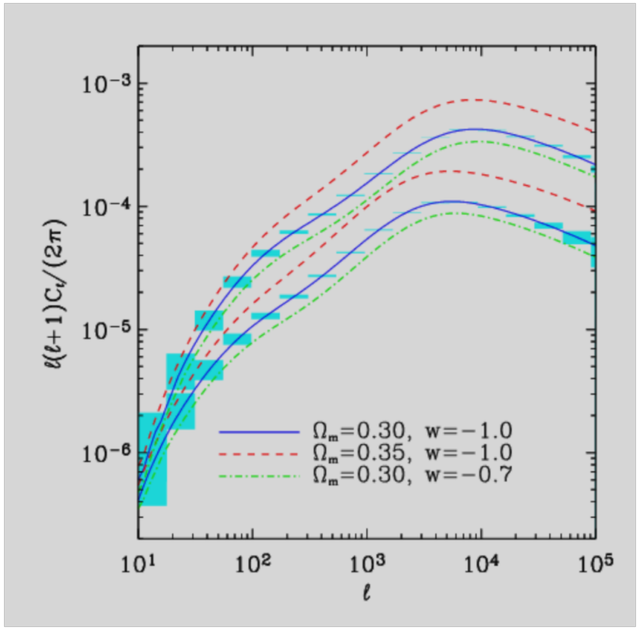
# Cosmic Shear Tomography in One Slide



## Weak Gravitational Lensing

- A consequence of General Relativity
- Overdensities along the lines of sight
- Distortion (and magnifaction) of galaxy shape
- A statistical effect : need for large samples
- A tiny effect : need for a stable PSF
- Binning in redshift : accurate photo – z
- Measurement of both expansion and growth



# Cosmic Shear Tomography : Cookbook

- *Shear power spectrum:*

$$\mathcal{C}_{ij}(\ell) = \frac{c}{H_0}\int_0^{z_h} \frac{\mathcal{W}_i^{\gamma}(z)\mathcal{W}_j^{\gamma}(z)}{E(z)\chi^2(z)} P_{\delta\delta}\left[\frac{\ell+1/2}{\chi(z)}, z\right] dz + \frac{c}{H_0}\int_0^{z_h} \frac{\mathcal{W}_i^{\gamma}(z)\mathcal{W}_j^{IA}(z) + \mathcal{W}_i^{IA}(z)\mathcal{W}_j^{\gamma}(z)}{E(z)\chi^2(z)} P_{\delta I}\left[\frac{\ell+1/2}{\chi(z)}, z\right] dz + \frac{c}{H_0}\int_0^{z_h} \frac{\mathcal{W}_i^{IA}(z)\mathcal{W}_j^{IA}(z)}{E(z)\chi^2(z)} P_{II}\left[\frac{\ell+1/2}{\chi(z)}, z\right] dz$$

- *Shear weight function:*

$$\mathcal{W}_i^{\gamma}(z) = \frac{3}{2}\left(\frac{H_0}{c}\right)\Omega_M(1+z)\tilde{\chi}(z)\int_z^{z_{max}} n_i(z')\left[1-\frac{\tilde{\chi}(z)}{\tilde{\chi}(z')}\right] dz'$$

- *IA weight function:*

$$\mathcal{W}_i^{IA}(z) = \frac{n_i(z)}{c/H(z)} = \left(\frac{H_0}{c}\right) n_i(z)E(z)$$

- *Redshift distribution:*

$$n_i(z) = \frac{\int_{z_{il}}^{z_{iu}} n(z)p_{ph}(z_p, z)dz_p}{\int_{z_{min}}^{z_{max}} dz \int_{z_{il}}^{z_{iu}} n(z)p_{ph}(z_p, z)dz_p}$$

- *Photo − z pdf:*

$$p_{ph}(z) = \frac{1-f_{out}}{\sqrt{2\pi}\sigma_b(1+z)}\exp\left\{-\frac{1}{2}\left[\frac{z-c_b z_p - z_b}{\sigma_b(1+z)}\right]^2\right\} + \frac{f_{out}}{\sqrt{2\pi}\sigma_o(1+z)}\exp\left\{-\frac{1}{2}\left[\frac{z-c_o z_p - z_o}{\sigma_o(1+z)}\right]^2\right\}$$

# Shear Tomography and Dark Energy

- *Background expansion:*

$$E^2(z) = \Omega_M(1+z)^3 + \Omega_X(1+z)^{3(1+w_0+w_a)} \mathrm{e}^{-w_a z/(1+z)} + \Omega_K(1+z)^2$$

- *Growth of structures − power spectrum:*

$$P_L(k,z) = \frac{9}{25}\frac{2\pi^2}{g_\infty^2}\left[\frac{3}{2}\Omega_M\left(\frac{H_0}{c}\right)^2\right]^{-2}\left(\frac{A_s}{k_0^{n_s-1}}\right)T_m^2(k)D^2(z)k^{n_s}$$

$$P_{\delta\delta}(k,z) = \mathcal{P}[P_L(k,z)]$$ *(need for a nonlinear recipe)*

- *Growth of structures − growth rate:*

$$\frac{d\ln D(a)}{d\ln a} = [\Omega_M(a)]^\gamma$$ *($\gamma$ = 0.55 for $\Lambda$CDM, slightly different for CPL)*

- *Intrinsic alignment (probe DE and galaxy physics):*

$$P_{\delta I}(k,z) = -[\mathcal{A}_{IA}\mathcal{C}_{IA}\Omega_M/D(z)]P_{\delta\delta}(k,z)\mathcal{F}_{IA}(z)$$

$$\mathcal{F}_{IA}(z) = (1+z)^{\eta_{IA}}\left[\langle L\rangle(z)/L_\star(z)\right]^{\beta_{IA}}$$

# Shear Tomography and DE vs MG

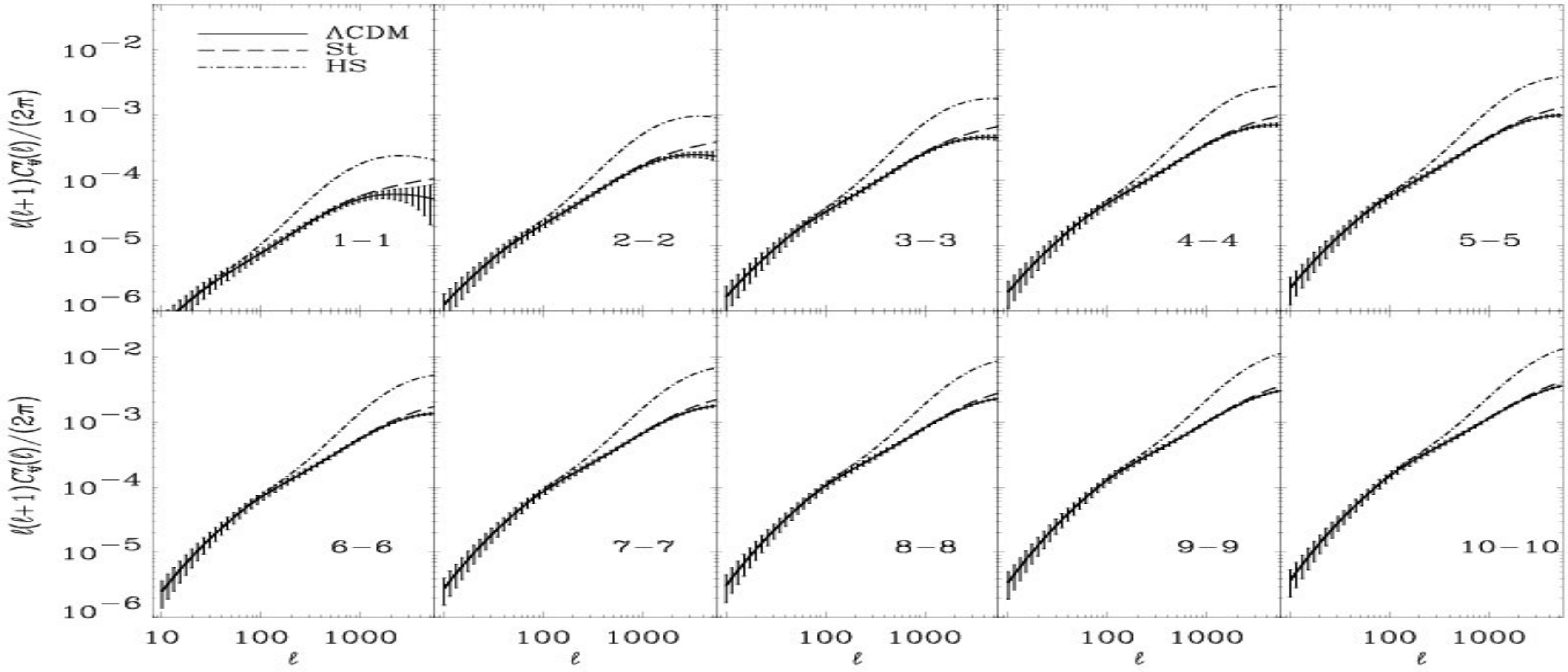
- *Growth of structures – growth rate:*

$$\frac{d\ln D(a)}{d\ln a} = [\Omega_M(a)]^\gamma$$

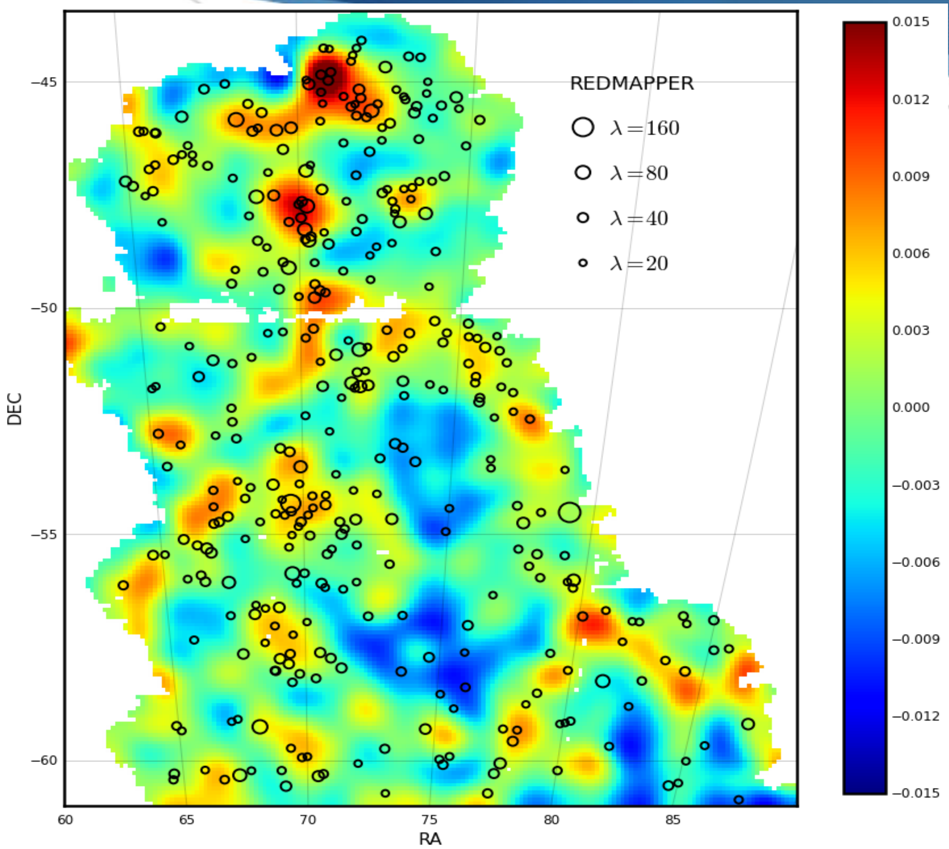
*($\gamma \neq 0.55$ for Modified Gravity models)*

- *Growth of structures – effective gravitational constant:*

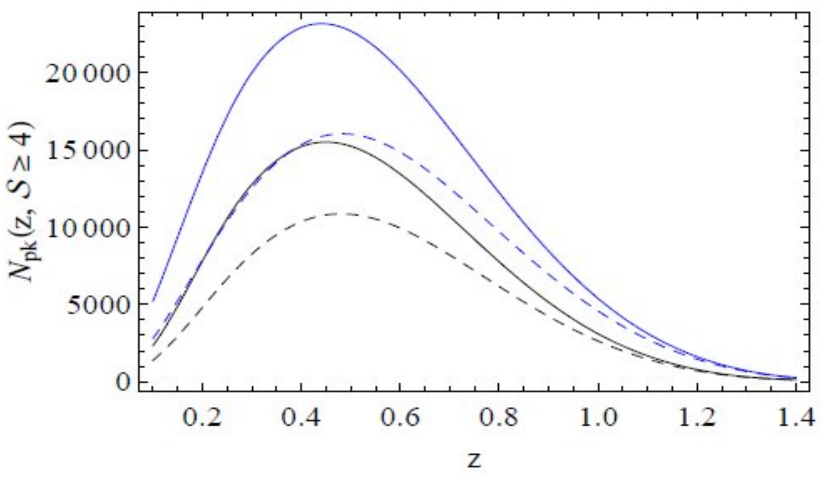
$$\ddot{\delta} + 2H\dot{\delta} - 4\pi\mathscr{G}(k,a)\rho\delta \simeq 0, \qquad \mathscr{G}(k,a) = \frac{G}{f_{,R}} \frac{1 + 4\frac{k^2}{a^2}\frac{f_{,RR}}{f_{,R}}}{1 + 3\frac{k^2}{a^2}\frac{f_{,RR}}{f_{,R}}}$$



# A Side Comment : There is More in Lensing!



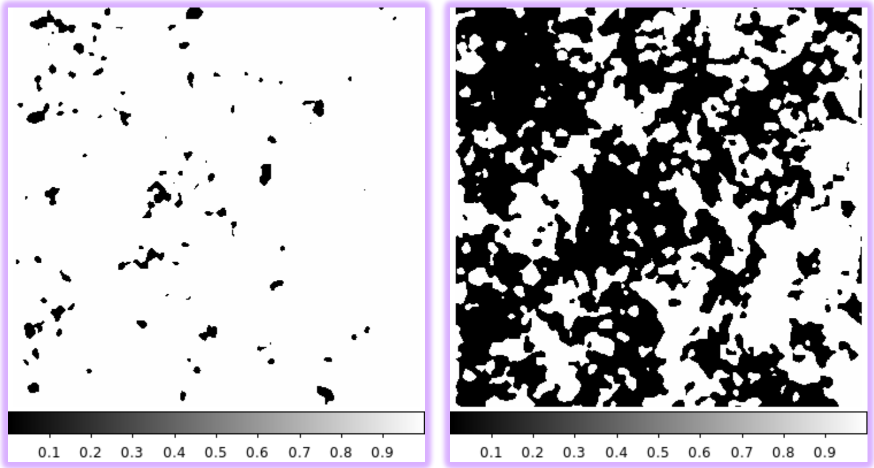

## Peaks Number Counts




## Lensing Convergence Maps

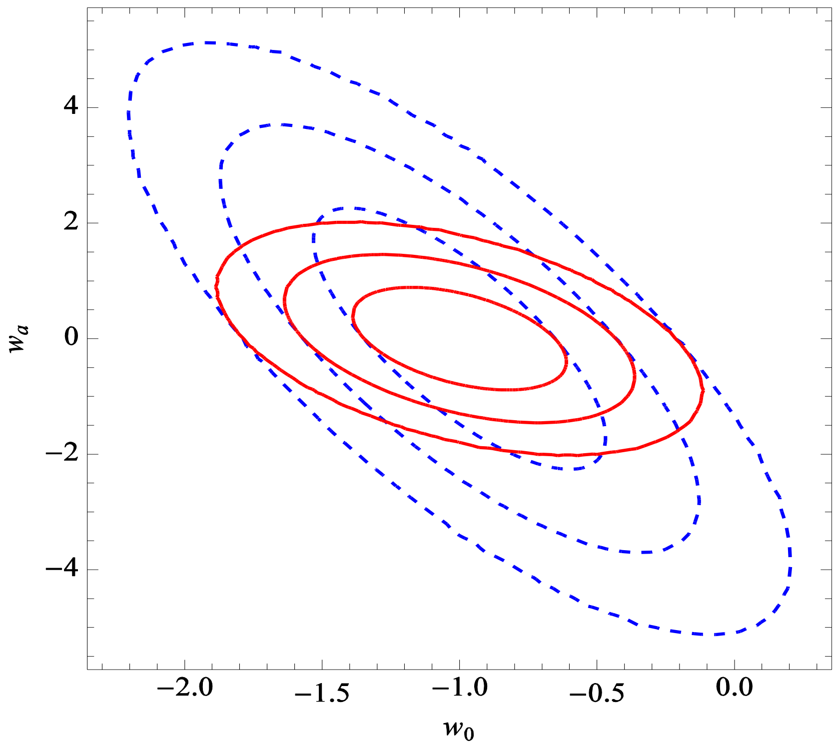
- excess surface mass density
- reconstructed from the shear field
- scalar quantity with different systematics
- a rich mine of informations

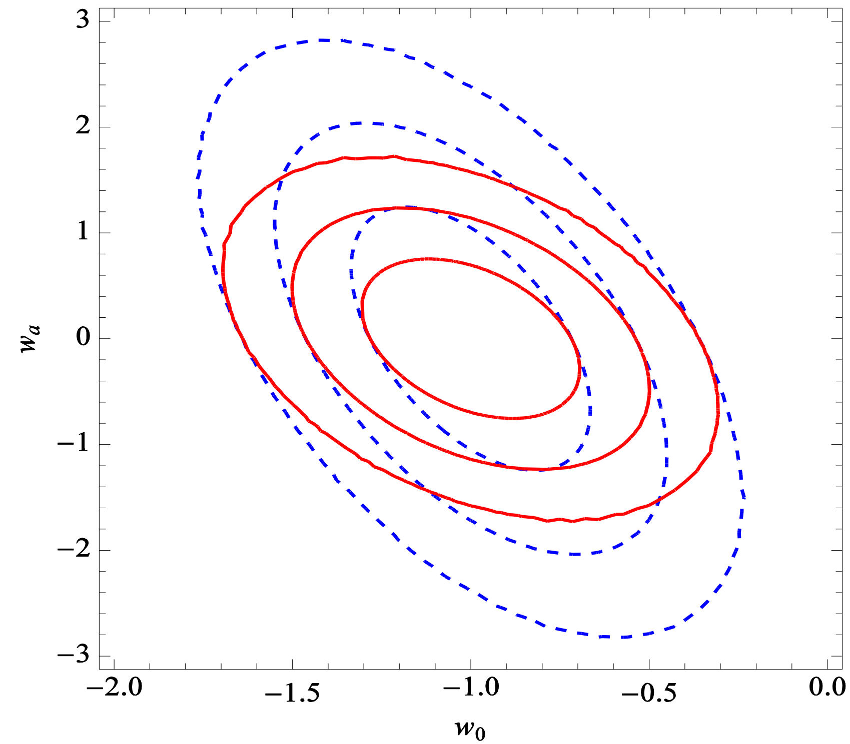
## Minkowski Functionals



# Optimizing a (Lensing) Survey: Figure of Merit

- *What is the aim of a survey?* *improving our understanding of the dark side of the universe*
- *What does "improving" mean?* *reducing uncertainties on the DE equation of state*
- *What does "reducing uncertainties" mean?* *smaller area in the ($w_0$, $w_a$) parameter space*




- *Quantifying the knowledge:* *Figure of Merit = inverse of the area of the 95% confidence level*
- *Estimating the FoM:* *FoM = $\{\det[Cov(w_0,w_a)]\}^{-1/2} = \{\det[F(w_0,w_a)]\}^{1/2}$*
- *Forecasting the accuracy:* *Fisher matrix (minimum variance estimator)*

# Forecasting the Accuracy: Fisher Matrix

## Approximating the Likelihood as Gaussian

- Taylor − like expansion around the best fit point: Gaussian approximation
- First non null order: first order derivatives of the observable wrt to cosmological parameters

$$F_{\alpha\beta} = \sum_{\ell=\ell_{min}}^{\ell_{max}} \frac{(2\ell+1) f_{sky} \Delta\ell}{2} \mathrm{Tr}\left[\frac{\partial \mathbf{C}(\ell)}{\partial p_\alpha} \mathbf{Cov}^{-1}(\ell) \frac{\partial \mathbf{C}(\ell)}{\partial p_\beta} \mathbf{Cov}^{-1}(\ell)\right]$$

$$\mathbf{Cov}_{ij}(\ell) = \mathcal{C}_{ij}(\ell) + \frac{\gamma_{int}^2 \delta_{ij}^K}{f_i n_g \times 3600(180/\pi)^2}$$

$$\mathbf{p}_c \equiv \{\Omega_M, \Omega_X, \Omega_b, w_0, w_a, h, n_s, \sigma_8\} = \{0.32, 0.68, 0.05, -1.0, 0.0, 0.67, 0.83\}$$

$$\mathcal{A} = 15000 \text{ sq deg} \quad , \quad n_g = 30 \text{ gal/arcmin}^2 \quad , \quad \gamma_{int} = 0.22 \quad , \quad \mathcal{N}_{bin} = 10$$

## The Best We Can Do but Yet Not Optimal

- Gaussian approximation vs non Gaussian likelihood
- Elliptical confidence contours vs banana − like observed contours
- Beware of technical yet important details (numerical derivatives and matrix inversion)
- Critically dependent on the data covariance matrix (more on this point later)

# Cosmic Shear Tomography : Ingredients

**Observational Inputs**

- Redshift estimate: photometric redshift
- Photo − z pdf: accuracy (bias)
- Photo − z pdf: failure rate
- Photo − z pdf: precision (scatter)
- Survey depth: limiting magnitude
- Survey duration: area coverage

**Theoretical Inputs**

- Matter power spectrum: linear regime
- Matter power spectrum: nonlinearities
- Matter power spectrum: baryons impact
- Growth of structures: growth rate
- Intrinsic alignment: IA power spectrum
- Intrinsic alignment: source properties

**Weak Lensing Requirements**

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**Galaxy Clustering Requirements**

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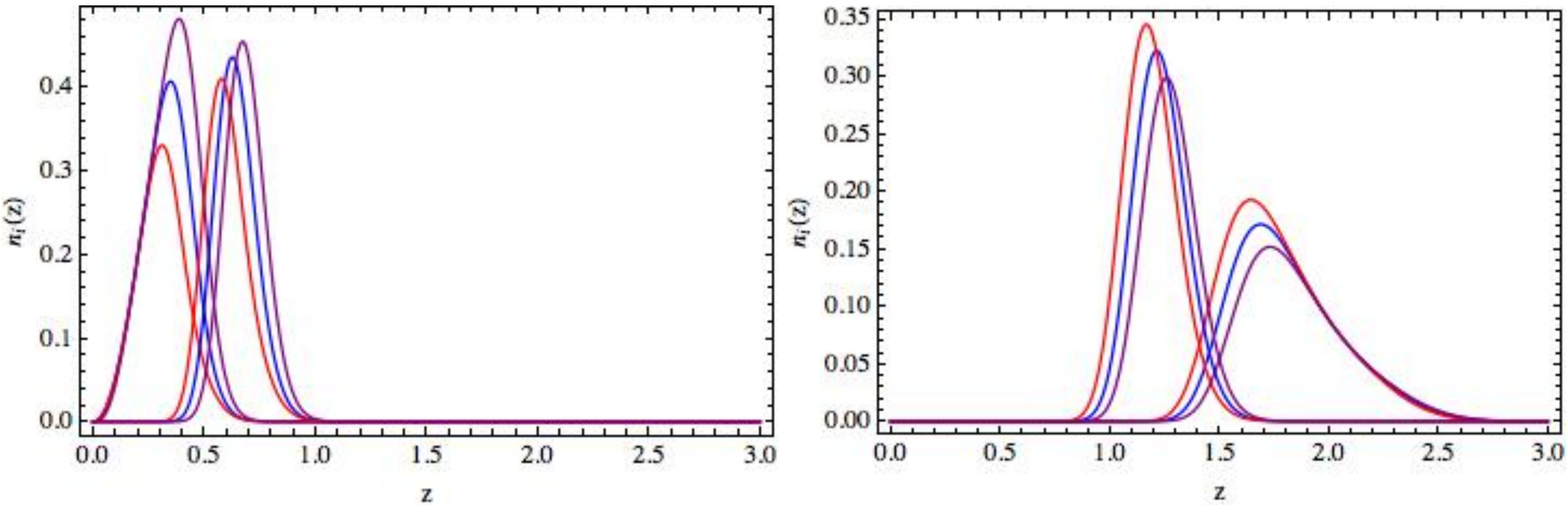
**Euclid Survey Requirements**

# Photo − z Requirements: Accuracy

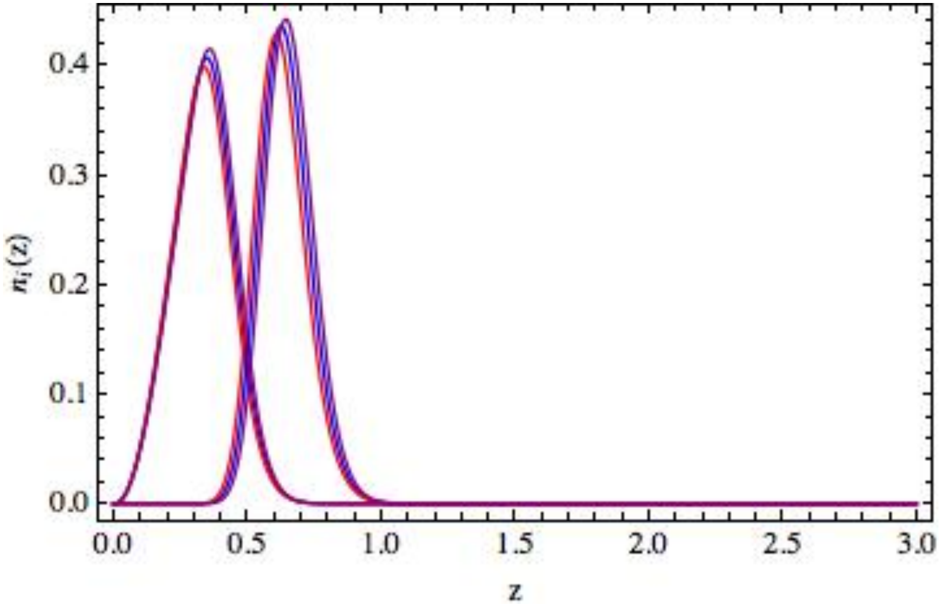
- *Additive bias: the centre of the bin is shifted with respect to the correct position*

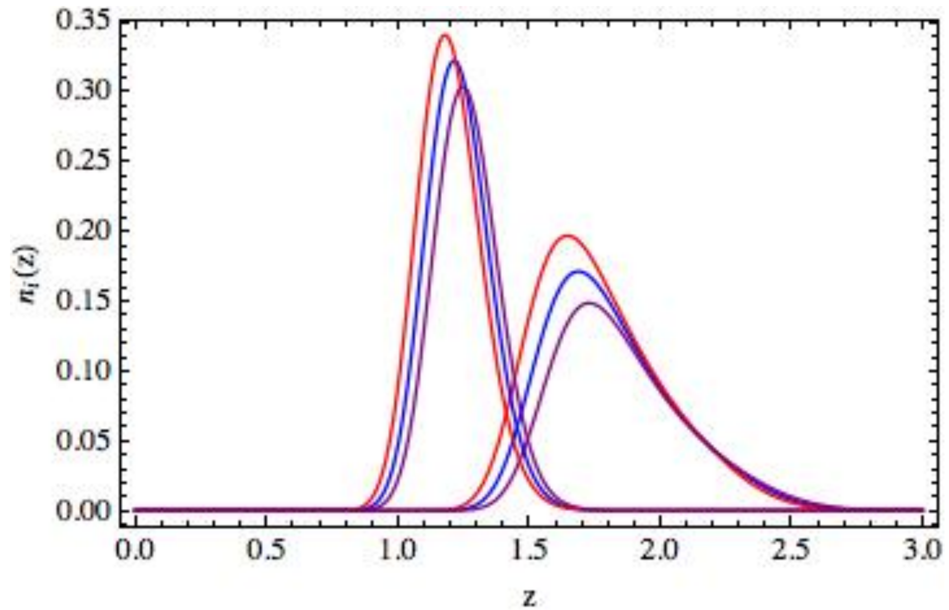



- *Why do we care? mixing galaxies from different bins washing out the shear signal*
- *FoM(-5%, 0%, +5%, noIA) = {48, 55, 49} ; FoM(-5%, 0%, +5%, eNLA) = {38, 46, 43}*
- *Impact of additive bias: reducing the FoM (up to 13% for noIA, up to 18% for eNLA)*
- *Requirement on additive bias: less than 0.01%*

# Photo − z Requirements: Accuracy

- *Multiplicative bias: the centre of the bin is shifted with respect to the correct position*

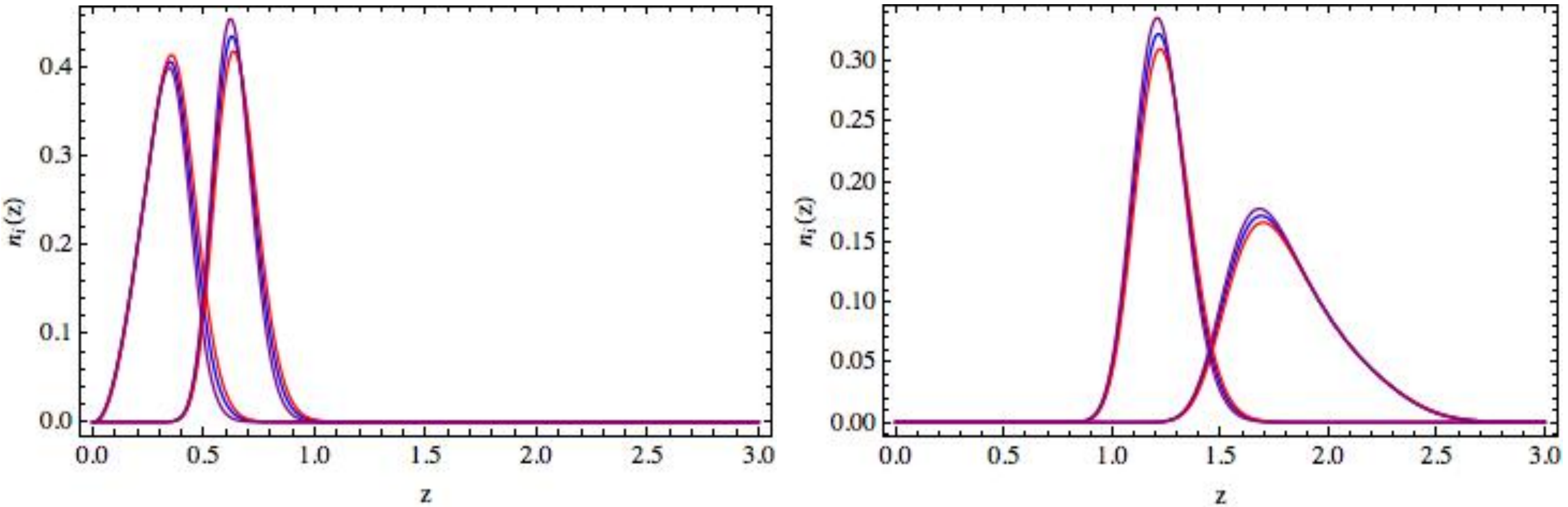



- *Why do we care? mixing galaxies from different bins washing out the shear signal*
- *FoM(-3%, 0%, +3%, noIA) = {47, 55, 50} ; FoM(-3%, 0%, +3%, eNLA) = {38, 46, 43}*
- *Impact of multiplicative bias: reducing the FoM (up to 15% for noIA, up to 18% for eNLA)*
- *Requirement on multiplicative bias: less than 0.01%*

# Photo − z Requirements: Failure Rate

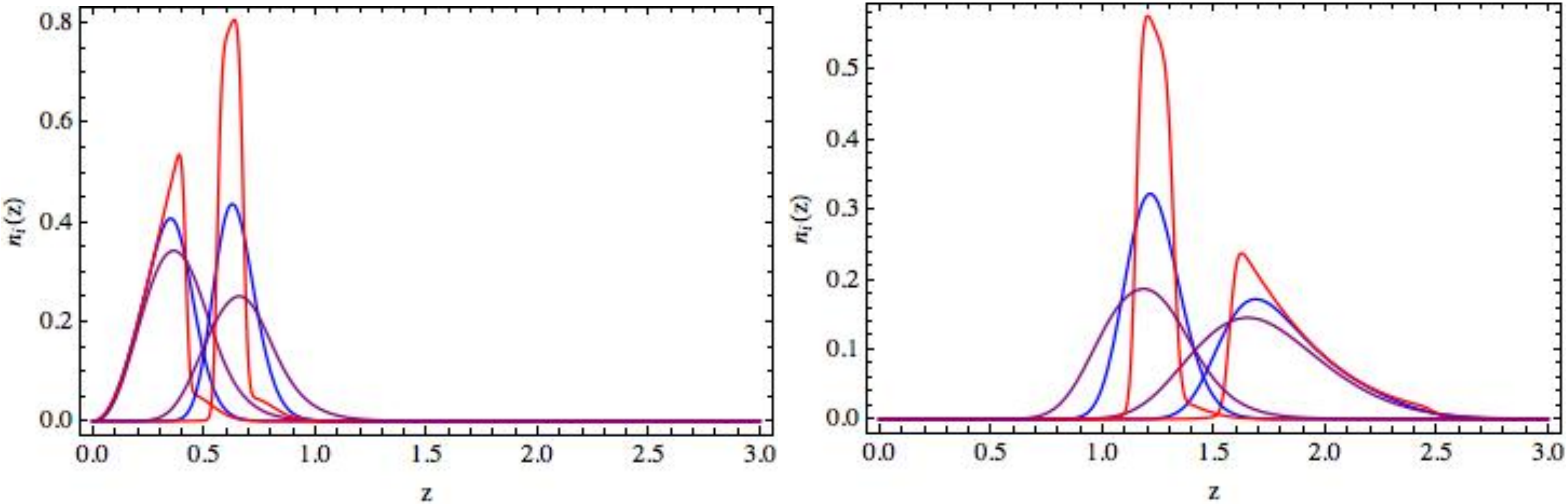
- *Catastrophic outliers: galaxies with photo − z quite different from the spec − z (degeneracy)*
- *Consequences: galaxies incorrectly assigned to the wrong redshift bin*




- *Why do we care? mixing galaxies from different bins washing out the shear signal*
- *FoM(20%, 10%, 0%, noIA) = {48, 55, 49} ; FoM(20%, 10%, +0%, eNLA) = {40, 46, 41}*
- *Impact of catastrophic outliers: reducing the FoM (up to 13% for noIA, up to 13% for eNLA)*
- *Counterintuitive result: no outliers causes some loss of signal? simplified photo − z model*
- *Requirement on outliers fraction: less than 10%*

# Photo − z Requirements: Precision

- Photo − z scatter: photo − z deviating from the spec − z no more than a given scatter




- Why do we care? smaller scatter, smaller correlation among bins, better signal
- FoM(1%, 5%, +10%, noIA) = {55, 55, 37} ; FoM(1%, 5%, 10%, eNLA) = {48, 46, 25}
- Impact of lower scatter: increasing the FoM for the eNLA case only (and not so much)
- Impact of higher scatter: dramatically decreasing the FoM for both the noIA and eNLA cases
- Requirement on photo − z scatter: less than 5% (3% goal)

# Requirements in Action: the Photo − z Example

### Photo − z Requirements

1. accuracy within 0.1%
2. outliers fraction < 10%
3. scatter < 5%

→

### Photo − z Measurement

i. template fitting
ii. population synthesis
iii. neural networks

→

### Measurement Requirements

- multiband photometry
- colors estimate (within 0.2%)
- jmprove photo − z modeling
- large training samples

+

### Photometry Requirements

- homogeneize data
- calibrate magnitudes
- choosing filters
- remove degeneracies

→

### Need for Additional Data

- ground based photometry
- spectroscopic samples
- companion surveys

# Deep and Narrow vs Wide and Shallow

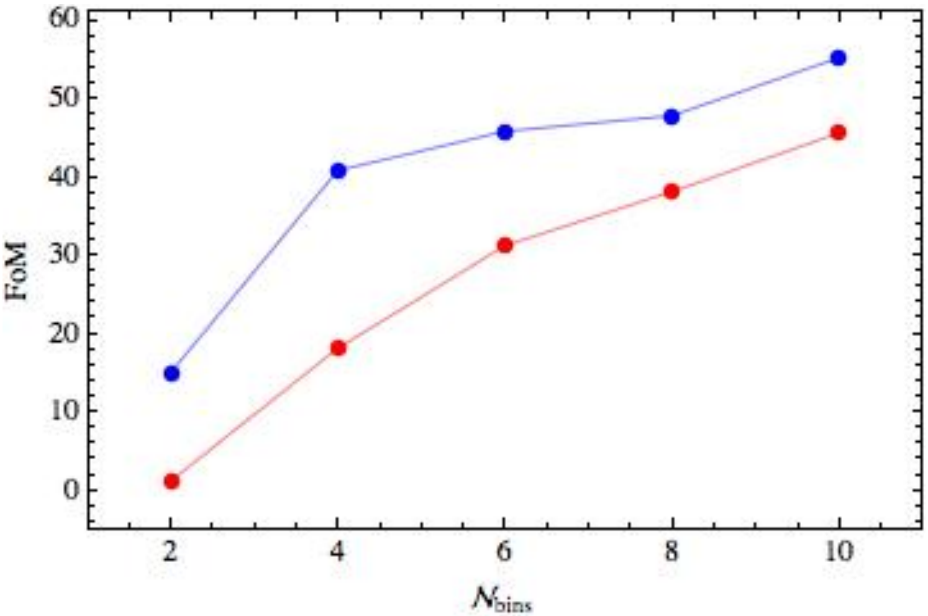
- *Deep vs Shallow: larger limiting magnitude, wider redshift range, larger galaxy number*
- *Narrow vs Wide: larger limiting magnitude, longer exposure time, lower survey area*

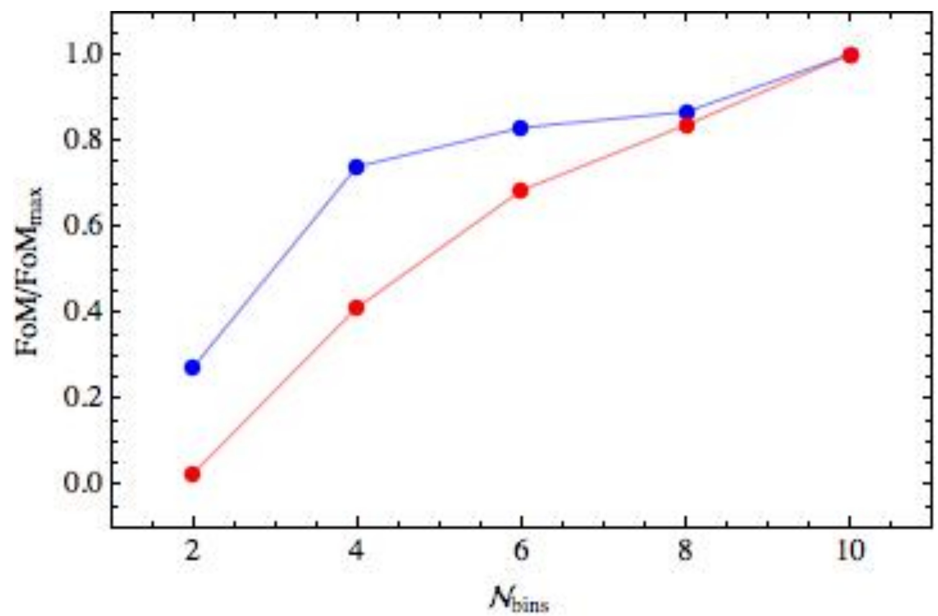
| $mag_{lim}$ | $z_m$ | $n_g$ | *A (sq deg)* | *FoM(noIA)* | *FoM(eNLA)* |
|---|---|---|---|---|---|
| 23.5 | 0.60 | 11.6 | 30000 | 43.9 | 25.3 |
| 24.0 | 0.75 | 18.7 | 30000 | 64.4 | 37.3 |
| 24.5 | 0.90 | 30.0 | 15000 | 55.1 | 43.0 |
| 25.0 | 1.05 | 47.6 | 5970 | 22.3 | 19.3 |
| 25.5 | 1.19 | 74.8 | 2377 | 9.5 | 8.0 |
| 26.0 | 1.34 | 116.5 | 946 | 3.9 | 3.3 |
| 26.5 | 1.49 | 180.0 | 377 | 1.7 | 1.4 |
| 27.0 | 1.63 | 275.8 | 150 | 0.7 | 0.6 |

- *Not a unique answer: modeling intrinsic alignment asks for the right combination*
- *Area vs Depth: FoM scaling with area much faster than with number density*
- *Dark Energy impact: the larger the redshift, the more DM dominated, the less EoS matters*

# Tracing the Universe Evolution and Growth

- *Why tomography? tracing DE properties through its impact on the growth of structures*
- *How many bins? more bins, more details on DE EoS, less galaxies in each bin, more noise*

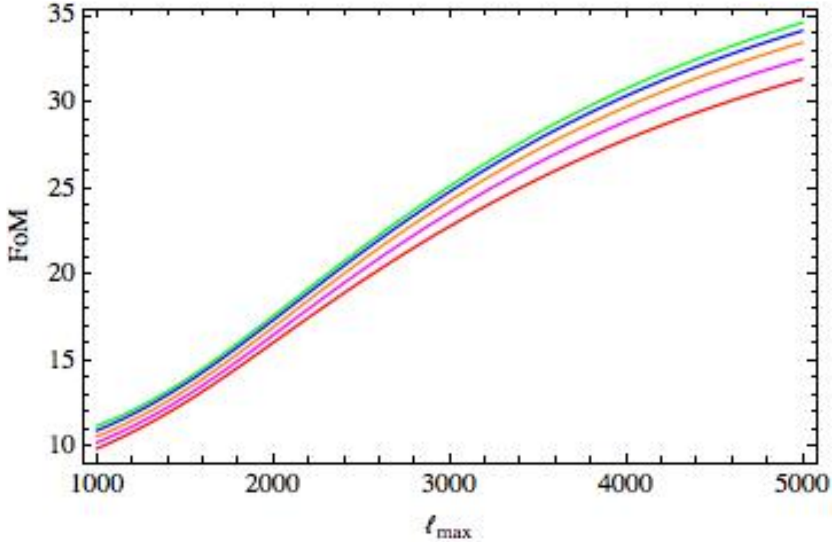


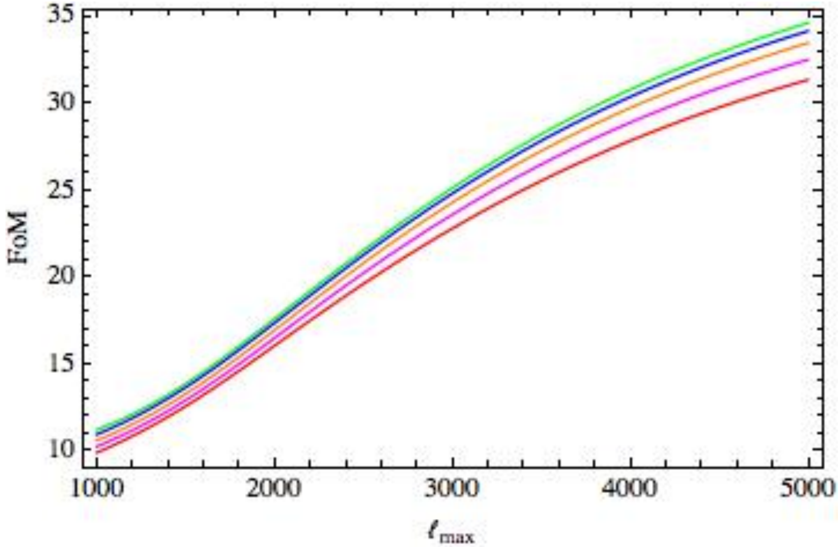



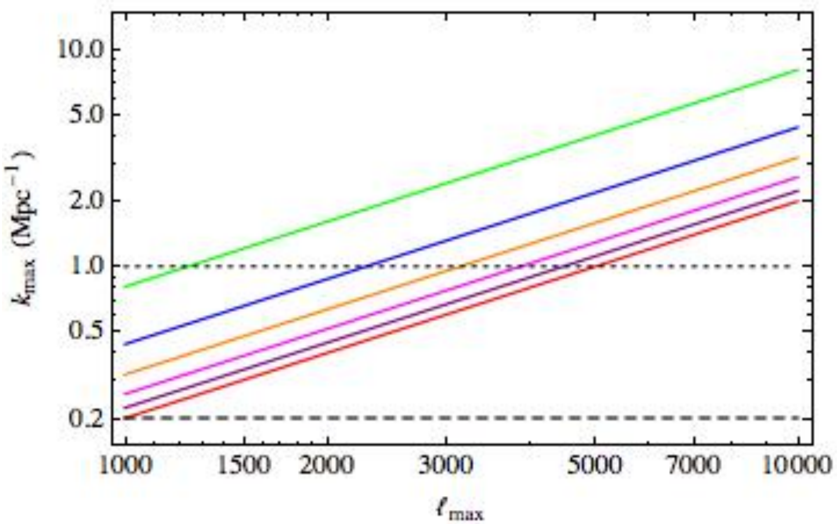

- *FoM scaling with no bins: increasing but flattening out after 10 bins*
- *noIA vs eNLA: larger number of bins preferred to model IA (to follow IA at low z)*
- *changing requirements: more bins, same range, narrower bins, higher photo − z accuracy*
- *looking for a compromise: 10 redshift bins with (super)accurate bin centres*

# *Tracing the Universe from Small to Large Scales*

- *Why power spectrum? quantifying the structures from the largest to the smallest scales*
- *Multipole range: how do we choose ($l_{min}$, $l_{max}$)?*




***Matter PS Requirements***

i. $k_{max} > 0.1$ Mpc$^{-1}$: nonlinearities

ii. $k_{max} > 0.5$ Mpc$^{-1}$: unknown regime

iii. $k_{max} > 1$ Mpc$^{-1}$ : baryons

iv. $0.0 < z < 2.5$ : MG growth rate

v. $l_{min} < 10$ : non flat sky

# Weak Lensing Survey(s) Requirements

**Photo − z Requirements**

1. accuracy within 0.1%
2. outliers fraction < 10%
3. scatter < 5%

+

**Dark Energy Requirements**

1. $10 < l < 5000$
2. $n_g = 30$ gal/arcmin$^2$
3. area = 15000 sq deg

=

**Weak Lensing Survey Requirements**

+

**Ground Based Data Requirements**

+

**Theory and N − body Simulations Requirements**

# Alice Out of the Wonderland - Systematics

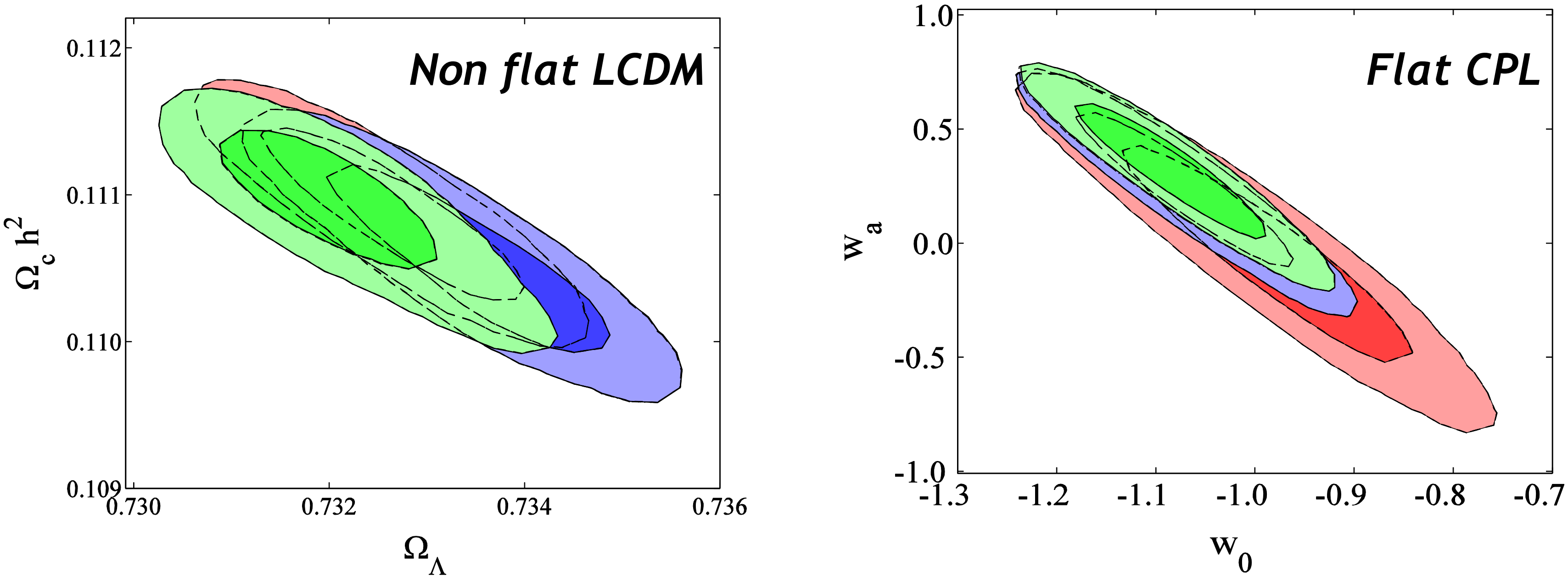
- *Cosmic shear changes the ellipticity of the source image but it's a tiny modification*
- *In an ideal world: measure the shape of the galaxies to get the shear from averaging*
- *Out of Wonderland:* {
  - *moderate S/N*
  - *background removal*
  - *shape measurement codes*
- *Observed shear:* $\gamma_{obs}(q,z) = [1 + m(z)]\,\gamma(\theta,z) + \gamma_{add}(\theta,z)$
- *m(z): redshift depedent multiplicative bias*
- $\gamma_{add}(\theta,z)$: *scale and redshift dependent additive bias*
- *Observed cosmic shear power spectrum:*

$$\hat{C}_{ij}(\ell) = \left(1 + \mathcal{M}_{ij}\right) C_{ij}(\ell) + \mathcal{A}_{ij}(\ell)$$

*observed* | *multiplicative bias* | *lensing* | *additive bias*

# Eyes Not Wide Shut Open: Bias

- *Euclid + Planck mock dataset :*
  - ✓ *cosmic shear tomography*
  - ✓ *systematics included !*
  - ✓ *Planck anisotropy power spectrum*
- *MCMC fitting assuming no systematics : bias on cosmological parameters*

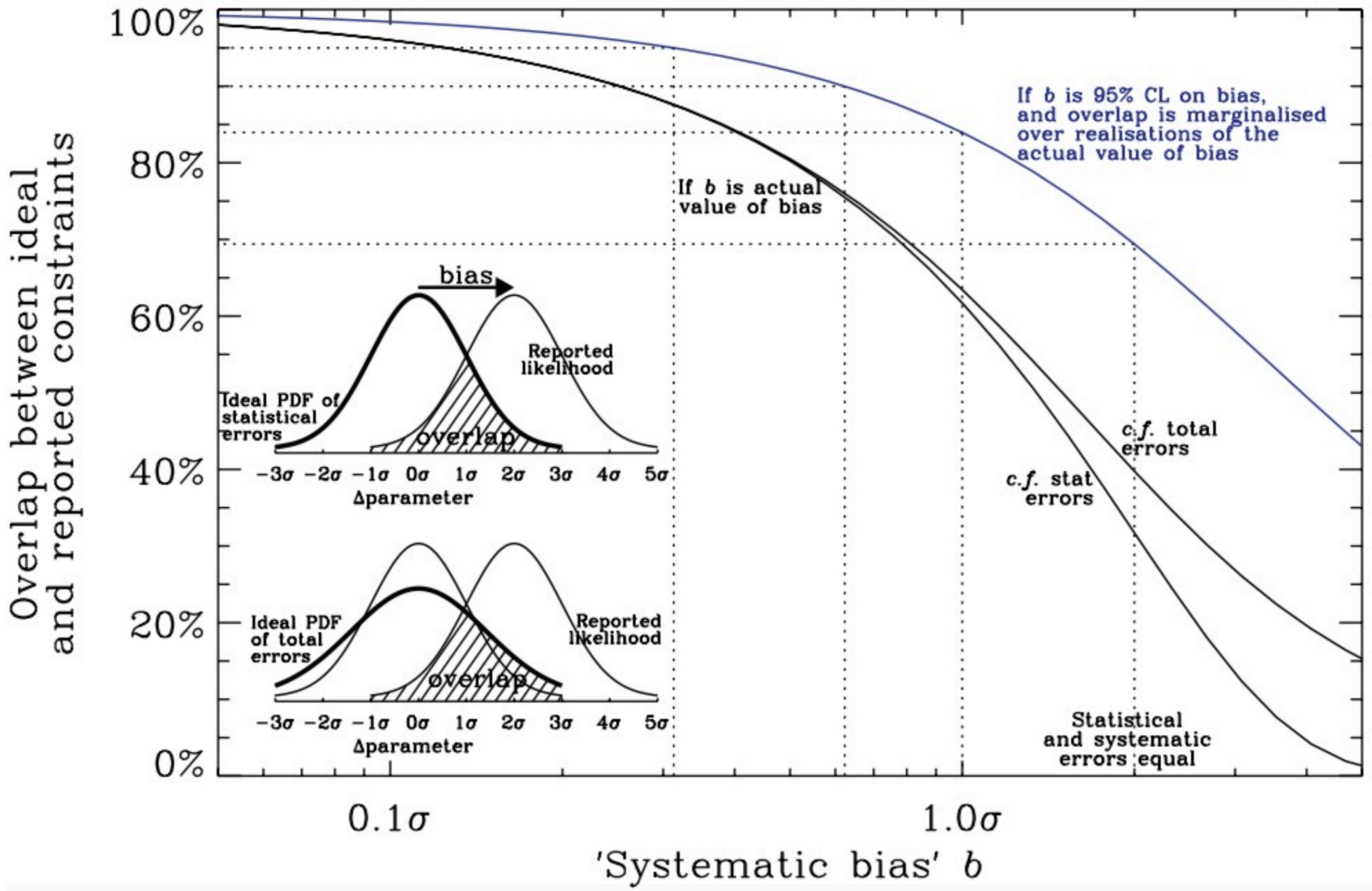



**Bias on Cosmological Parameters**

- *Two fiducial cosmological models considered : non flat LCDM and flat CPL*
- *Bias negligible if the variance of systematics is small enough*

# When Stop Caring About Systematics

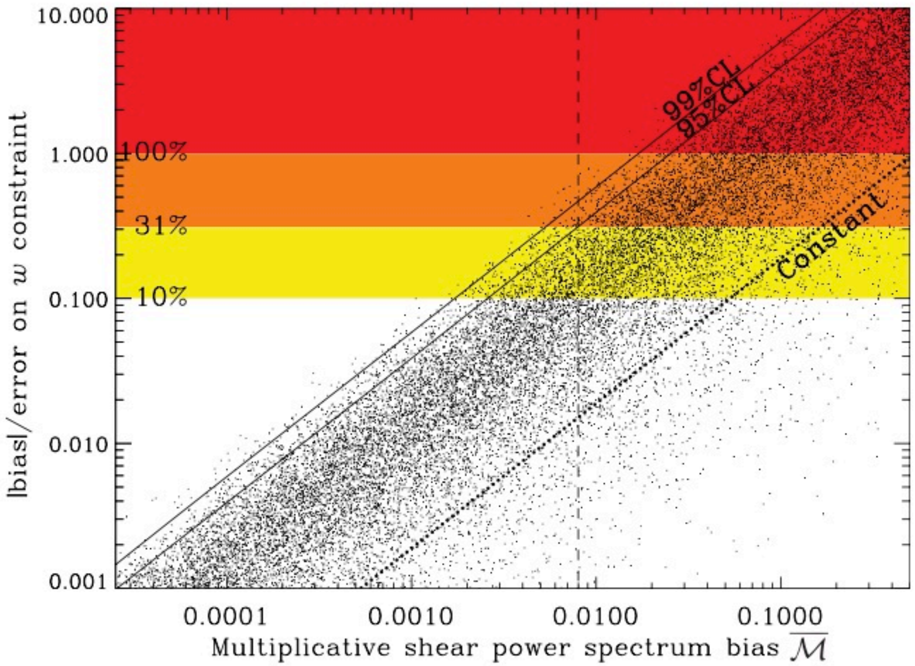
- *Impact of systematics*: *bias on cosmological parameters*
- *When bias matters*: *when the biased confidence levels are distant from the true ones*

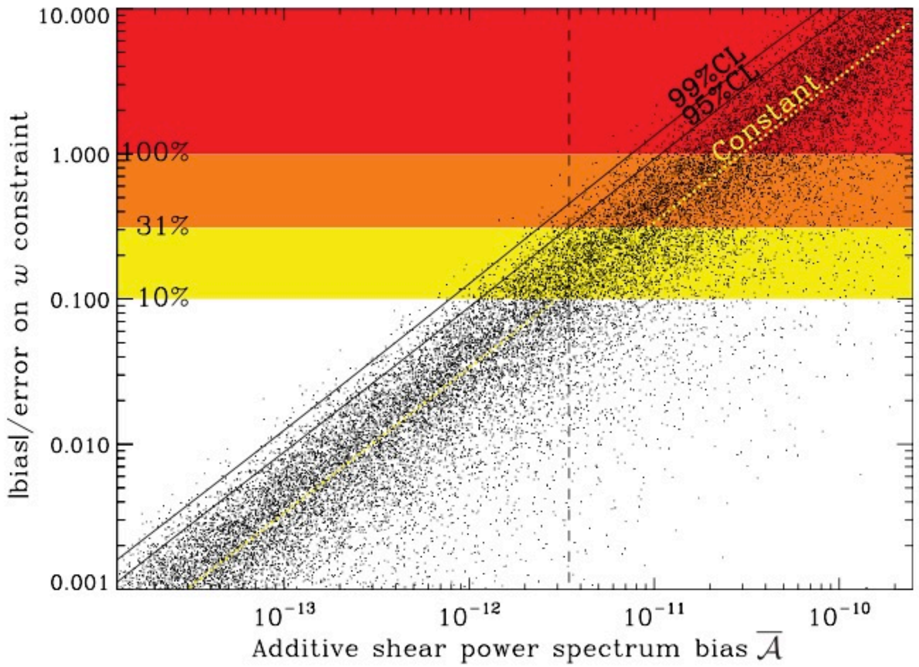



- *Biased and actual pdf overlapping*: *negligible bias* − $b < 0.31\ \sigma$

# When Too Much is Too Much

- *Limits on systematics:*
  - ✓ *assume a model for (m, $\gamma_{add}$)*
  - ✓ *propagate systematics*
  - ✓ *estimate bias*



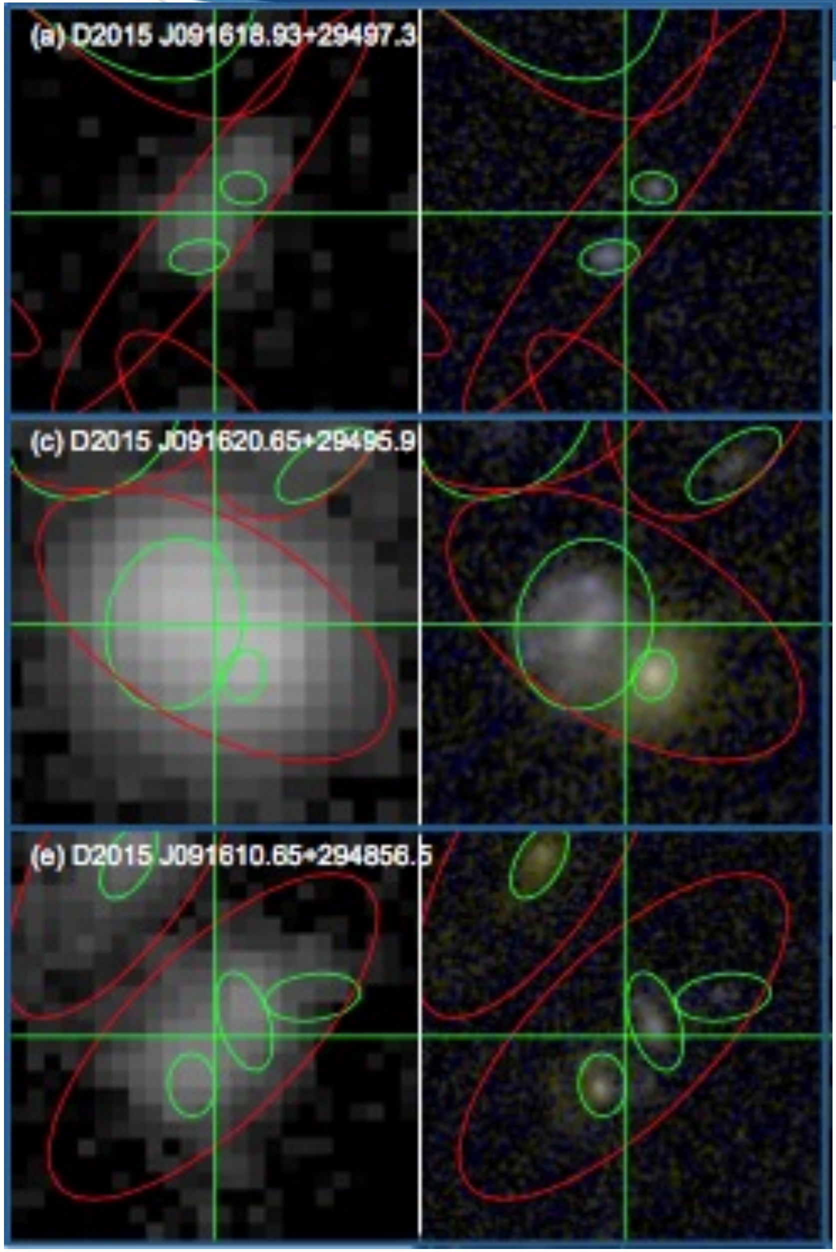

$$\overline{\mathcal{M}} \equiv \frac{\sum_{z\,\mathrm{bins}} \frac{1}{2\pi} \int_{\ell_{\min}}^{\ell_{\max}} |\mathcal{M}(\ell, z_A, z_B)| \ell^2 \mathrm{d}\ln\ell}{\sum_{z\,\mathrm{bins}} \frac{1}{2\pi} \int_{\ell_{\min}}^{\ell_{\max}} \ell^2 \mathrm{d}\ln\ell}$$ **$< 4.0 \times 10^{-3}$**

$$\overline{\mathcal{A}} \equiv \frac{\sum_{z\,\mathrm{bins}} \frac{1}{2\pi} \int_{\ell_{\min}}^{\ell_{\max}} |\mathcal{A}(\ell, z_A, z_B)| \ell^2 \mathrm{d}\ln\ell}{\sum_{z\,\mathrm{bins}} \frac{1}{2\pi} \int_{\ell_{\min}}^{\ell_{\max}} \ell^2 \mathrm{d}\ln\ell}$$ **$< 1.8 \times 10^{-12}$**

# *Where Systematics Come From – Raw Data*

- *Our instruments are awesome! yet they are made by humans*
- *Charge Transfer Inefficiency*
  - *space based instruments damaged by radiation and cosmic rays*
  - *trails along a preferred direction due to readout problems*
  - *distortion of the shape of objects mimicking lensing shear*
  - *well known effect already corrected for (... if you believe that)*
- *Brighter – Fatter effect*
  - *the brighter the object the larger the charge in the CCD pixel*
  - *scattering out light by residual charge after readout*
  - *the brighter the object the more light is scattered the fatter it looks*
  - *possibly corrected by flat field techniques*
- *Non optical detectors*
  - *observations made in the optical with "standard" instruments*
  - *what if observing in other photometric bands? new problems?*

# Where Systematics Come From – Blending




### Ground vs Space Based Problems

- what you see is not what is there
- a composite rather than a single object
- dependent on magnitude limit

### Why Do We Care About Blending

- wrong shape measurement
- wrong interpretation of the colors
- wrong photometric redshift estimate

### Can We Correct for Blending?

- remove recognized blends
- correct for blending from simulations
- multiband photometry (if possible)

# Systematics from Raw Data and Requirements

- *Quantifying the impact of detector systematics*

$$\mathcal{M} = 2\left\langle\frac{R_{\rm PSF}^2}{R_{\rm gal}^2}\right\rangle\left(\frac{\left\langle\delta\left(R_{\rm PSF}^2\right)\right\rangle}{\left\langle R_{\rm PSF}^2\right\rangle} + 2\frac{\langle\delta(R_{\rm NC})\rangle}{\langle R_{\rm obs}\rangle}\right)$$

$$+\left\langle\frac{R_{\rm PSF}^4}{R_{\rm gal}^4}\right\rangle\left(\frac{\sigma^2\left[R_{\rm PSF}^2\right]}{\left\langle R_{\rm PSF}^4\right\rangle} + 4\frac{\sigma^2[R_{\rm NC}]}{\left\langle R_{\rm obs}^2\right\rangle}\right)$$

$$\mathcal{A} = \frac{1}{P_\gamma^2}\left\langle\frac{R_{\rm PSF}^4}{R_{\rm gal}^4}\right\rangle\sigma^2[|\boldsymbol{\varepsilon}_{\rm PSF}|]$$

$$+\frac{1}{P_\gamma^2}\left\langle\left(1+\frac{R_{\rm PSF}^2}{R_{\rm gal}^2}\right)^2\right\rangle\sigma^2[|\boldsymbol{\varepsilon}_{\rm NC}|]$$

$$+\frac{\langle|\boldsymbol{\varepsilon}_{\rm PSF}|^2\rangle}{P_\gamma^2}\left\langle\frac{R_{\rm PSF}^4}{R_{\rm gal}^4}\right\rangle\left(\frac{\left\langle\delta\left(R_{\rm PSF}^2\right)\right\rangle^2}{\left\langle R_{\rm PSF}^4\right\rangle} + \frac{\sigma^2\left[R_{\rm PSF}^2\right]}{R_{\rm PSF}^4}\right)$$

$$+4\frac{\langle|\boldsymbol{\varepsilon}_{\rm PSF}|^2\rangle}{P_\gamma^2}\left\langle\frac{R_{\rm PSF}^4}{R_{\rm gal}^4}\right\rangle\left(\frac{\langle\delta R_{\rm NC}\rangle^2}{\left\langle R_{\rm NC}^2\right\rangle} + \frac{\sigma^2[R_{\rm NC}]}{R_{\rm NC}^2}\right).$$

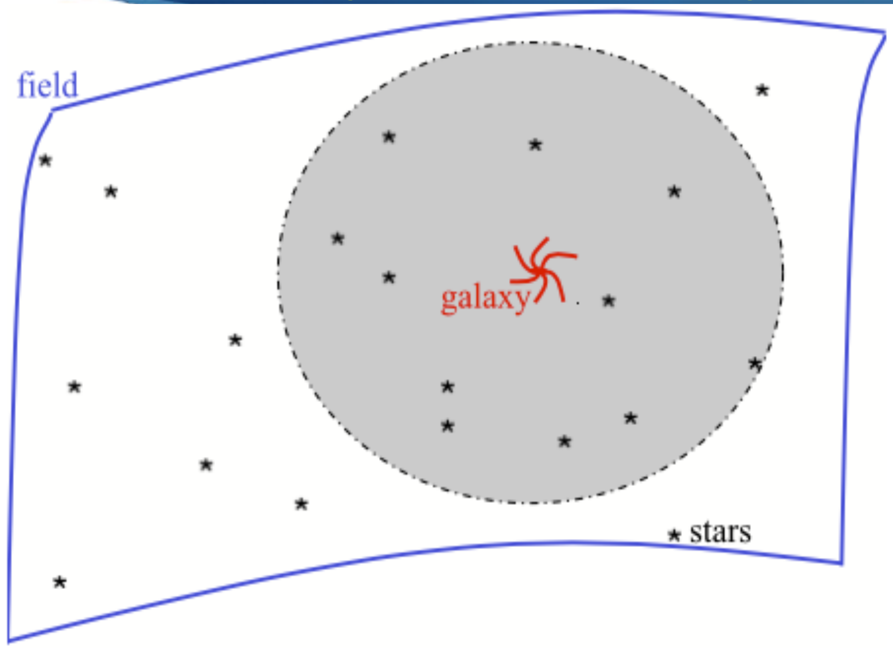
### *Ingredients to Care About*

1. $R_{PSF}$ : PSF size
2. $R_{PSF}/R_{gal}$ : typical PSF/gal size ratio
3. $R_{NC}$ : effective size of the
4. $\varepsilon_{PSF}$ : PSF ellipitcity
5. $\sigma(\varepsilon_{PSF})$ : error on PSF ellipticity
6. $\sigma(R_{PSF})$ : error on PSF size

### *Requirements from Systematics*

i. small PSF size
ii. galaxies larger than 1.5 x PSF
iii. correct for detector inefficiency
iv. reduce PSF ellipitcity
v. accuracy on PSF size and ellipticity

# Systematics from PSF Modeling

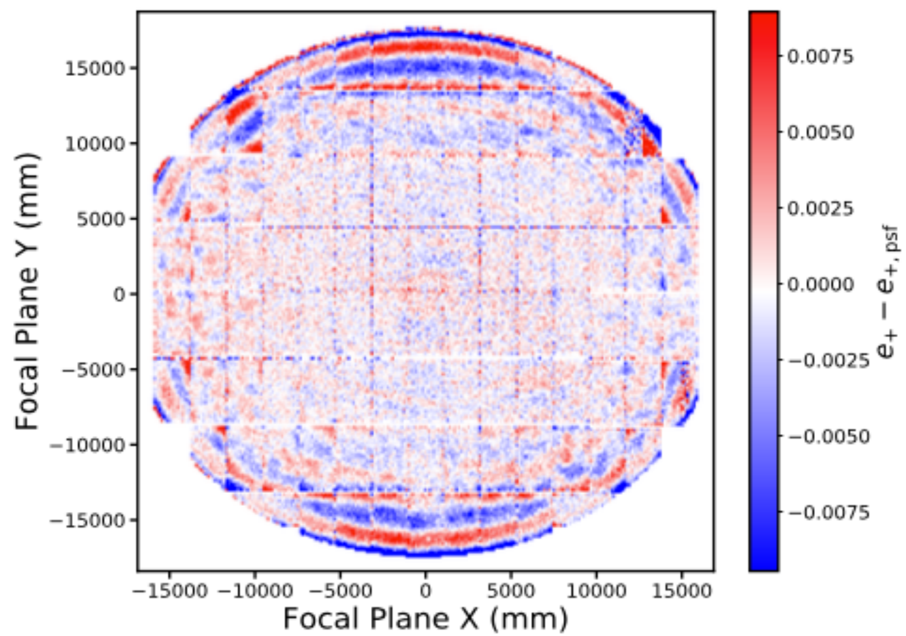



### *Ground vs Space Based*

- model PSF from stars in the field
- interpolate where galaxies are
- depends on number density
- model PSF from telescope optics
- no need for interpolation
- harder to code and more demanding

### *Correcting for PSF*

- model PSF and compute its moments
- “subtract” from the image ones
- additive bias from imperfect removal
- Include PSF in your modeling
- lens fitting codes (e.g., lensfit)
- multiplicative and additive bias



# Systematics from PSF and Requirements

- *Quantifying the impact of imperfect PSF modeling*

$$\mathcal{M} = 2\left\langle \frac{R^2_{\rm PSF}}{R^2_{\rm gal}} \right\rangle \frac{\left\langle \delta\left(R^2_{\rm PSF}\right)\right\rangle}{\left\langle R^2_{\rm PSF}\right\rangle} + \left\langle \frac{R^4_{\rm PSF}}{R^4_{\rm gal}} \right\rangle \frac{\sigma^2\left[R^2_{\rm PSF}\right]}{\left\langle R^4_{\rm PSF}\right\rangle}$$

$$\mathcal{A} = \frac{1}{{P_\gamma}^2}\left\langle \frac{R^4_{\rm PSF}}{R^4_{\rm gal}} \right\rangle \sigma^2[|\boldsymbol{\epsilon}_{\rm PSF}|]$$

$$+ \frac{\langle|\boldsymbol{\epsilon}_{\rm PSF}|^2\rangle}{{P_\gamma}^2}\left\langle \frac{R^4_{\rm PSF}}{R^4_{\rm gal}} \right\rangle \left( \frac{\left\langle \delta\left(R^2_{\rm PSF}\right)\right\rangle^2}{\left\langle R^4_{\rm PSF}\right\rangle} + \frac{\sigma^2\left[R^2_{\rm PSF}\right]}{R^4_{\rm PSF}} \right)$$

- *Dependent on shear responsivity: method dependent systematics*
- *Requirements: same as before but method dependent*
- *Caveats: underestimating the impact of PSF modeling*

# From Data to Shear : Shape Measurement

- Observed shear : $\gamma_{obs} = (1 + m)\,\gamma + \chi_{add}$
- Multiplicative and Additive bias dependent on galaxy properties

$$\mathcal{M} = \frac{2}{P_R}\left\langle \frac{R^2_{\rm PSF}}{R^2_{\rm gal}} \right\rangle \left( \frac{\left\langle \delta\left(R^2_{\rm PSF}\right)\right\rangle}{\left\langle R^2_{\rm PSF}\right\rangle} + 2\frac{\langle \delta(R_{\rm NC})\rangle}{\langle R_{\rm obs}\rangle} + \langle \mu \rangle \right) + \frac{1}{P_R^2}\left\langle \frac{R^4_{\rm PSF}}{R^4_{\rm gal}} \right\rangle \left( \frac{\sigma^2\left[R^2_{\rm PSF}\right]}{\left\langle R^4_{\rm PSF}\right\rangle} + 4\frac{\sigma^2[R_{\rm NC}]}{\left\langle R^2_{\rm obs}\right\rangle} \right).$$

$$\mathcal{A} = \frac{1}{P_R^2 P_\gamma^2}\left\langle \frac{R^4_{\rm PSF}}{R^4_{\rm gal}} \right\rangle \frac{\sigma^2[|\boldsymbol{\varepsilon}_{\rm PSF}|]}{P^2_{\varepsilon_{\rm PSF}}} + \frac{1}{P_R^2 P_\gamma^2}\left\langle \left( P_R^2 + \frac{R^2_{\rm PSF}}{R^2_{\rm gal}} \right)^2 \right\rangle \frac{\sigma^2[|\boldsymbol{\varepsilon}_{\rm NC}|]}{P^2_{\varepsilon_{\rm NC}}} + \frac{\langle |\boldsymbol{\varepsilon}_{\rm PSF}|^2\rangle}{P_R^2 P_\gamma{}^2 P^2_{\varepsilon_{\rm PSF}}}\left\langle \frac{R^4_{\rm PSF}}{R^4_{\rm gal}} \right\rangle \left( \frac{\left\langle \delta\left(R^2_{\rm PSF}\right)\right\rangle^2}{\left\langle R^4_{\rm PSF}\right\rangle} + \frac{\sigma^2\left[R^2_{\rm PSF}\right]}{R^4_{\rm PSF}} \right) + \frac{4\,\langle |\boldsymbol{\varepsilon}_{\rm PSF}|^2\rangle}{P_R^2 P_\gamma{}^2 P^2_{\varepsilon_{\rm PSF}}}\left\langle \frac{R^4_{\rm PSF}}{R^4_{\rm gal}} \right\rangle \left( \frac{\langle \delta R_{\rm NC}\rangle^2}{\left\langle R^2_{\rm NC}\right\rangle} + \frac{\sigma^2[R_{\rm NC}]}{R^2_{\rm NC}} \right) + \frac{\langle |\boldsymbol{\varepsilon}_{\rm PSF}|^2\rangle}{P_R^2 P_\gamma{}^2 P^2_{\varepsilon_{\rm PSF}}}\left\langle \frac{R^4_{\rm PSF}}{R^4_{\rm gal}} \right\rangle \alpha^2,$$

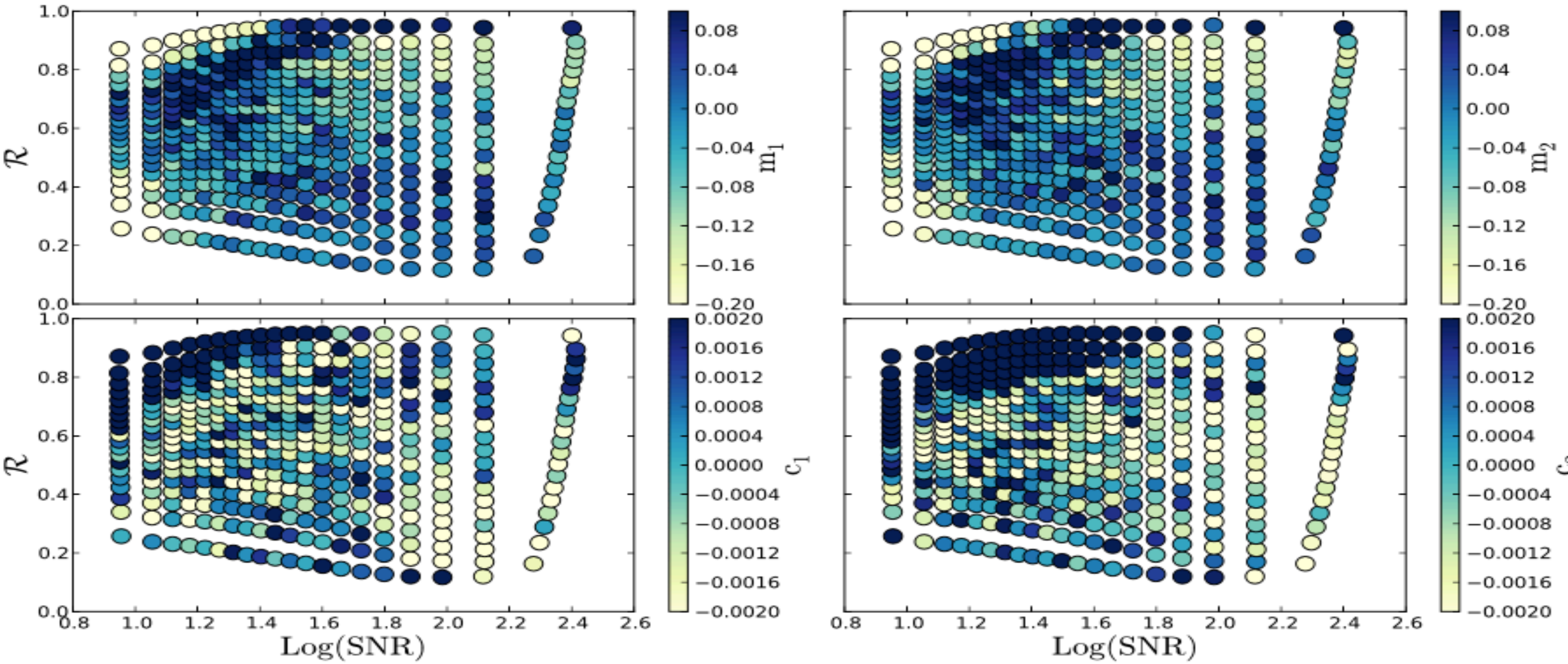
### *Shape Measurement Requirements*

- dependent on survey properties
- dependent on shape measurement code
- hard to quantify analytically
- rely on simulated data
- dependent on details of simulated data

# Shape Measurement Methods and Challenges

- *Shape measurement codes:* *moments based* / *template combinations* / *model +PSF fitting* — *challenges to choose the best*

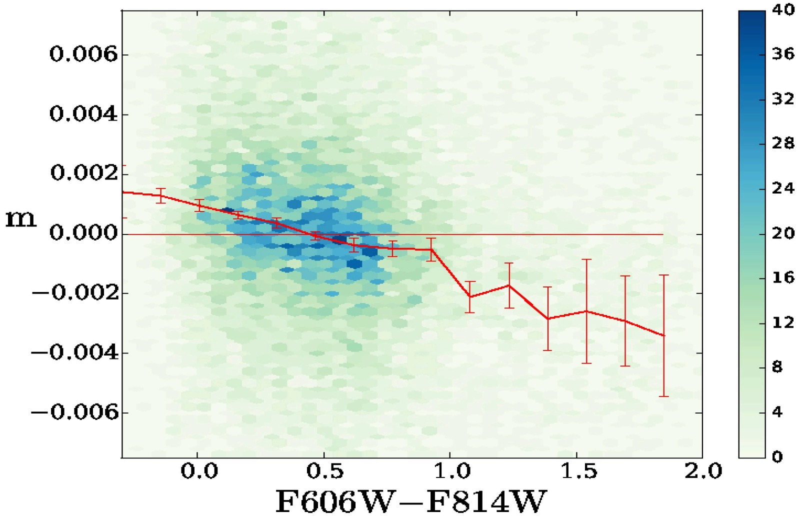
- *For all methods:* *calibration against simulated images*

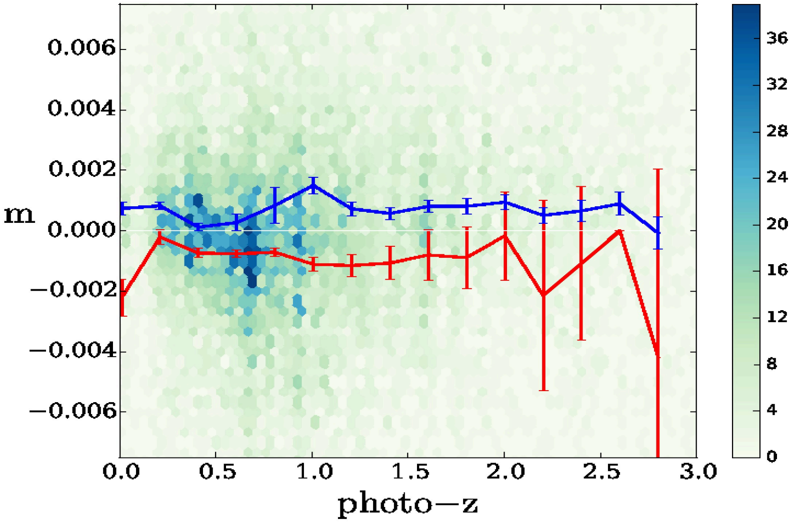



- *Calibration:* *multiplicative and additive bias as function of S/N and size*

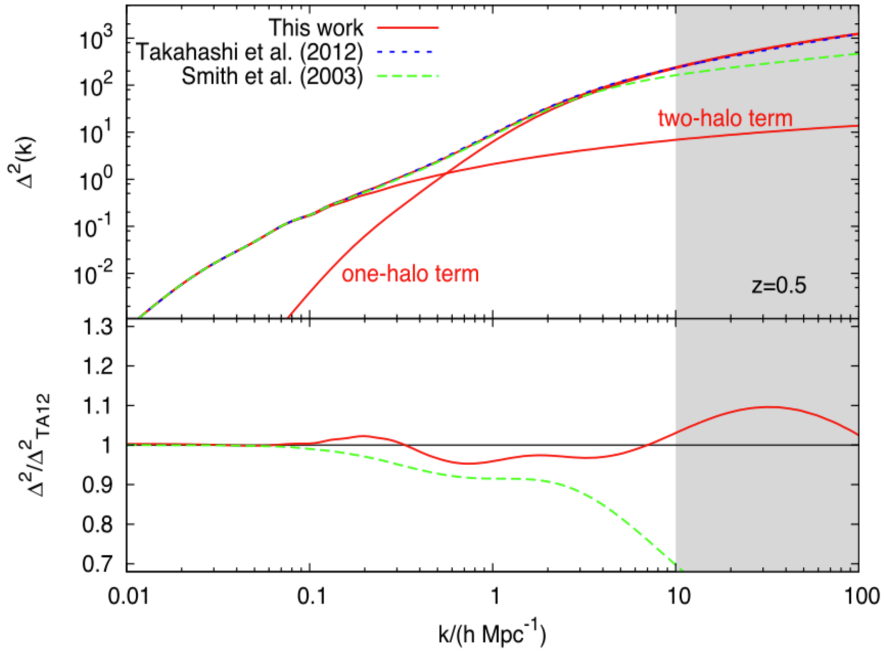
# New Systematics for Precision Cosmology

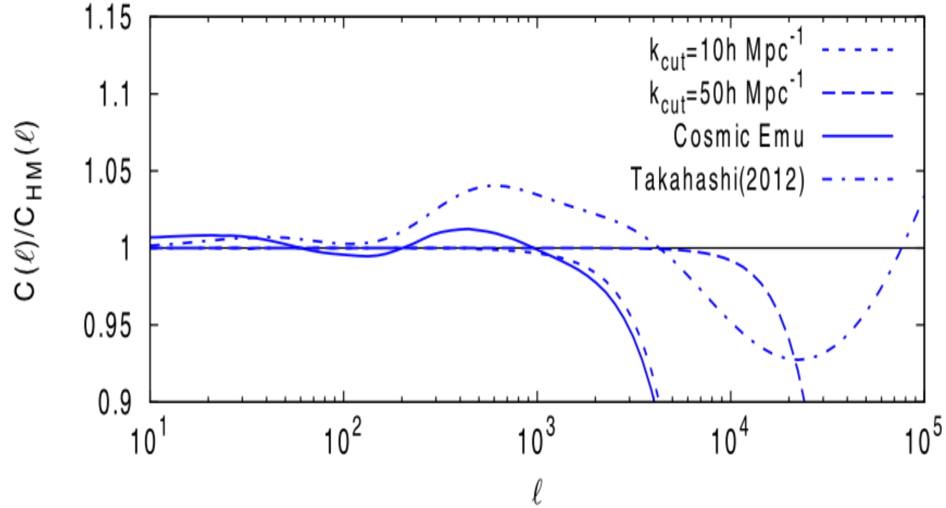
- Galaxy ellipticity : $\epsilon_1 + i\epsilon_2 \approx \dfrac{Q^0_{11} - Q^0_{22} + 2iQ^0_{12}}{Q^0_{11} + Q^0_{22} + 2(Q^0_{11}Q^0_{22} - (Q^0_{12})^2)^{1/2}}$
- Image moments : $Q^{\rm obs}_{ij} = \dfrac{1}{F_{\rm w}} \int_{\Delta\lambda} {\rm d}\lambda \int {\rm d}^2\boldsymbol{\theta}\, I^0(\boldsymbol{\theta};\lambda) * P(\boldsymbol{\theta},\lambda)\, \theta_i\theta_j\, W(\boldsymbol{\theta})$
- $I^0(\theta, \lambda) = I(\theta)\, S(\lambda)$ : SED dependent effective PSF – color bias
- $I^0(\theta, \lambda) = I(\theta)\, S(\theta, \lambda)$ : spatially varying SED – color gradient bias
- Correcting CG bias: 1. take galaxies with known color gradient
  2. measure ellipticity w/o color gradient into account
  3. compare and estimate bias (400k galaxies needed!)



# Contradiction at Works: Sytematics in Theory

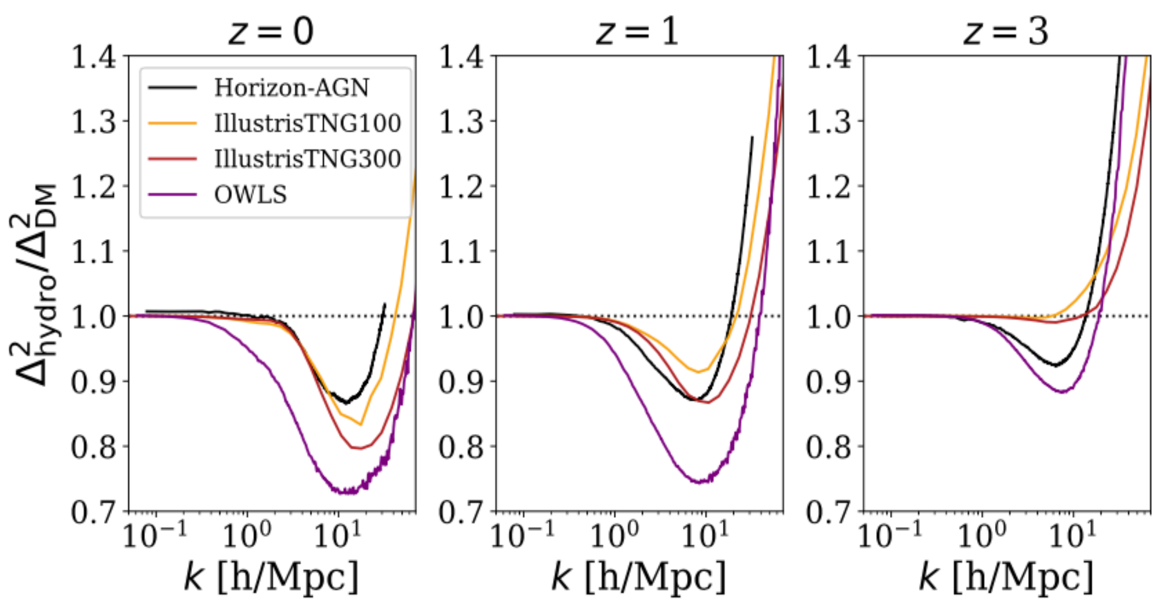


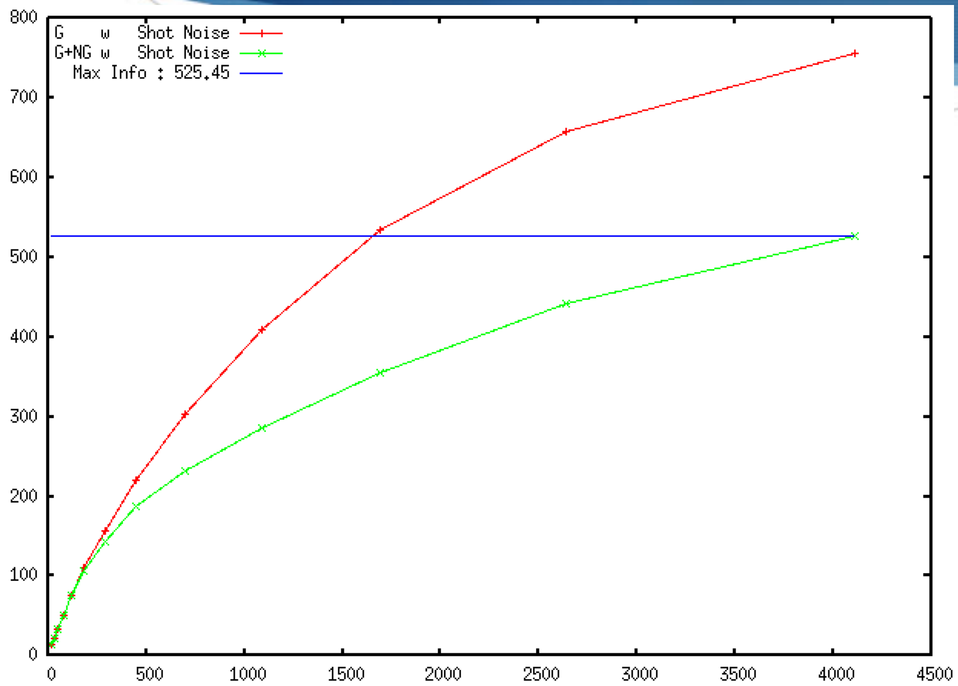

## Smith vs Takahashi vs Mead

## Baryonic Effects

- dramatic at large k
- Simulation dependent
- AGN and/or feedback
- approximated correction
- still uncertain
- degenerate with?



# Systematics in the Errors and Bias Again




## Cosmic Shear Covariance Matrix

- only Gaussian (shot noise) matter
- non Gaussian terms do matter a lot
- and supersample covariance maybe
- we know how to compute them
- but we do not know what we need
- rely on simulations to check
- but we do not have enough time

## *The (Not So) Unaware Belief that Everything is Fine: Confirmation Bias*

- **m**ore and more data and still the same model: *why should I do not find it ?*
- blinding the data and/or the analysis and/or the results as long as possible

## *The (Not So) Secret Desire to be the First One: Glorious Bias*

- unprecedented accuracy to find the unexpected: *why should I do not get glory?*
- triple check every step and then check again: *remember first CFTHLenS data*

# *The Reward of Matching Requirements*

***Never Give Up Controlling Systematics and Matching Requirements***

- *Theory systematics addressed with improved methods and simulations*
- *Shape systematics reduced by shear measurement challenges*
- *Galaxy clustering forecast updated and improved*
- *Further probes combination (Euclid and non – Euclid surveys)*

| | **Modified Gravity** | **Dark Matter** | **Initial Conditions** | **Dark Energy** | | |
|---|---|---|---|---|---|---|
| **Parameter** | $\gamma$ | $m_\nu/eV$ | $f_{NL}$ | $w_p$ | $w_a$ | *FoM* |
| Euclid Primary | 0.010 | 0.027 | 5.5 | 0.015 | 0.150 | 430 |
| Euclid All | 0.009 | 0.020 | 2.0 | 0.013 | 0.048 | 1540 |
| Euclid+Planck | 0.007 | 0.019 | 2.0 | 0.007 | 0.035 | 4020 |
| Current | 0.200 | 0.580 | 100 | 0.100 | 1.500 | ~10 |
| **Improvement Factor** | **30** | **30** | **50** | **>10** | **>50** | **>300** |

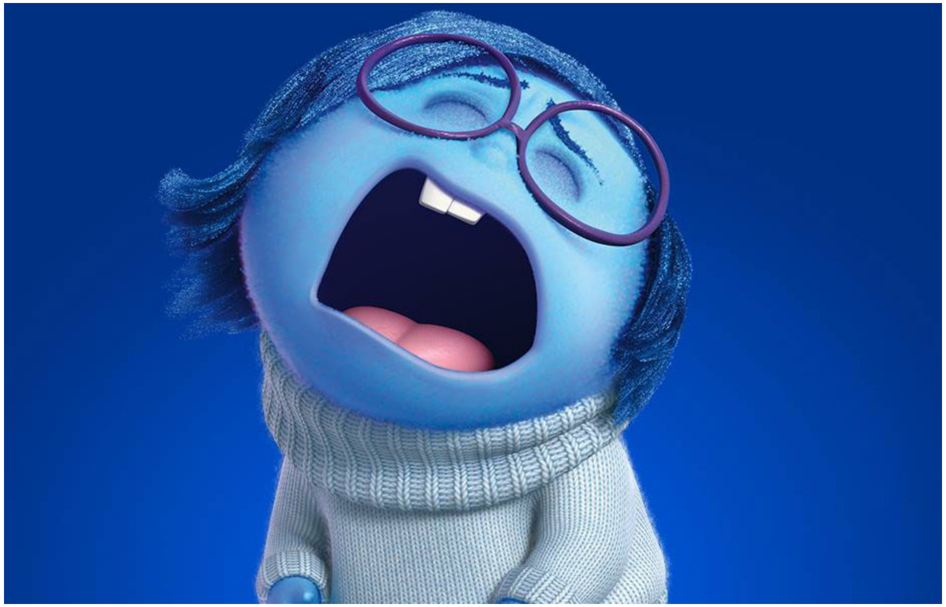
# Dealing with Requirements and Systematics

### *The Joy Of Dealing with Them*

- we can do the best survey ever and ever
- we know systematics are out there
- some of them may be taken under control
- part of them may also teach us something
- overall we know what we have to do
- we have time to understand all but the details

### *The Sadness Of Dealing with Them*

- better surveys harder requirements
- too much systematics out there
- “may be taken” is not “are taken”
- too difficult to understand them all
- that’s why I can’t stop crying
- but the devil lives in the details



# Two Talks in Two Sentences

*Requirements as an Opportunity to Make the Best of Weak Lensing*

*No Precision Cosmology Without Complete Systematics Removal*