A03 Dark Energy talk III

Some Activities Related to Dark Energy and Cosmic Shear Likelihood

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Research topics from A03

Dark Energy & Modified Gravity

"Distinguishing quintessence models"

Y. Takeuchi, K.Ichiki, T. Takahashi, M. Yamaguchi, JCAP, '14

"PCA of modified gravities"

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Cosmic Shear analysis

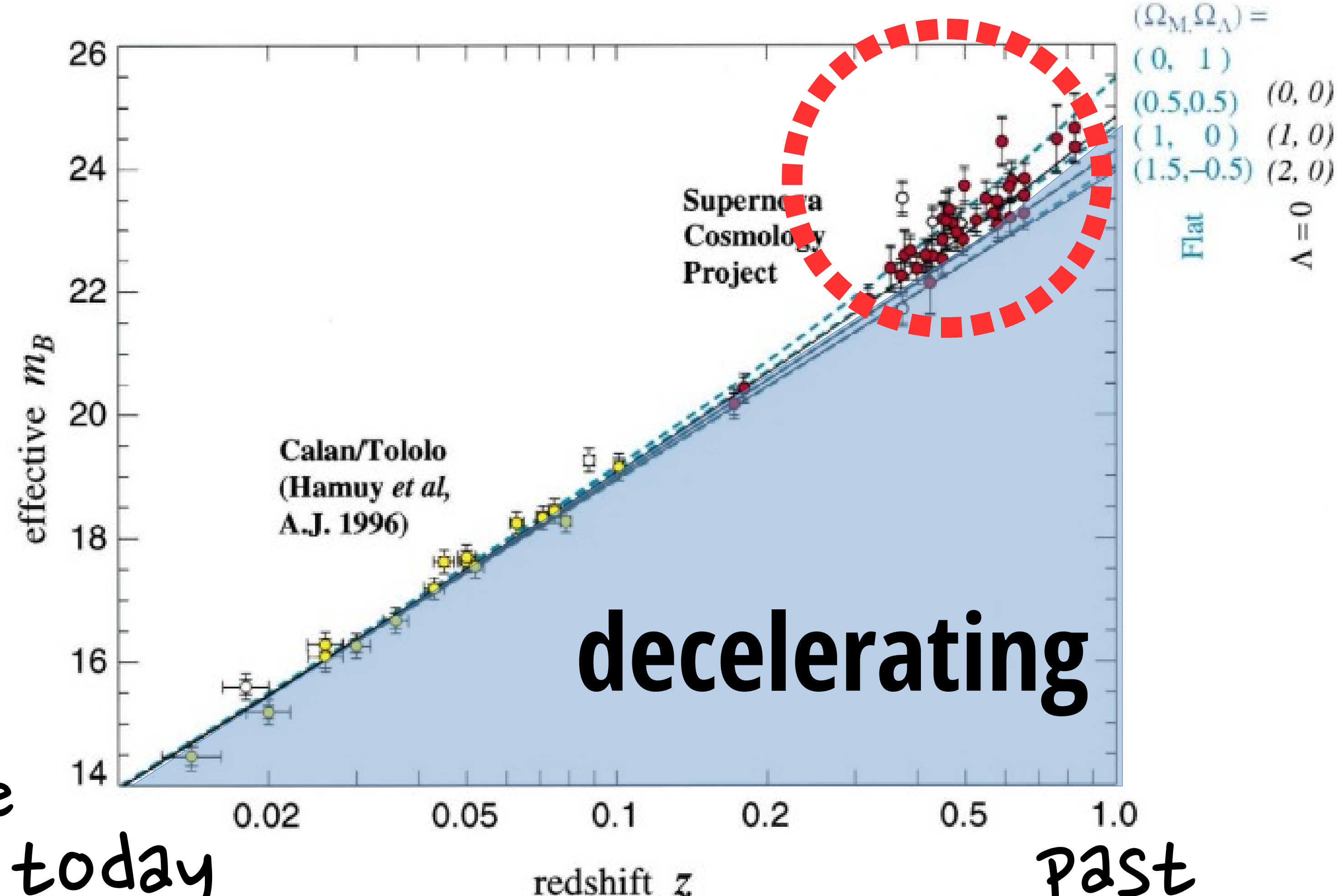
"Copula likelihood"

M Sato, K.Ichiki, T.T. Takeuchi, PRL, '10; PRD, '11

current cosmic expansion is accelerating

faint ↔ far

bright ↔ close



today

past

Perlmutter+, ApJ, '99

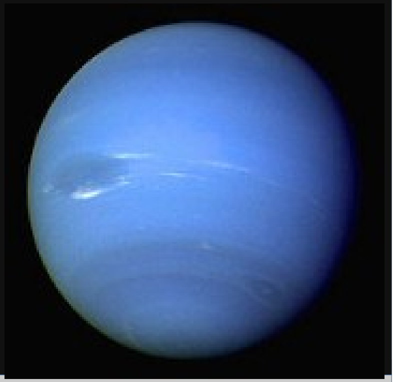
Dark Energy or Modified Gravity?

$$S = \int d^4x \sqrt{-g} \left[\frac{1}{2\kappa^2} R + \mathcal{L}_{\rm matter} \right]$$

idea 1 $\mathcal{L}_{\rm matter} \to \mathcal{L}_{\rm matter} + \mathcal{L}_{\rm dark\ energy}$

e.g., anomalous motion of uranus

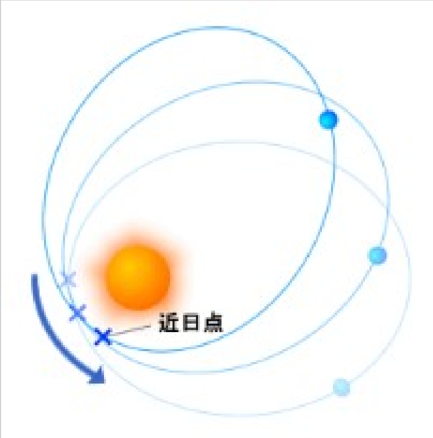
(the discovery of Neptune (dark planet))



idea 2 $R \to f(R)$

e.g., perihelion shift of Mercury

(modified gravity)

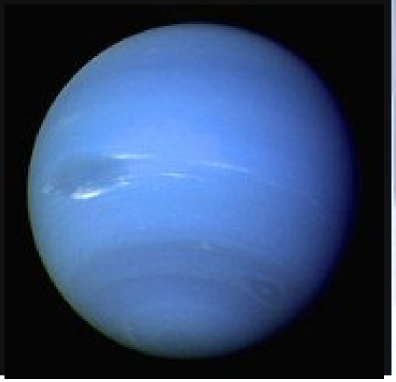


idea 1

$$\mathcal{L}_{\text{matter}} \to \mathcal{L}_{\text{matter}} + \mathcal{L}_{\text{dark energy}}$$

e.g., anomalous motion of uranus

(the discovery of Neptune (dark planet))



The Quintessential Universe (Zlatev, Wang, Steinhardt, PRL, '99)

$$\mathcal{L}_{\text{dark energy}} = -\frac{1}{2} g^{\mu\nu} \partial_\mu Q \partial_\nu Q - V(Q)$$

$$w_Q = \frac{p_Q}{\rho_Q} = \frac{\frac{1}{2}\dot{Q}^2 - V(Q)}{\frac{1}{2}\dot{Q}^2 + V(Q)}$$

Pressure can be negative if V(Q) dominates

→ accelerating expansion!

Types of Quintessence

for a review, Tsujikawa, '10

Freezing

the EoS w is decreasing in time

$$V(Q) = m^4 \left(\frac{Q}{M_{\rm pl}} \right)^{-\alpha}$$

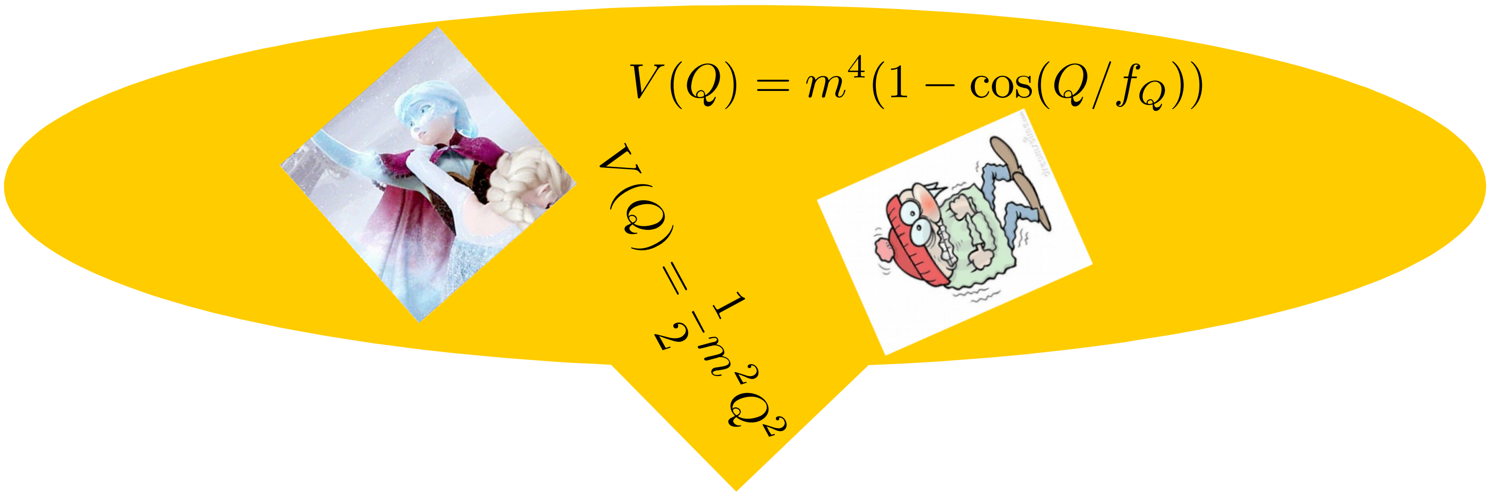
Thawing

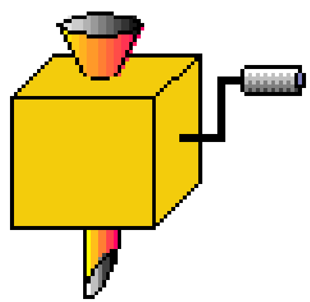
The EoS w is increasing in time

(Thawing I) $$V(Q) = \frac{1}{2} m^2 Q^2$$

(Thawing II) $$V(Q) = m^4 (1 - \cos(Q/f_Q))$$

Dark Energy parameters





Pick out the main part of DE essentially relevant to observations

w_0 & w_1

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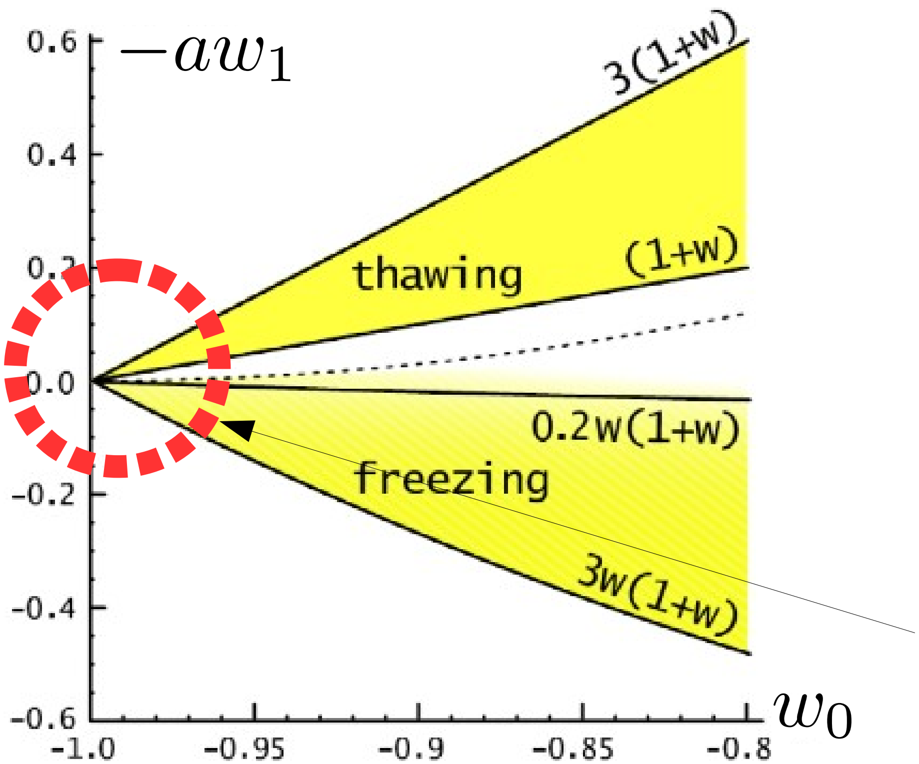
Λ corresponds to $w_0 = 1 \; w_1 = 0$

$$w_Q(a) = w_0 + (1-a)w_1$$

(Chevallier&Polarski, '01; Linder, '02)



Caldwell & Linder, PRL, '05

Different Quintessence models are in different positions

The lower bound on w:

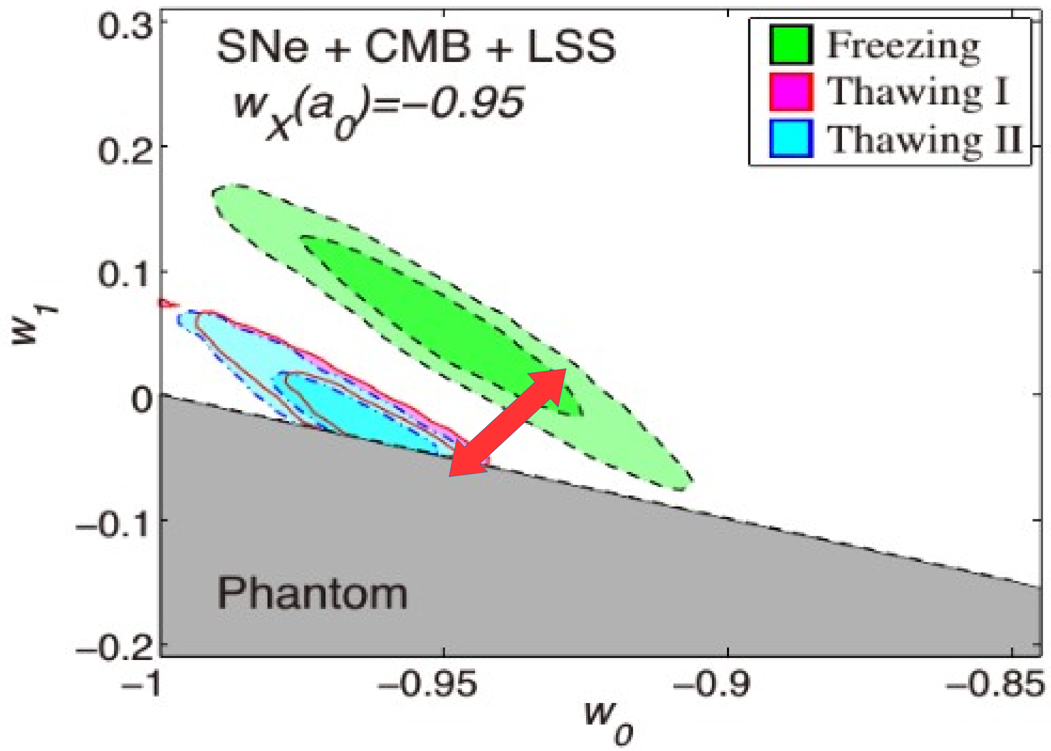
$w \gtrsim -0.996$ (Thawing)

$w \gtrsim -0.990$ (freezing)

Message to go

Takeuchi, Ichiki, Takahashi, Yamaguchi, JCAP, '14

1. CMB+3D information will enable us to distinguish between freezing & thawing models even if w is close to -1.



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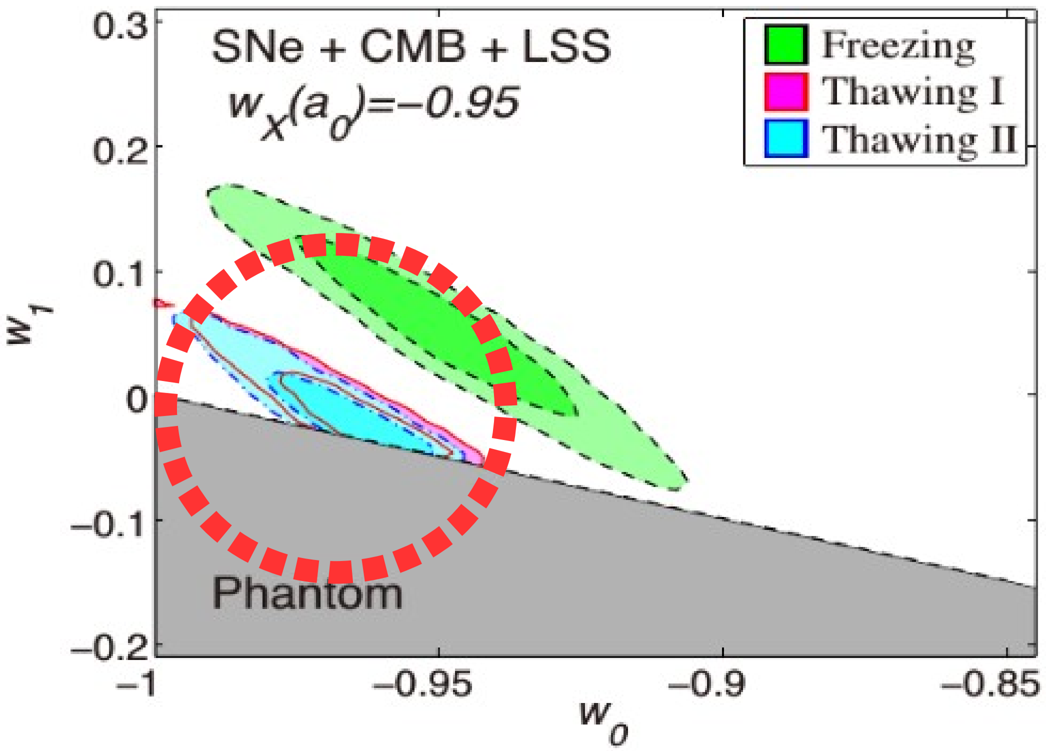
2. simple (w0,w1) parameter can Not distinguish between different thawing models.



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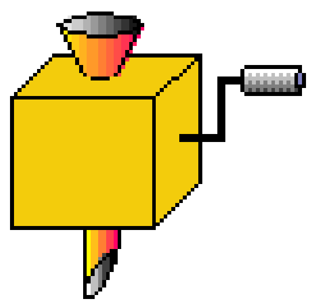
Where is the difference between GR and MG?

DGP braneworld

$$-\lambda R_c\left[1-\left(1+R^2/R_c^2\right)^{-n}\right]$$

$$\lambda R_c \tanh(R/R_c)$$

$$-\lambda R_c \frac{(R/R_c)^{2n}}{(R/R_c)^{2n}+1}$$



Pick out the main part of MG essentially relevant to observations

μ & Σ

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GR corresponds to $\mu = \Sigma = 0$

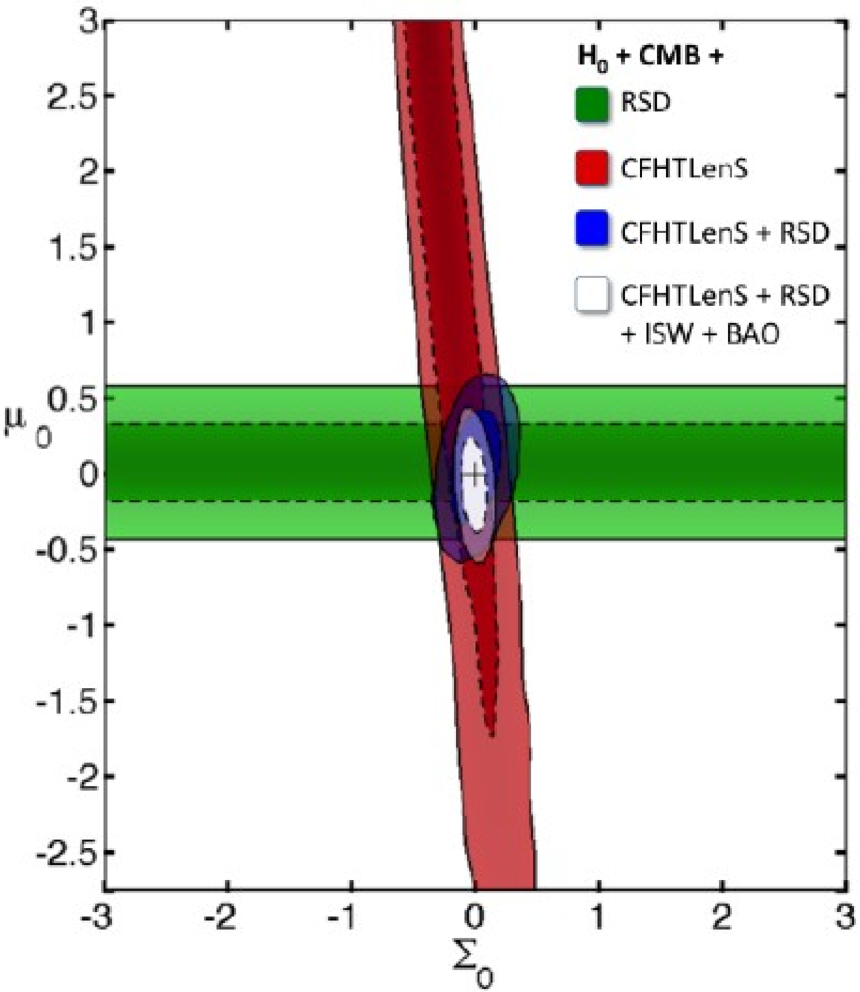
$$\Psi(k,a) = (1+\mu)\Psi_{\rm GR}(k,a)$$

$$\ddot{\delta} + 2H\dot{\delta} = \underline{4\pi G\rho\delta(1+\mu)}$$

gravitational acceleration

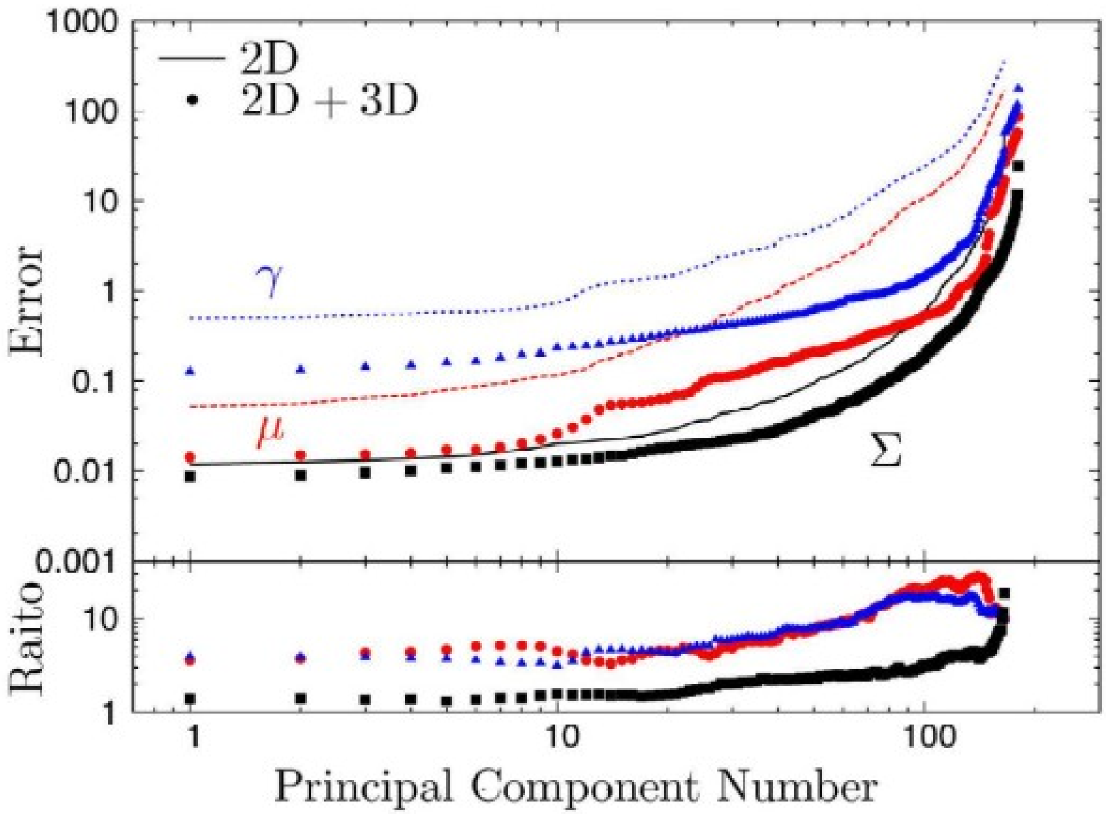
$$\Psi + \Phi = \underline{(1+\Sigma)\left(\Psi_{\rm GR} + \Phi_{\rm GR}\right)}$$

Lensing potential



Simpson et al., MNRAS, '13

Using PCA, investigate how future observations constrain μ and Σ



3D info. from surveys such as SuMIRe can significantly improve the constraints

$$\delta\mu \sim 0.01$$

$$\delta\Sigma \sim 0.01$$

because redshift space distortion can break degeneracy between the parameters

S. Asaba et al., JCAP, '13

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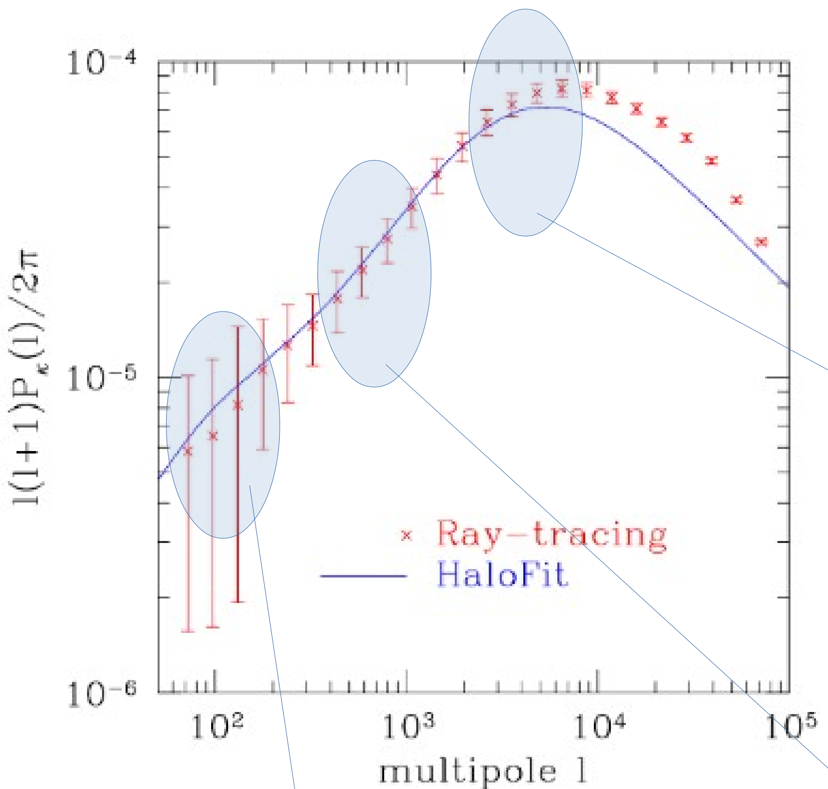
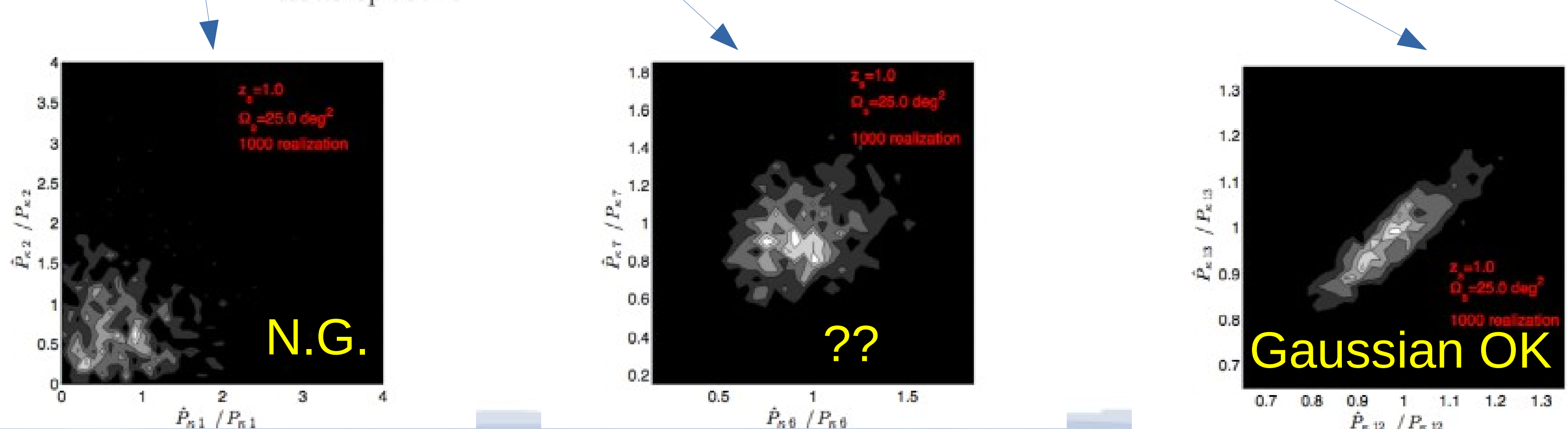
Motivations to use Copula are:

- to constrain cosmological parameters, **an accurate likelihood model** is essential
- weak lensing power spectrum **does not obey Gaussian distributions** (Sato et al., '09; Hartlap et al., '09).
- include non-Gaussianity accurately in the likelihood function
  - **Copula** will help us do this!
- in previous works, almost all authors assumed the Gaussian likelihood (see however, Fu et al.,'15).

Sato+(09)



On large scales, PDF deviates from Gaussian due to less independent modes available



what's copula?

- Copula (接合分布関数) links 1point PDFs to the n-point (full) distribution (Sklar, 1959)

Full likelihood — 1point marginal likelihoods

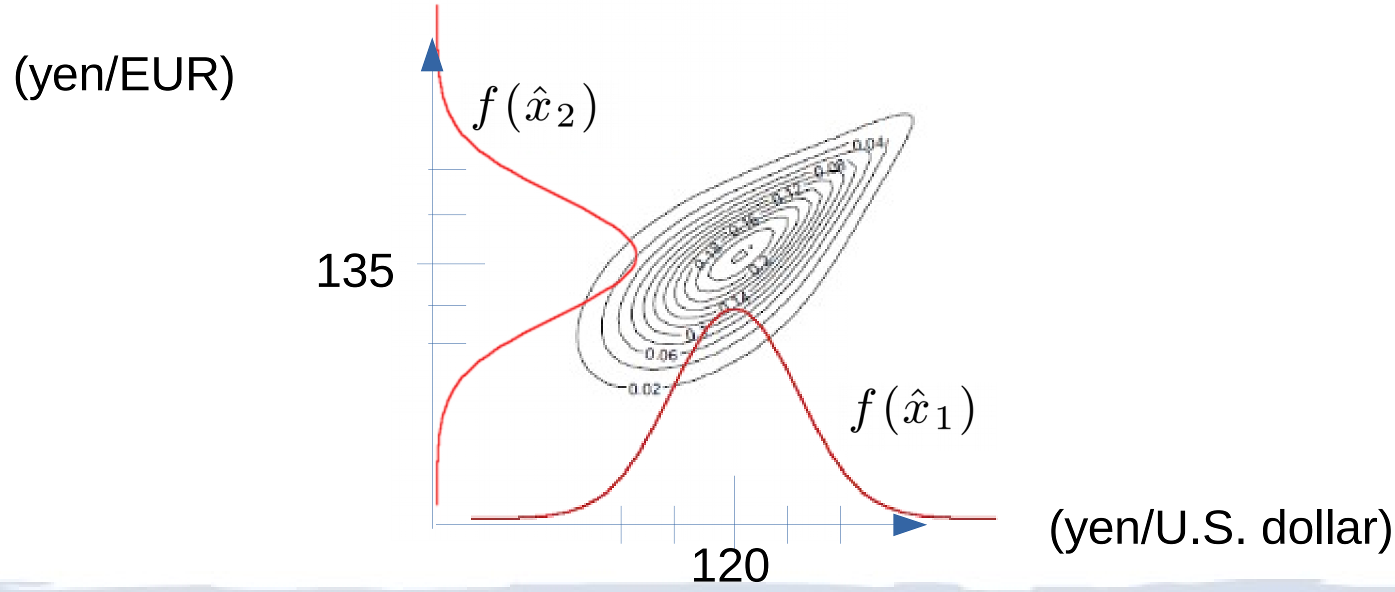
$$f(\hat{x}_1, \hat{x}_2) = c(u_1, u_2) f_1(\hat{x}_1) f_2(\hat{x}_2)$$

Copula density

$$u_i \equiv \int_{-\infty}^{\hat{x}_i} f_i(x)dx$$

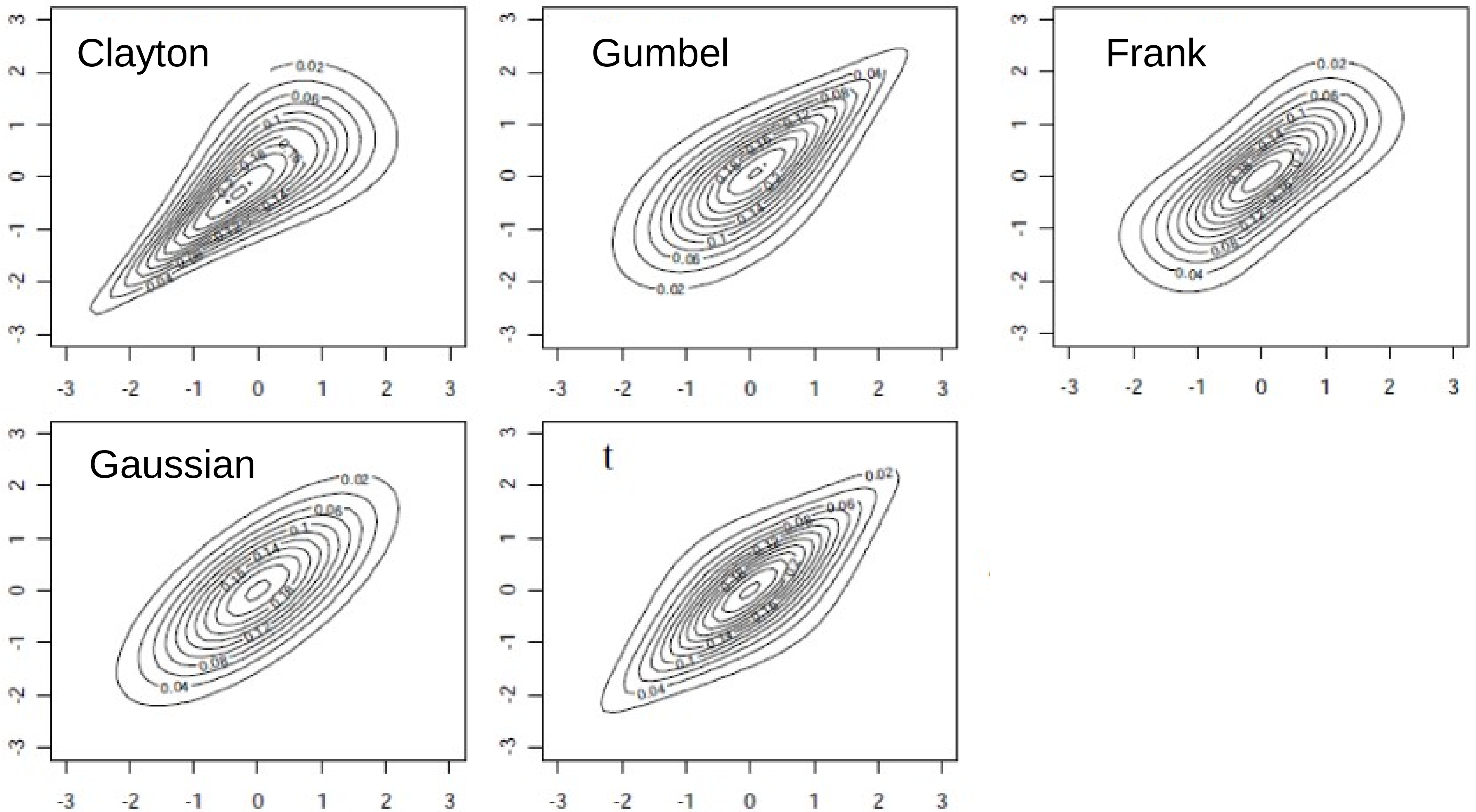
1point cumulative dist.

- Copula can express arbitrary non-gaussian structure



examples of copula

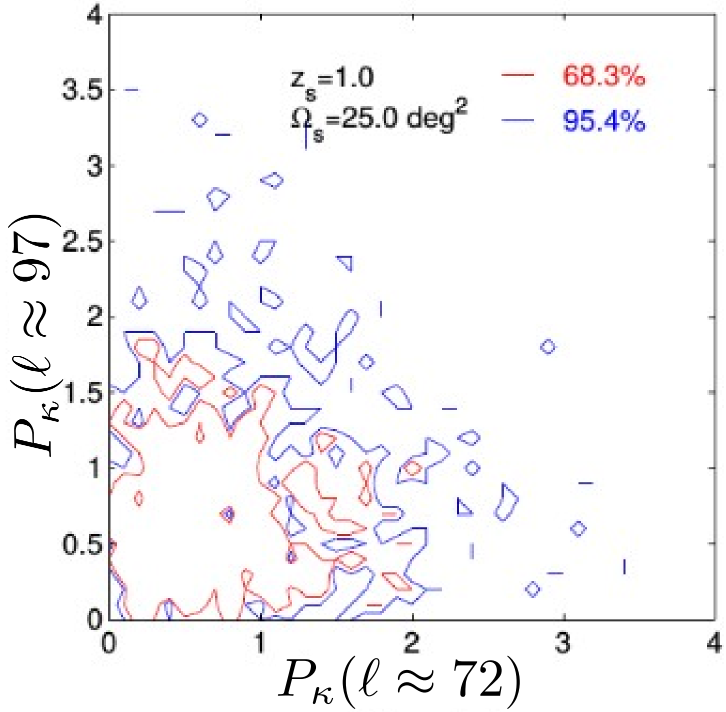
Note that all marginal distributions are Gaussian !



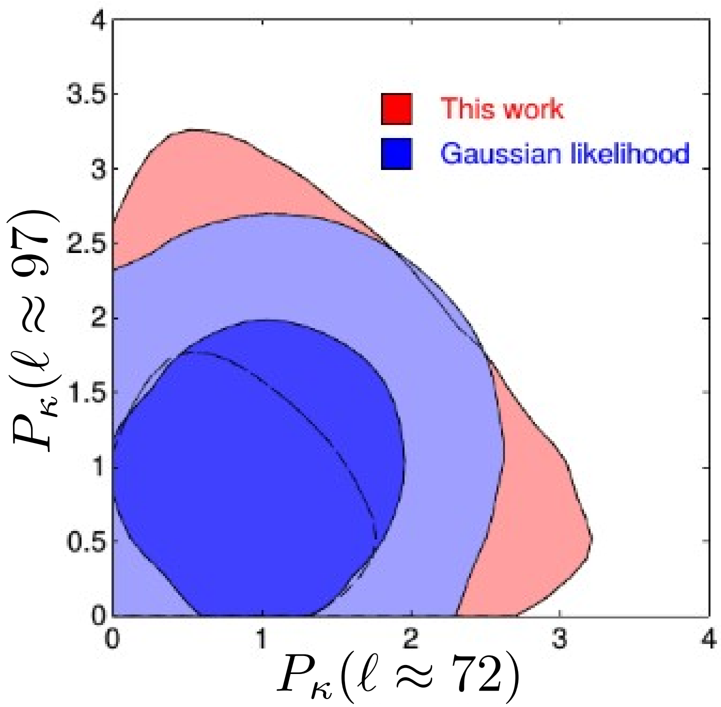
Taken from “Financial risks and Copula”, yoshiba, 2009

Seeing is Believing

Simulations



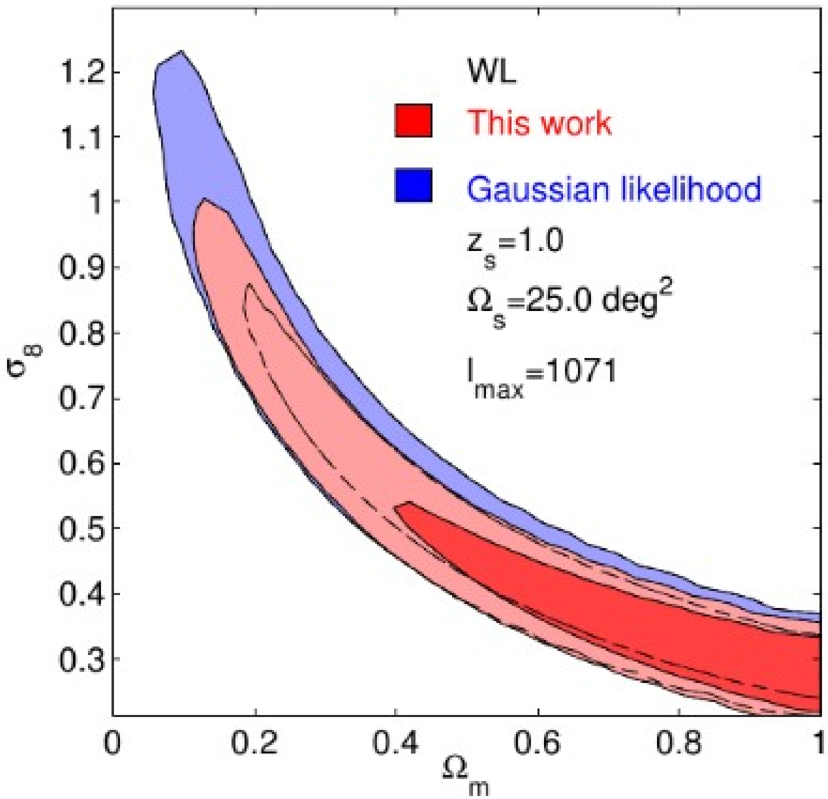
Likelihood models

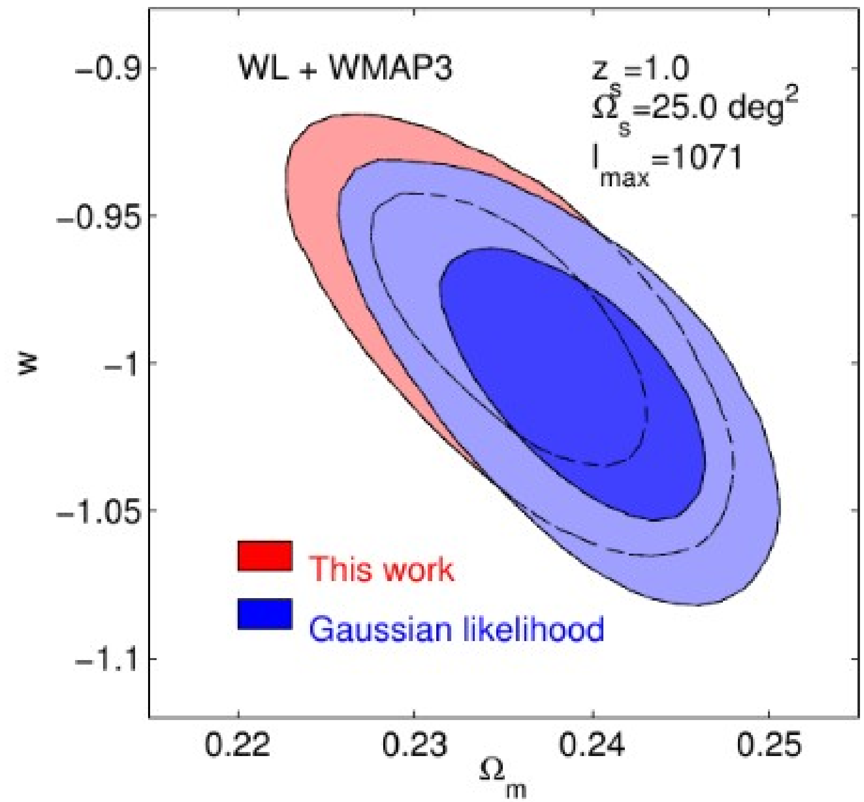


- Gaussian likelihood has two parameters: mean and covariance
- Copula is constructed using the same covariance and means

Two Models contain the same number of parameters !

Impact on parameters





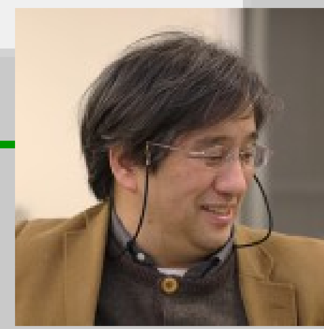
σ_8 ↘ Ω_m ↘ → w ↗

summary

Accuracy improvement

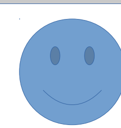
Non-linearity of gravitational clustering

Non-Gaussian likelihood
(N-body simulations)



Model building

Modified gravity
Quintessence
k-essence



and
You!

Fitting to data

Cosmic Shear
RSD
CMB