Cosmological model discrimination with Weak Lensing

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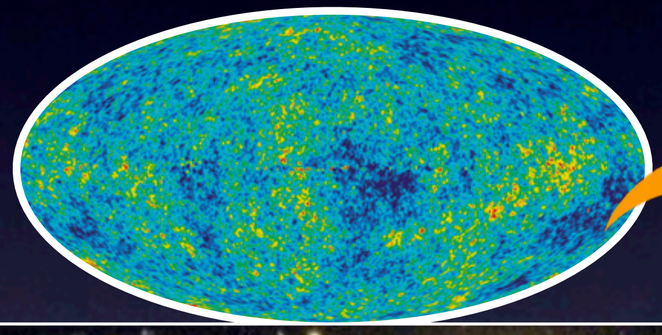
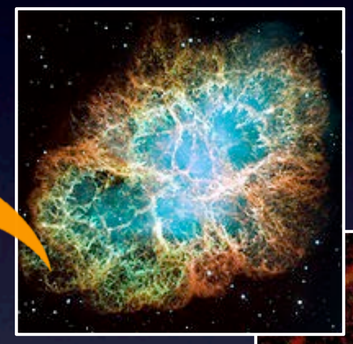
Outline

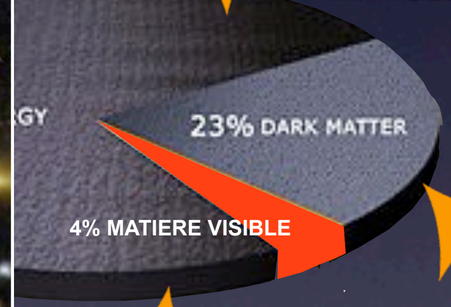
- ✓ Introduction
  - ✓ Introduction to weak lensing
  - ✓ Introduction to statistical estimation
- ✓ Missing data and standard methods
  - ✓ Statistical estimation with missing data
  - ✓ A global solution to missing data
- ✓ Non-Gaussian statistics
  - ✓ Systematic comparison
- ✓ Conclusions

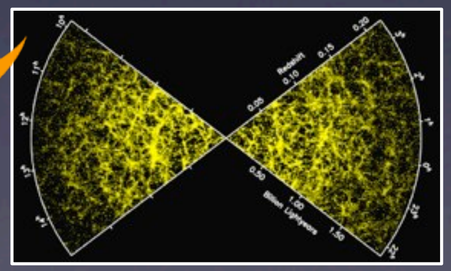
From observations to cosmological model

$$\mathcal{M}(\Omega_M, \Omega_\Lambda, \Omega_b, \sigma_8, ...)$$

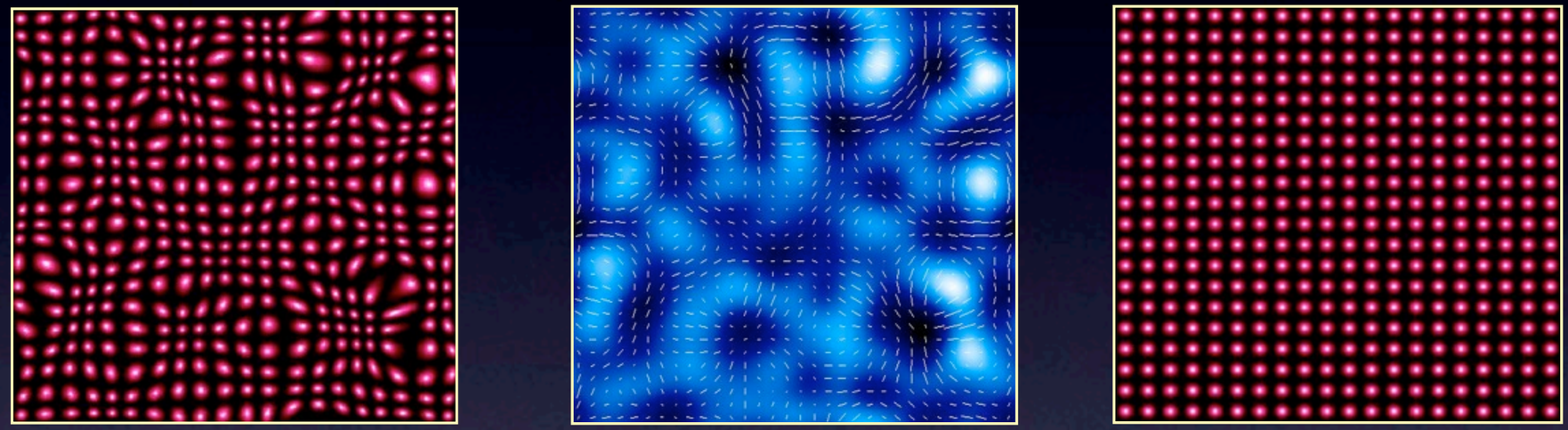


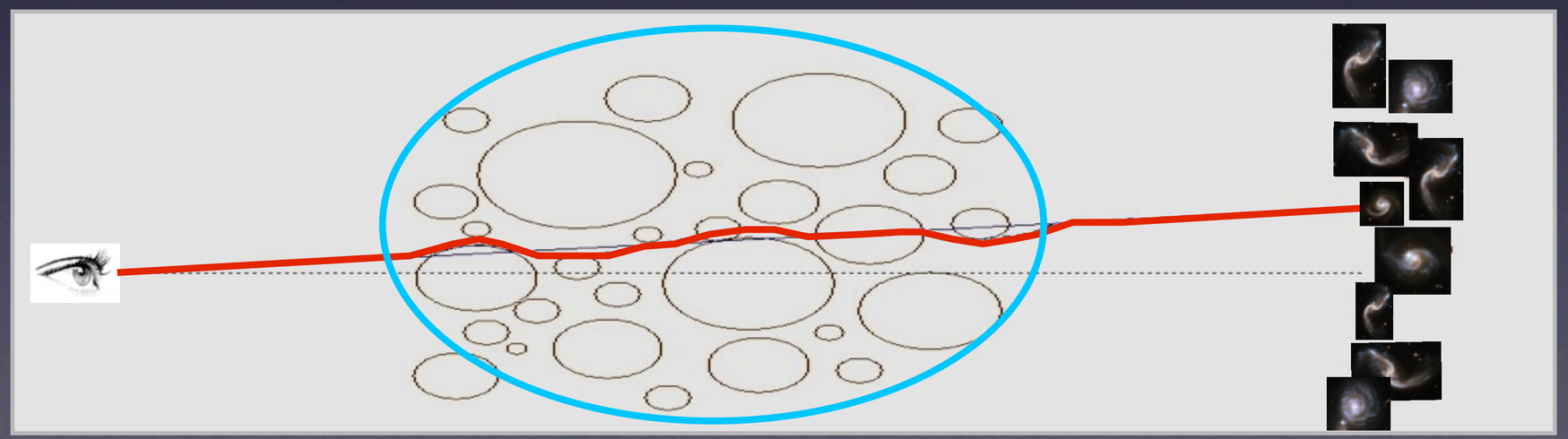




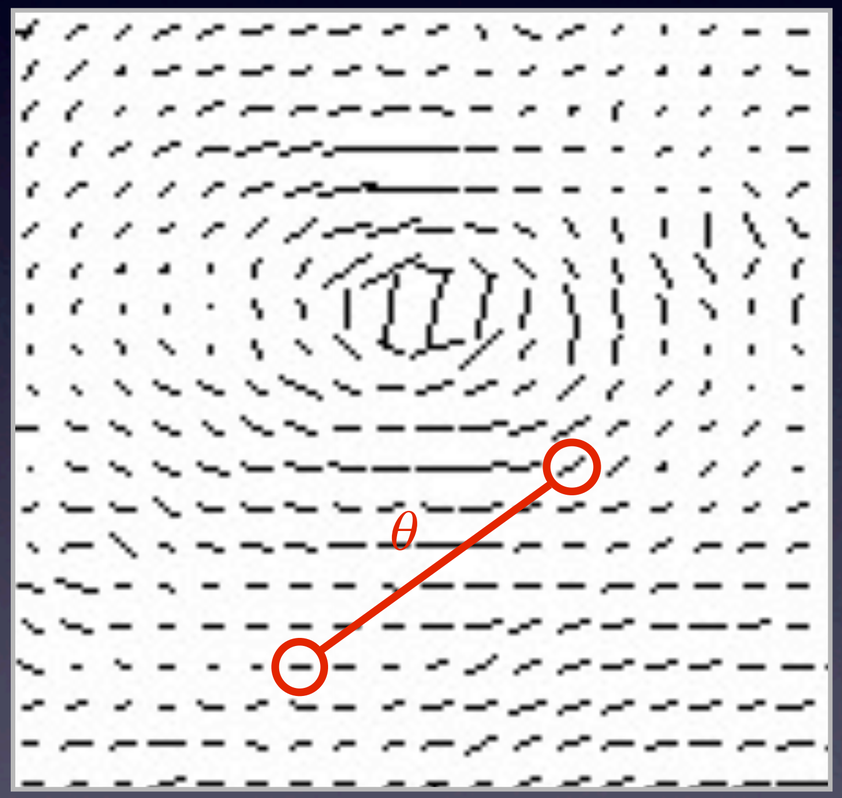


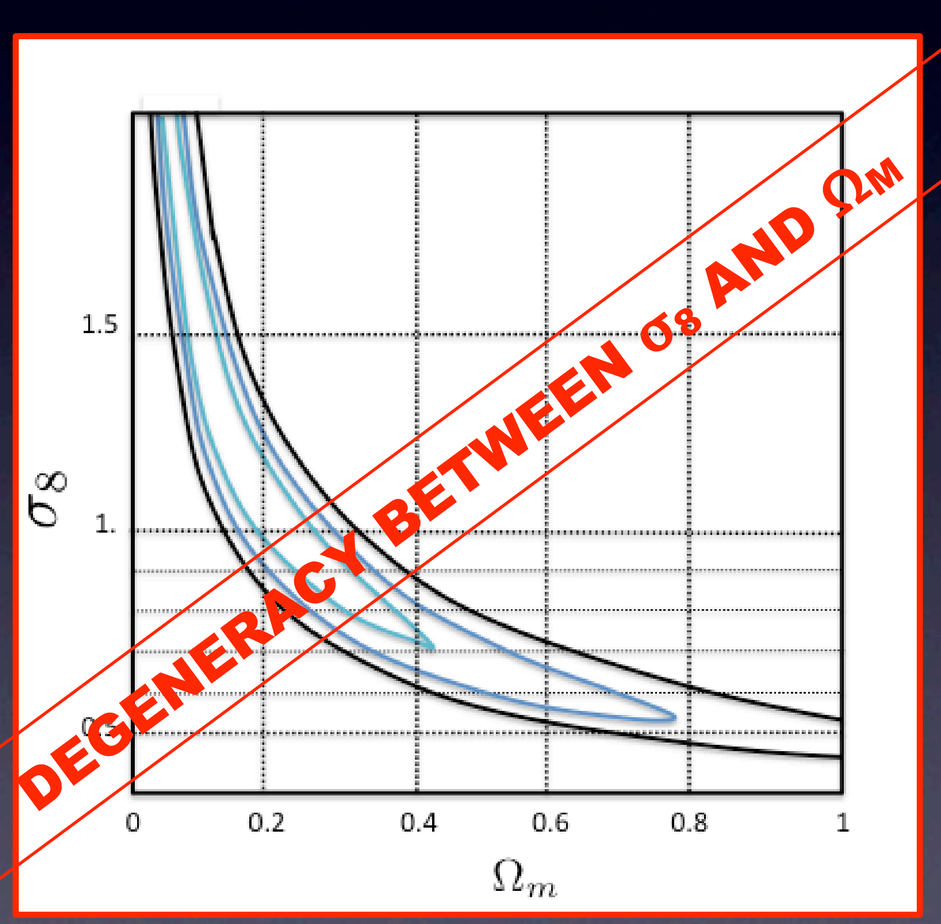
Weak Gravitational Lensing





Statistical estimation



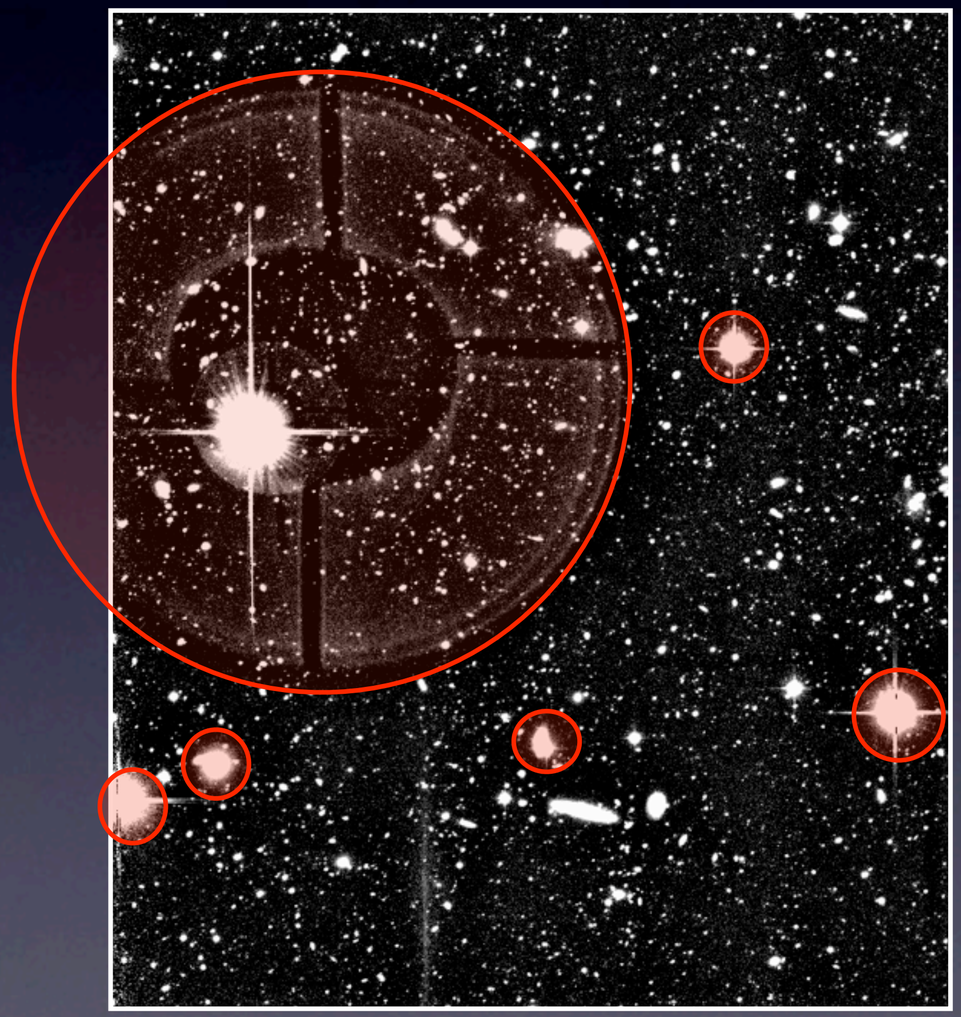


Statistical estimation

GAUSSIAN ESTIMATORS | NON-GAUSSIAN ESTIMATORS

TWO-POINT STATISTICS	THREE-POINT STATISTICS	FOUR-POINT STATISTICS
$\sigma^2 = \sum_1^N (\kappa_i - \bar{\kappa})^2$	$S = \frac{\sum_1^N (\kappa_i - \bar{\kappa})^3}{N\sigma^3}$	$K = \frac{\sum_1^N (\kappa_i - \bar{\kappa})^4}{N\sigma^4} - 3$
VARIANCE	SKEWNESS	KURTOSIS
$\xi_{i,j} =< \kappa(\theta_i)\kappa(\theta_j) >$	$\xi_{i,j,k} =< \kappa(\theta_i)\kappa(\theta_j)\kappa(\theta_k) >$	$\xi_{i,j,k,l} =< \kappa(\theta_i)\kappa(\theta_j)\kappa(\theta_k)\kappa(\theta_l) >$
TWO-POINT CORRELATION FUNCTION	THREE-POINT CORRELATION FUNCTION	FOUR-POINT CORRELATION FUNCTION
$P_\kappa =< \hat{\kappa}(\theta_i)\hat{\kappa}(\theta_j) >$	$B_\kappa =< \hat{\kappa}(\theta_i)\hat{\kappa}(\theta_j)\hat{\kappa}(\theta_k) >$	$T_\kappa =< \hat{\kappa}(\theta_i)\hat{\kappa}(\theta_j)\hat{\kappa}(\theta_k)\hat{\kappa}(\theta_l) >$
POWER SPECTRUM	BISPECTRUM	TRISPECTRUM

Weak Lensing missing data

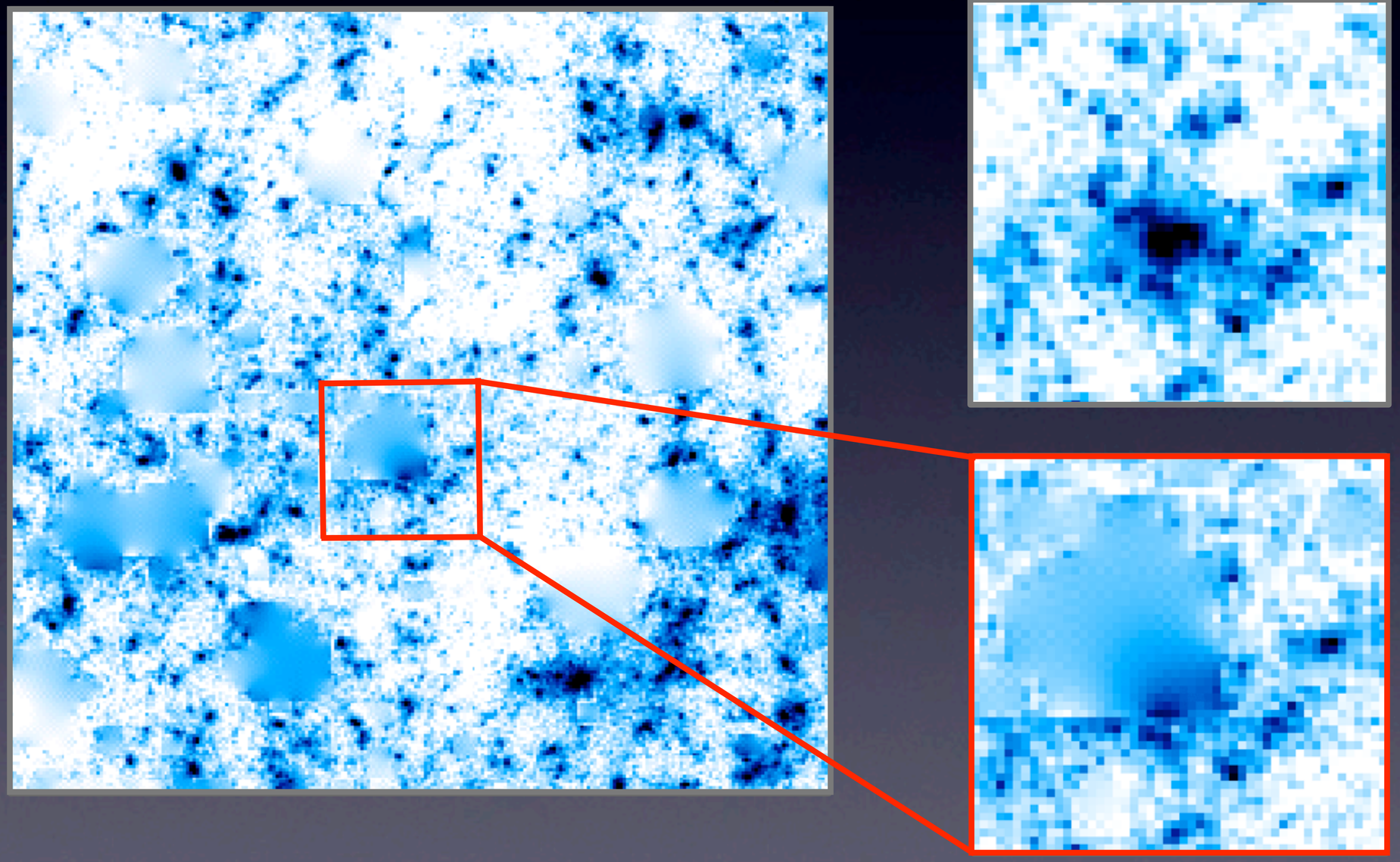


Statistical estimation with missing data

- ✓ Estimation of N-point correlation functions in direct space by avoiding the points falling into the gaps
  - ✓ pros: unbiased by missing data
  - ✓ cons: time comsuming
- ✓ Estimation of the power spectrum in Fourier space by applying a mask correction
  - ✓ pros: fast estimation with FFT
  - ✓ cons:
    - ✓ stability depending on the shape of the mask
    - ✓ estimation of the mask correction can be long

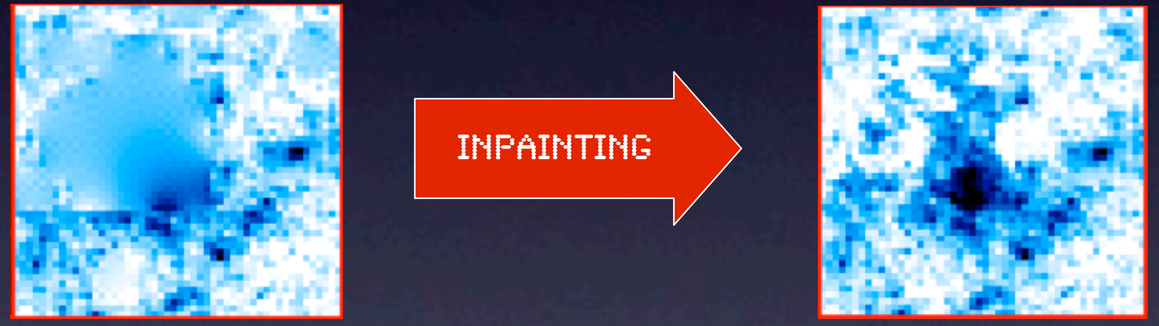
Inpainting on simulated weak lensing data

(S. Pires, 2009a)



FASTLens
(FAst STatistics for weak Lensing)
http://www-irfu.cea.fr/Ast/fastlens_software.php

✓ Estimation of a complete dark matter mass map from incomplete shear maps

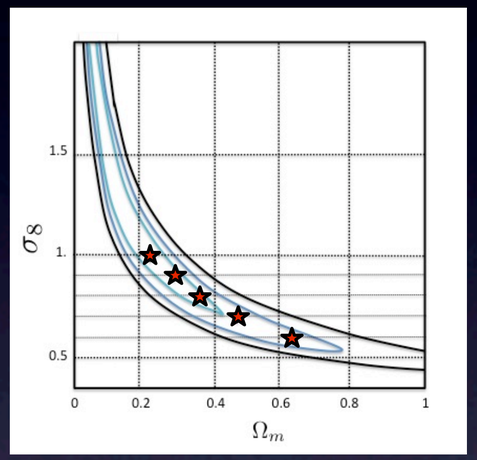


✓ Statistical estimation
- ✓ Variance, skewness, kurtosis...
- ✓ N-point correlation functions
- ✓ Power spectrum, bispectrum, trispectrum...

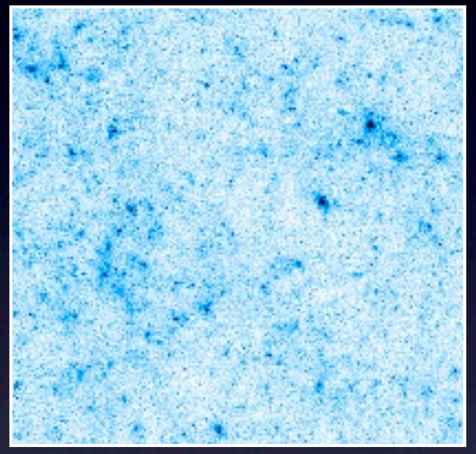
INPAINTING

✓Variance, skewness, kurtosis...
✓ N-point correlation functions
✓ Power spectrum, bispectrum, trispectrum...
✓ Cluster abundance, cluster correlations...

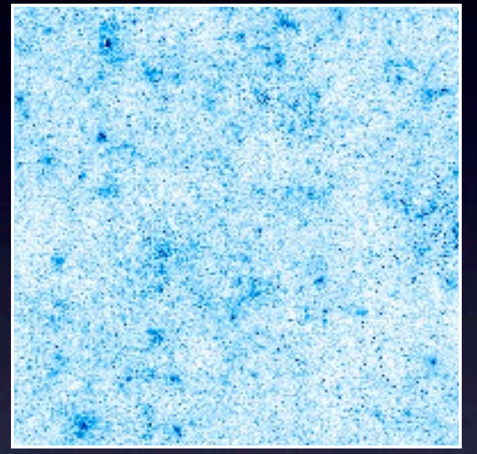
Cosmological model simulations



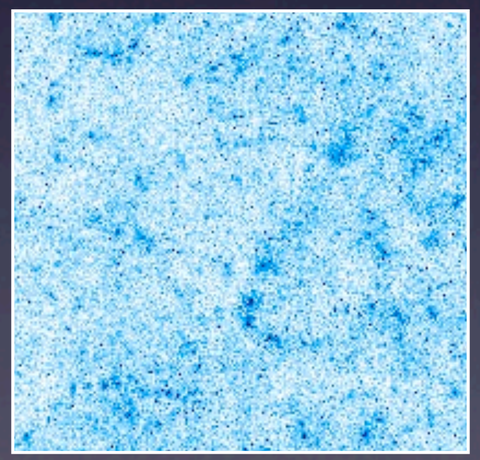
MODEL1 (σ_8=1, Ω_M=0.23)



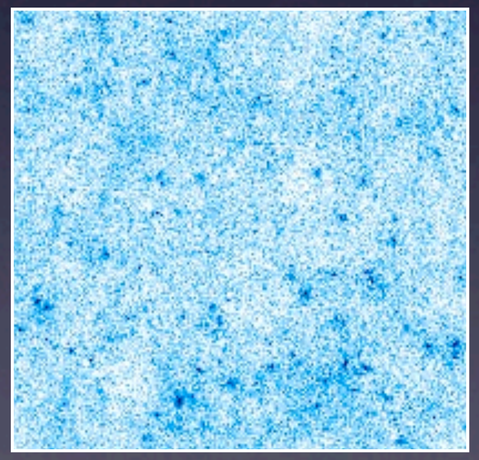
MODEL2 (σ_8=0.9, Ω_M=0.3)



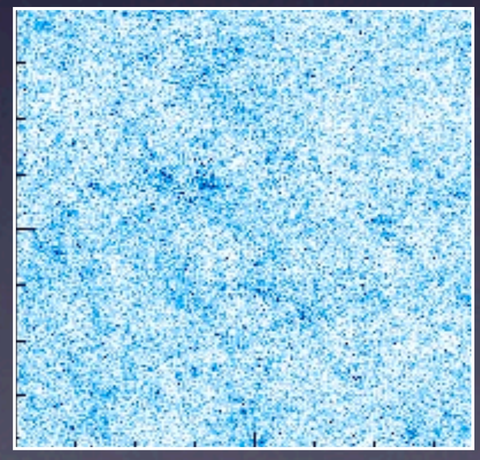
MODEL3 (σ_8=0.8, Ω_M=0.36)



MODEL4 (σ_8=0.7, Ω_M=0.47)



MODEL5 (σ_8=0.6, Ω_M=0.64)

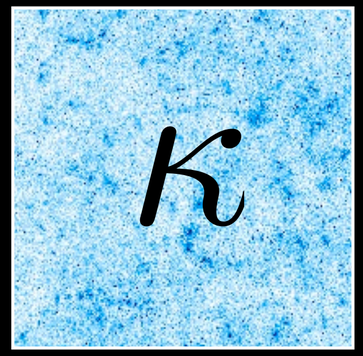


Inverse problem

$\{\Omega_m, \sigma_8 ...\}$

Direct problem

Hydrodynamic equations
with initial conditions



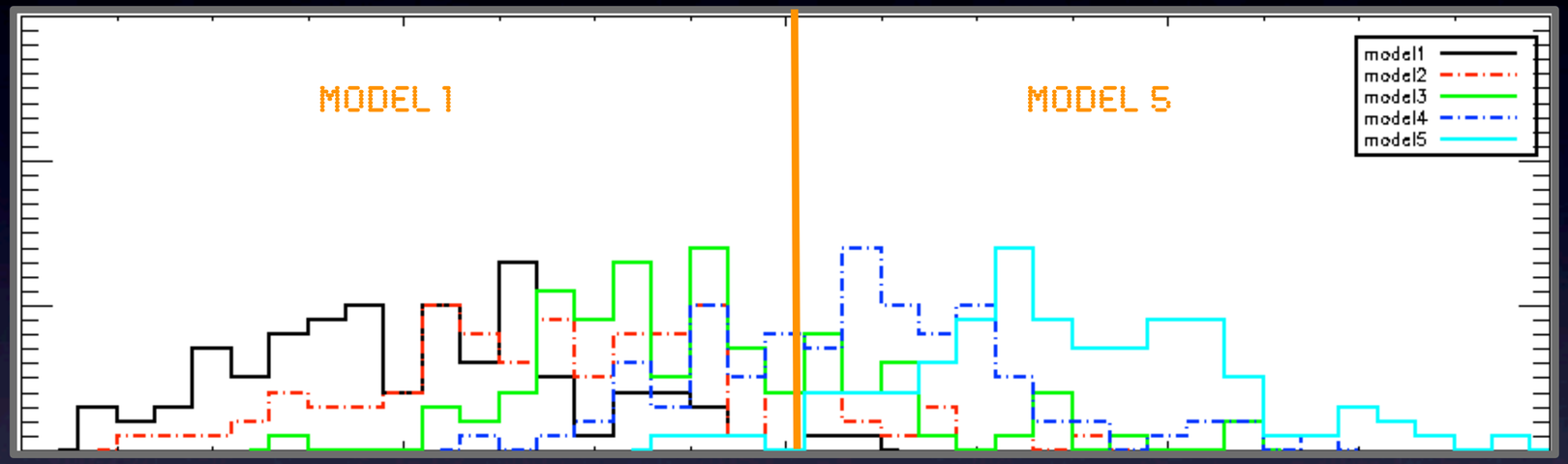
Inverse problem

- Inversion of the hydrodynamic equations
- Caracterisation of the morphology of non-Gaussian structures

Candidate statistics

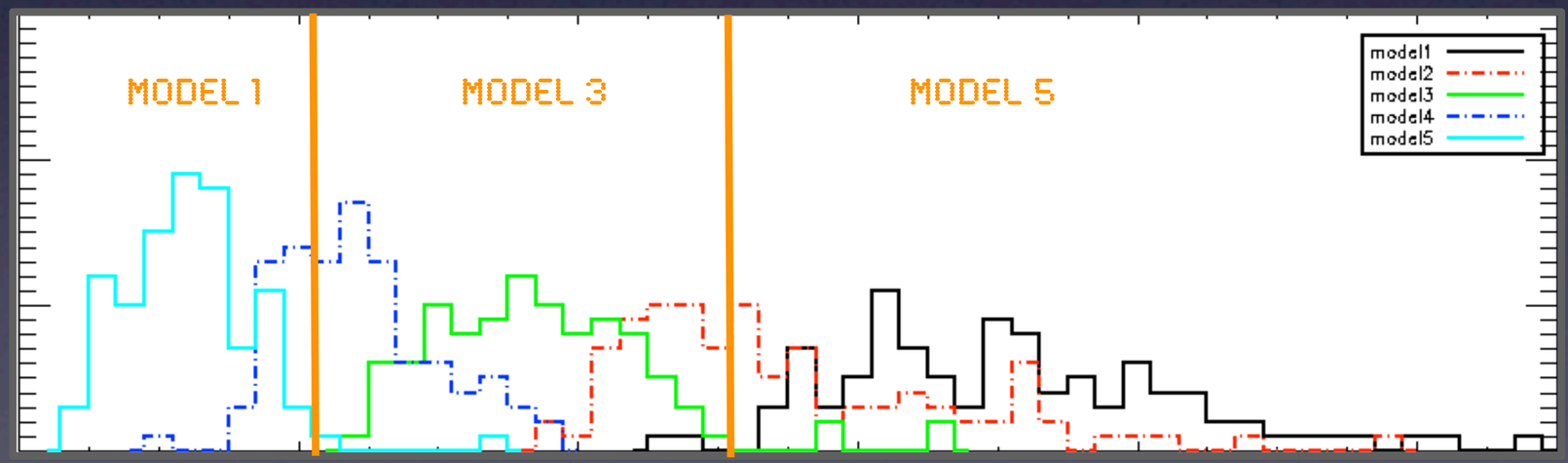
- ✓ Skewness (third-order moment) estimated on a Direct, Fourier, Wavelet, Ridgelet and Curvelet representation
- ✓ Kurtosis (fourth-order moment) estimated on a Direct, Fourier, Wavelet, Ridgelet and Curvelet representation
- ✓ Higher Criticism (Donoho & Jin, 2004) estimated on a Direct, Fourier, Wavelet, Ridgelet and Curvelet representation
- ✓ Bispectrum (Fourier space analog of the three-point correlation function)
- ✓ Peak counting (cluster abundance)
- ✓ WPC - Wavelet Peak Counting (Pires et al, 2008b)

Discrimination power



(kilbinger, 2005)

SKEWNESS ON NOISY MAPS (AT SCALE OF ABOUT 1 ARCMIN)

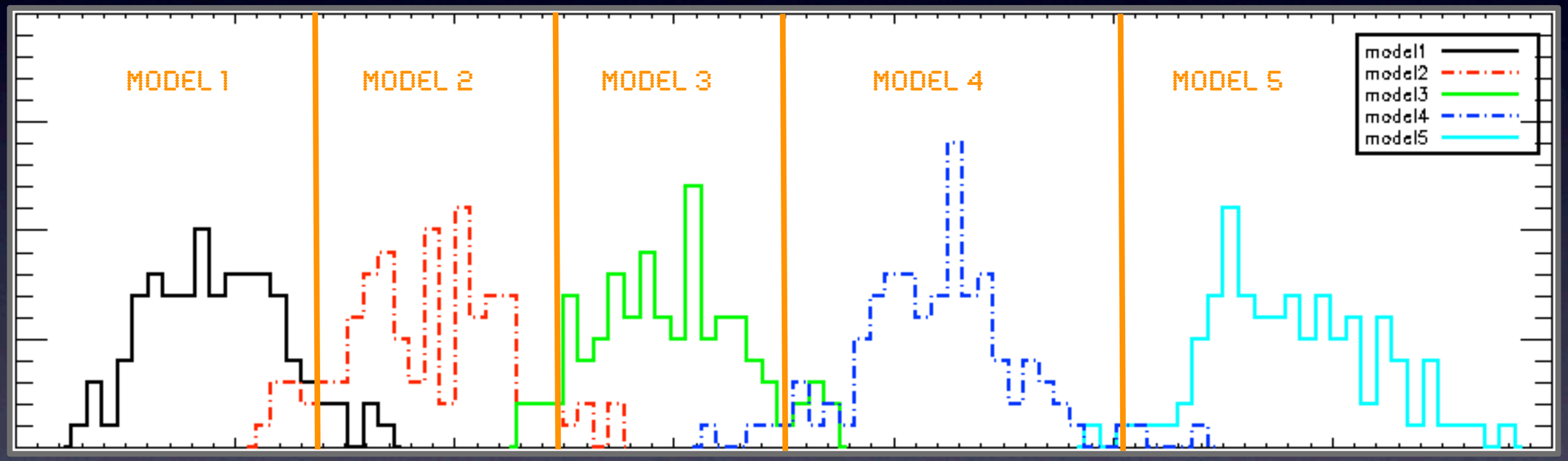


(S. Pires, 2009b)

SKEWNESS ON MRLENS (Starck, 2005) FILTRED MAPS (AT SCALE OF ABOUT 1 ARCMIN)

Best discrimination : WPC

(S. Pires, 2009b)



WAVELET PEAK COUNTING ON MRLENS FILTRED MAPS (AT SCALE OF ABOUT 1 ARCMIN)

Conclusions

- ✓ A method to reconstruct full Weak Lensing mass map from incomplete shear maps has been developed (FASTLens)
  - ✓ A solution to statistical estimation with missing data
- ✓ We have shown that a wavelet transform denoising method like MRLens filtering helps statistics to better characterize the non-Gaussianity
- ✓ We have introduced a new statistic called Wavelet Peak Counting (WPC)
- ✓ WPC has been found to be the best statistic compared to others that we have tested
  - ✓ Strong discrimination obtained between the 5 selected models