Analysing the full shape of the PDF of cosmic density fluctuations

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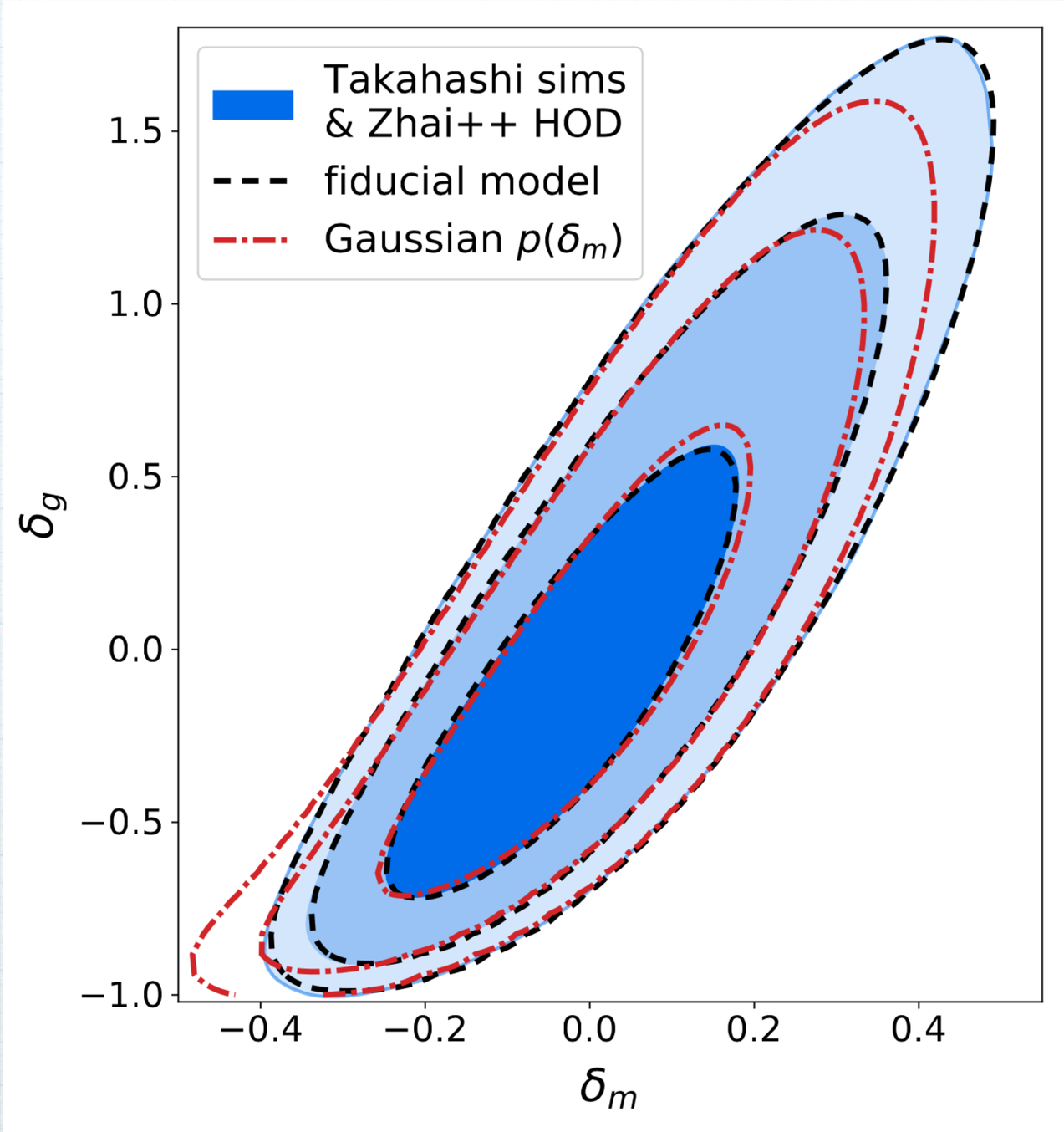
work with Cora Uhlemann, Anik Halder, Aoife Boyle, Dylan Britt, Sandrine Codis, Daniel Gruen, ChangHoon Hahn, Tobias Baldauf, Francisco Villaescusa-Navarro, Marc Manera, Takahiro Nishimichi and more!



But first…
You may know me from my covariance work.

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→ I’m retiring from this subject

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→ I'm retiring from this subject
→ Last shout-out to my work on that:

- **Friedrich** et al. (2016)
  Internal covariance estimation

- **Friedrich** & Eifler (2018)
  Have a bit of analytic knowledge of your covariance?
  → Strongly boost accuracy of covariance estimate from simulations!

- **Friedrich** et al. (2021a)
  "Instruction manual" on covariance modelling, estimation and validation for multi-probe 2-point functions

- Percival, **Friedrich**, Selentin, Heavens (2021)
  Taking into account covariance uncertainties in parameter constraints

- 2-point statistics:
  Variance as a function of scale

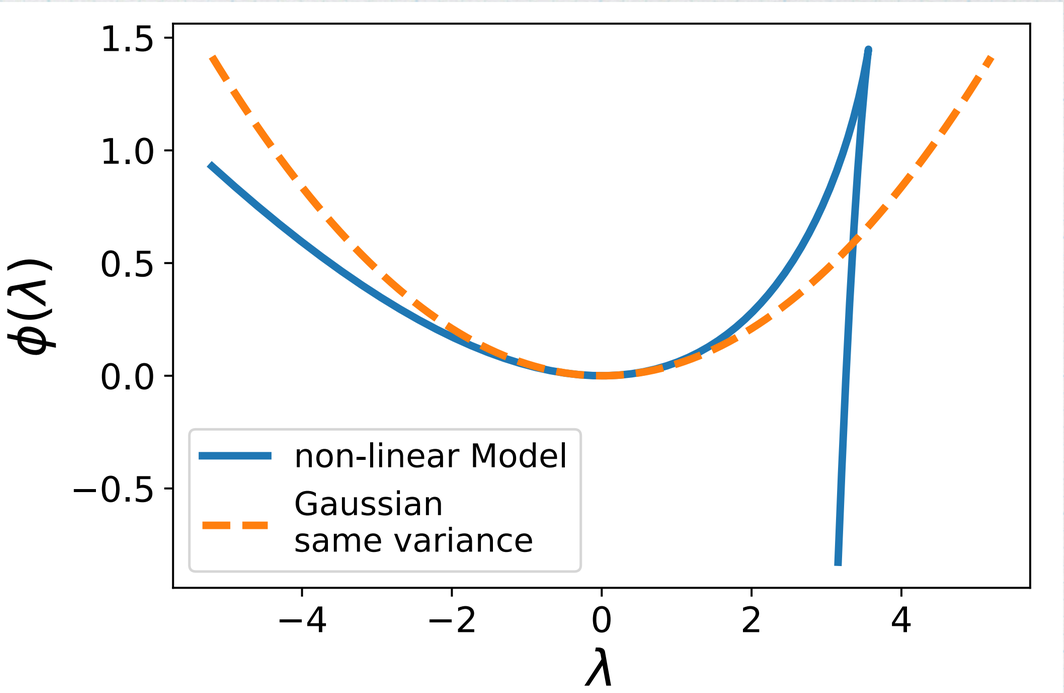
$$\langle \delta_{\mathbf{k}} \delta_{\mathbf{q}} \rangle \sim P(k)\ \delta_D(\mathbf{k}+\mathbf{q})$$

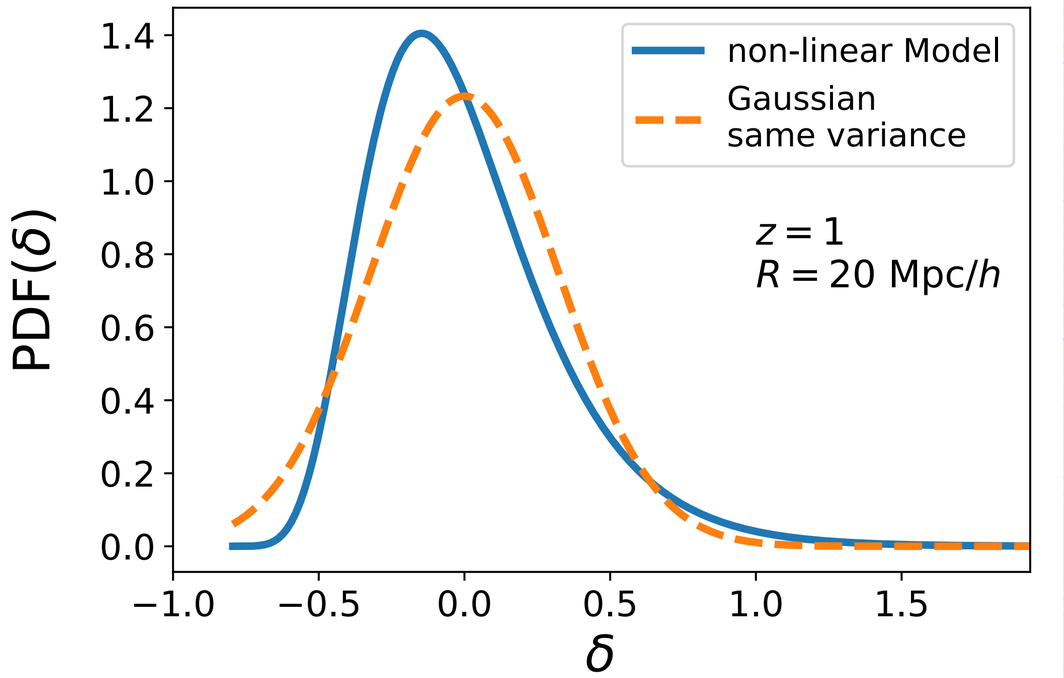
- Cumulant generating function (CGF):
  All moments at one scale

$$\varphi_R(\lambda) = \langle e^{\lambda \delta_R} \rangle \equiv \sum_n \langle \delta_R^n \rangle_c \frac{\lambda^n}{n!}$$

- PDF and CGF related by Laplace transform

$$e^{\varphi_R(\lambda)} = \int \mathrm{d}\delta_R\ p(\delta_R)\ e^{\lambda \delta_R}$$





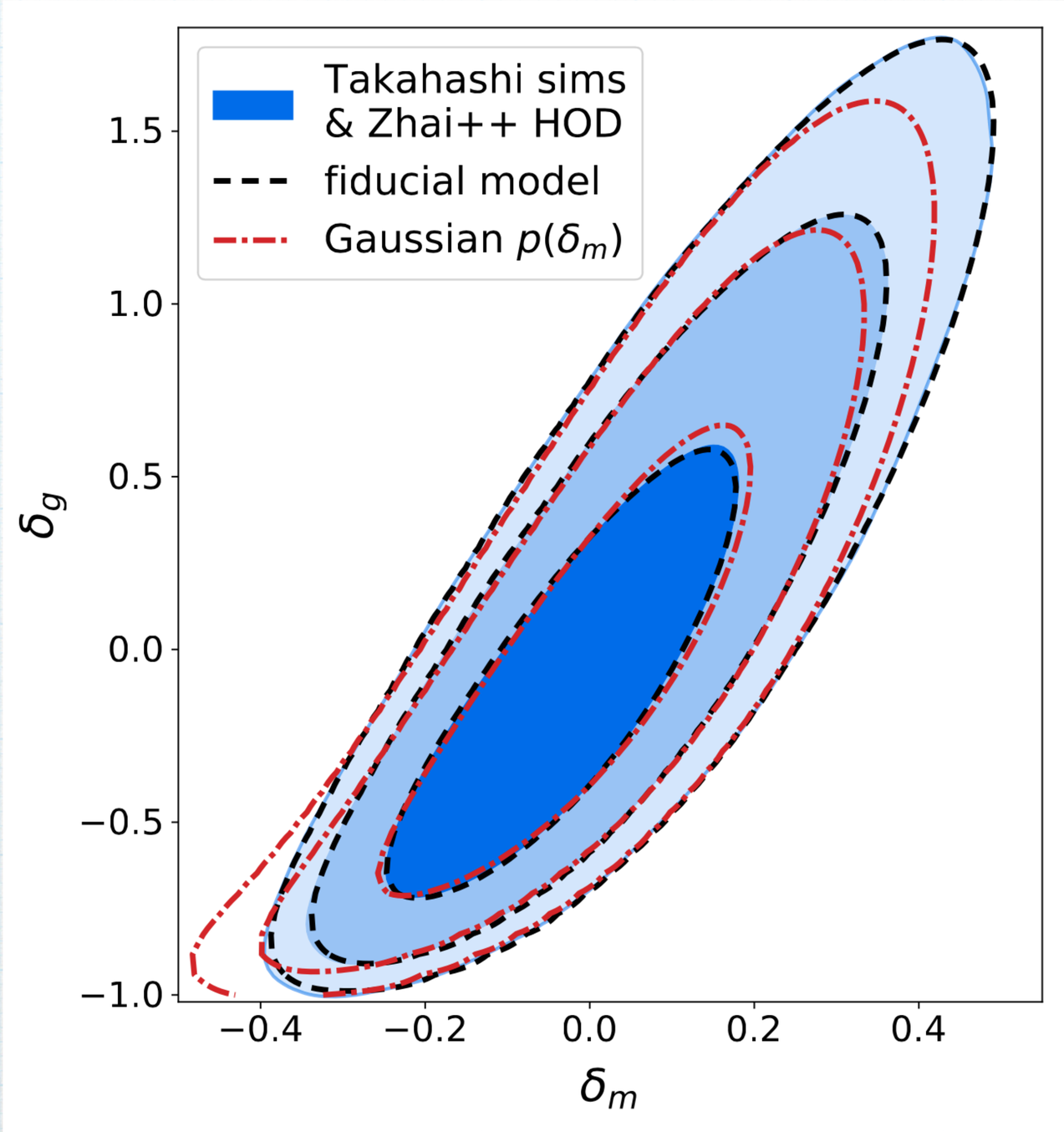
…. now including galaxies.

“3 x 2-point analyses”:
compressing joint PDF of galaxy and matter density to 3 numbers!

cosmic shear ~ variance of matter density
gal. clustering ~ variance of galaxy density
gal.-gal. lensing ~ covariance of the two

→ Can we do better?

→ Is it worth it to do better?

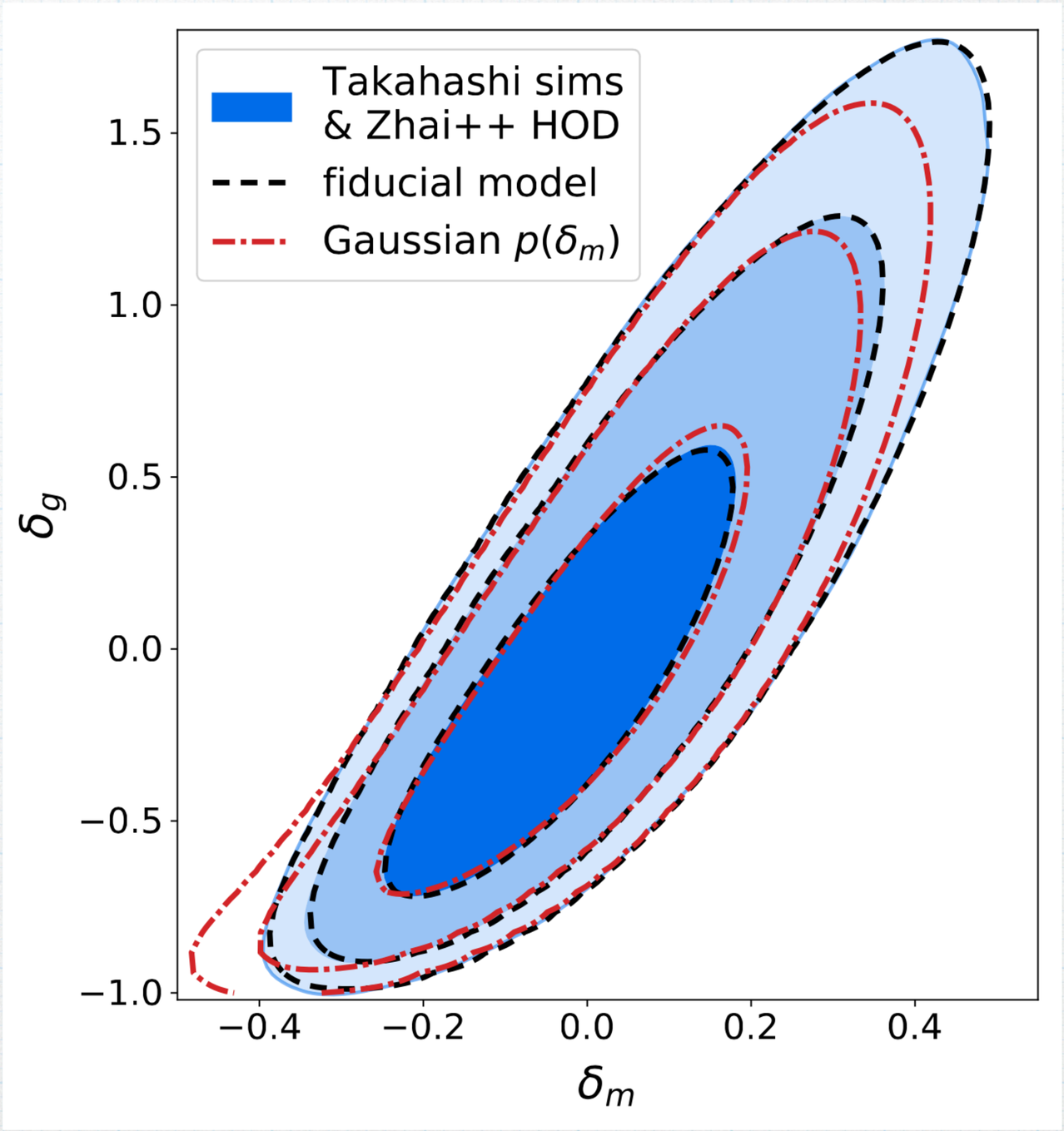


Recent work:

- **Friedrich** et al. (2020)
  → **Accurate modelling of PDF for general primordial non-Gaussianity**
  → **Can measure fNL even when marginalising over power spectrum uncertainty**

- Uhlemann, **Friedrich** et al. (2020) ,
  Boyle, Uhlemann, **Friedrich** et al. (2021)
  → **matter density PDF and lensing convergence PDF complement 2-point function**
  → **Strongly improved constraints on neutrino mass and DE equation of state**

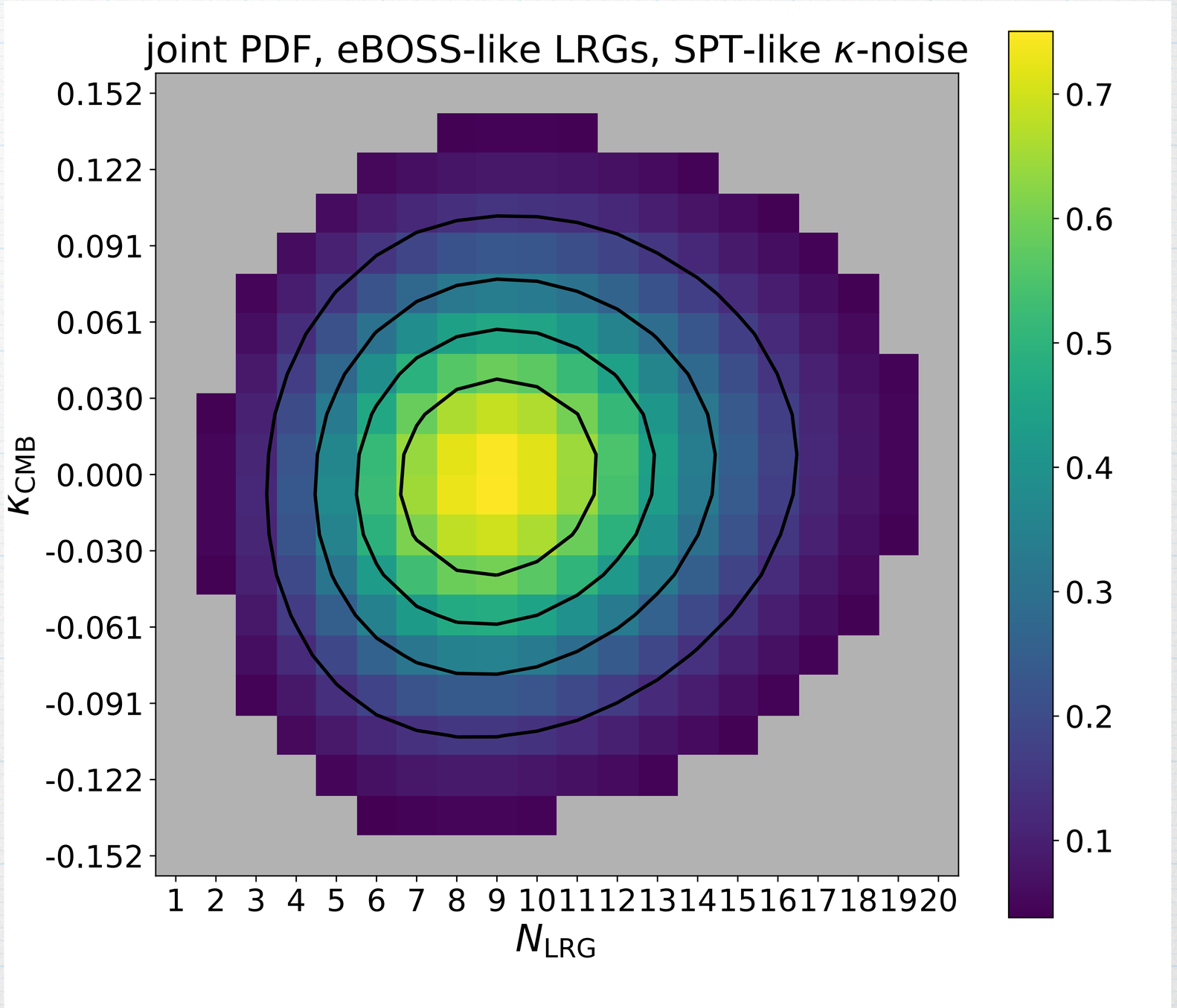
- **Friedrich** et al. (2021b)
  → **Developing Lagrangian bias expansion for PDFs**
  → **Accurate modelling of joint PDF(matter, galaxies), including non-Poisson shot-noise**
  → **2D language appropriate for photometric data**


Takahashi sims
& Zhai++ HOD
fiducial model
Gaussian $p(\delta_m)$
1.5
1.0
0.5
0.0
−0.5
−1.0
δ_g
−0.4
−0.2
0.0
0.2
0.4
δ_m

Moving to real data:
Friedrich ++ in prep.

- in the following assume:
  → LRGs within 0.6 < z < 0.9
  → CMB lensing with SPT-like noise
  → 20 arcmin smoothing scale
  → 5000 square degrees on the sky

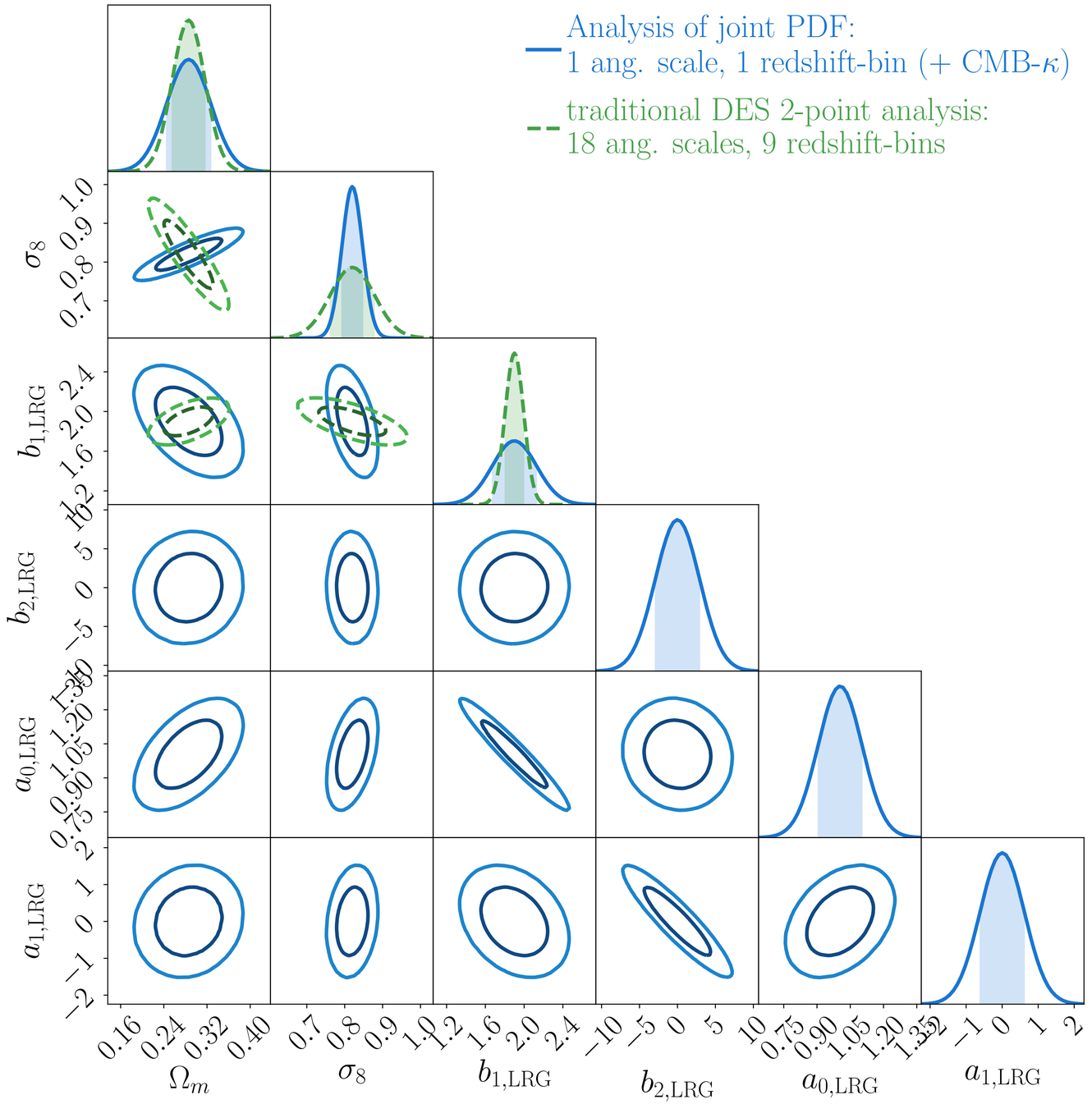
- Data vector:
  → pixelizing PDF, 20x20
  → use pixels that include 95% of probability



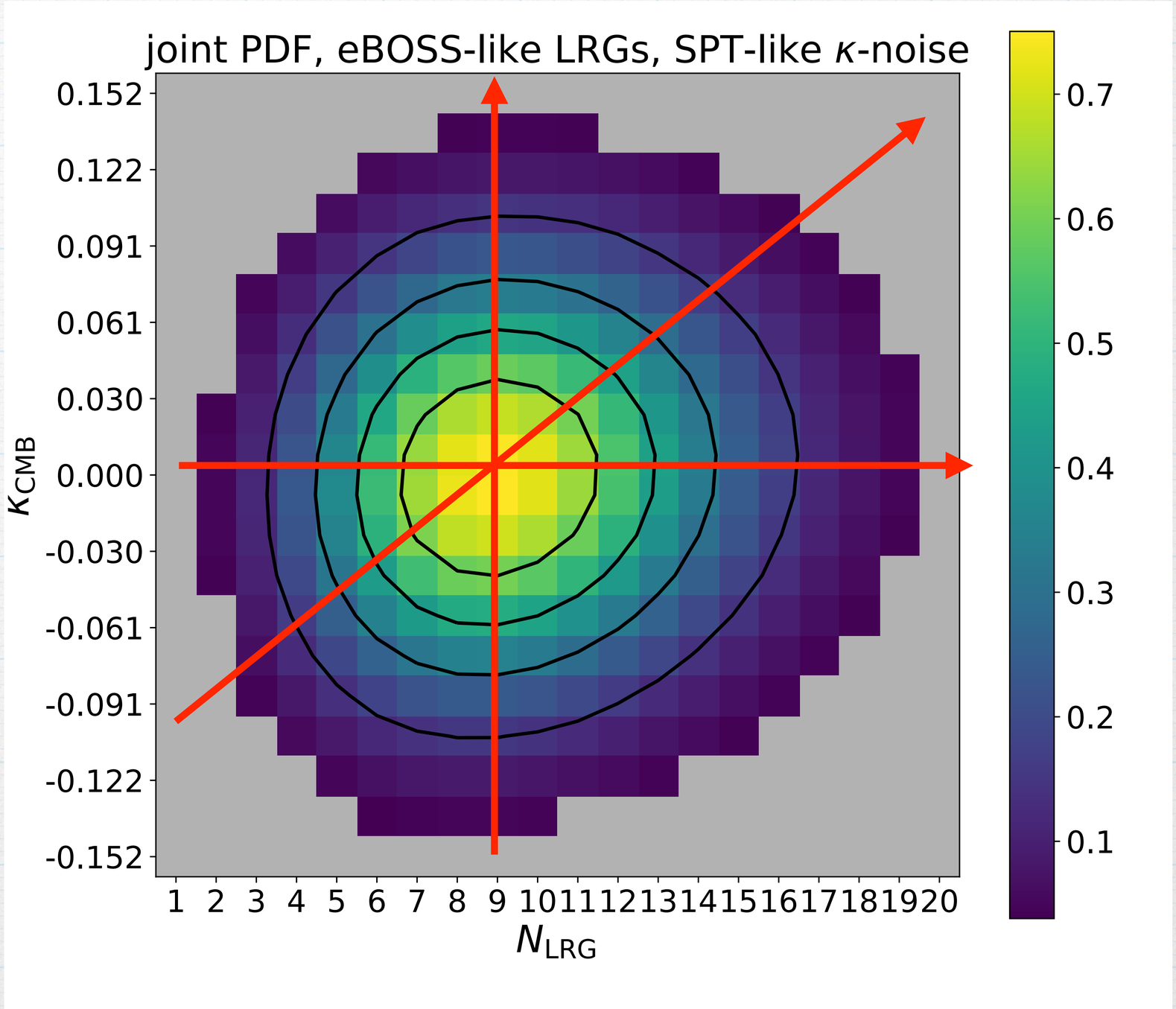
PDF can measure

- Omega_m
- sigma_8
- linear & quadratic bias
- two parameters of shot-noise

using only one angular scale &
1 redshift bin!

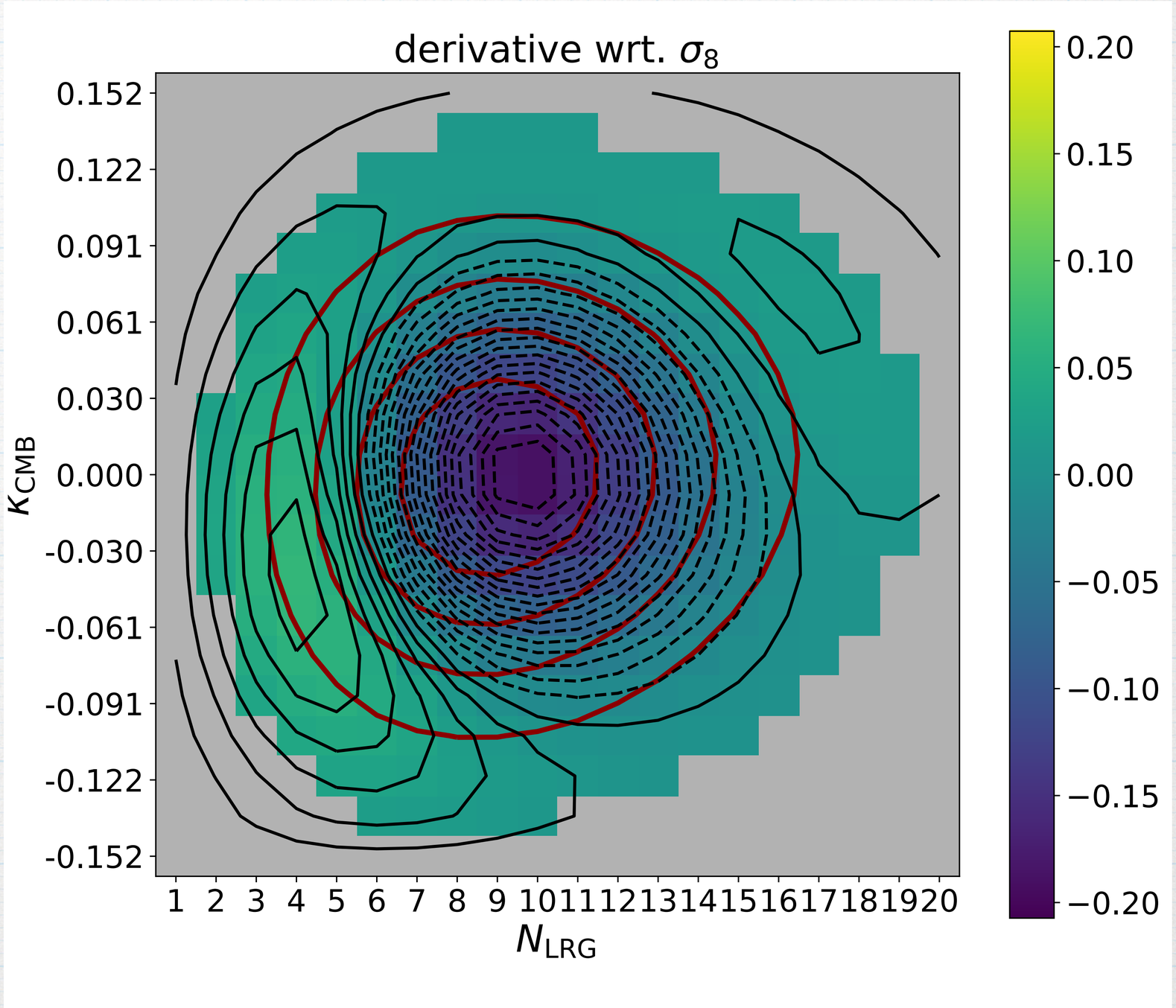


recall: **2point statistics only extract three numbers** from PDF!



Red contours:
PDF

Black contours and colormap:
derivative of PDF wrt. different parameters



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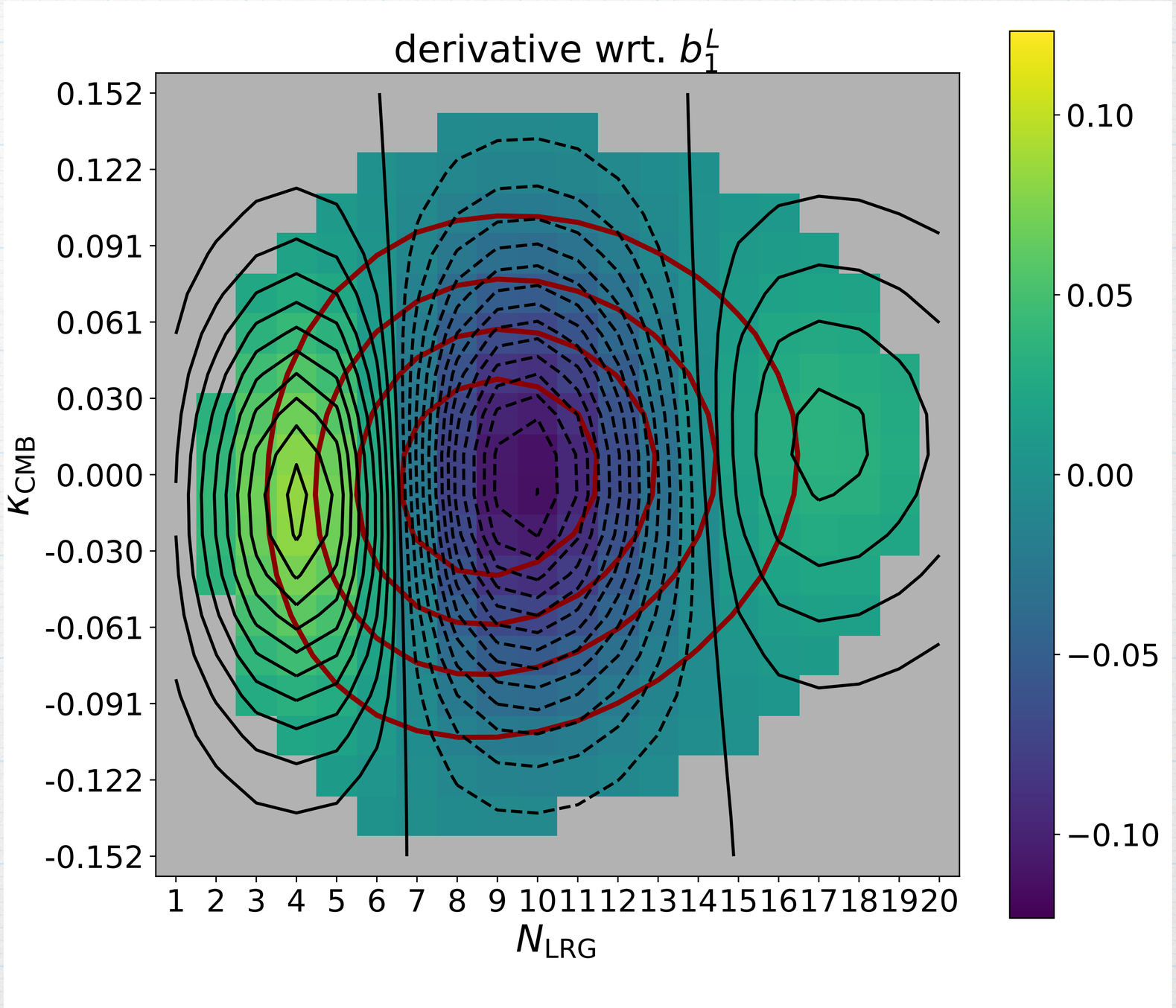

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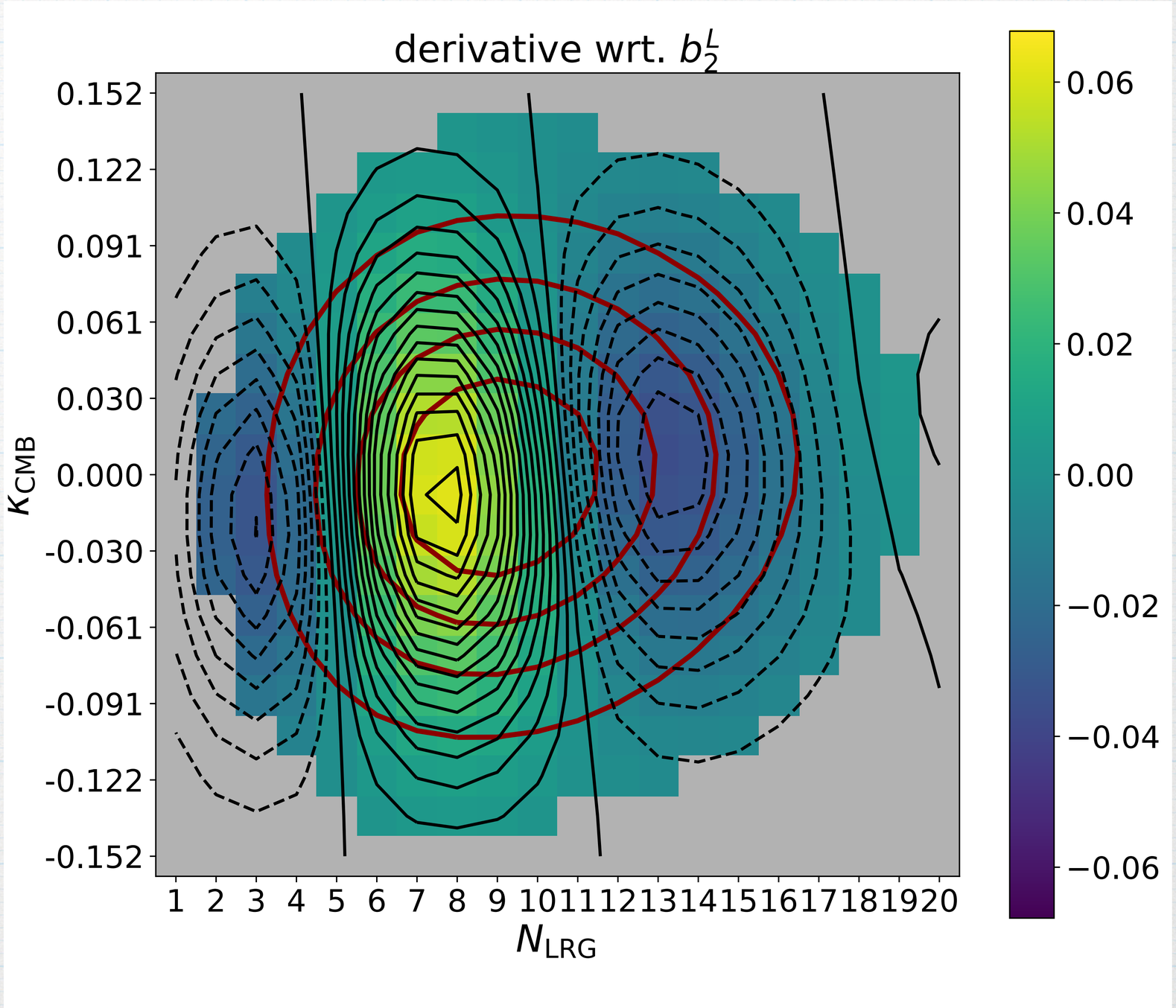


You can do PDF calculations yourself with **CosMomentum**:

https://github.com/OliverFHD/CosMomentum

Also, section 4.6 of https://arxiv.org/abs/1912.06621 describes **step-by-step details of numerical implementation**!

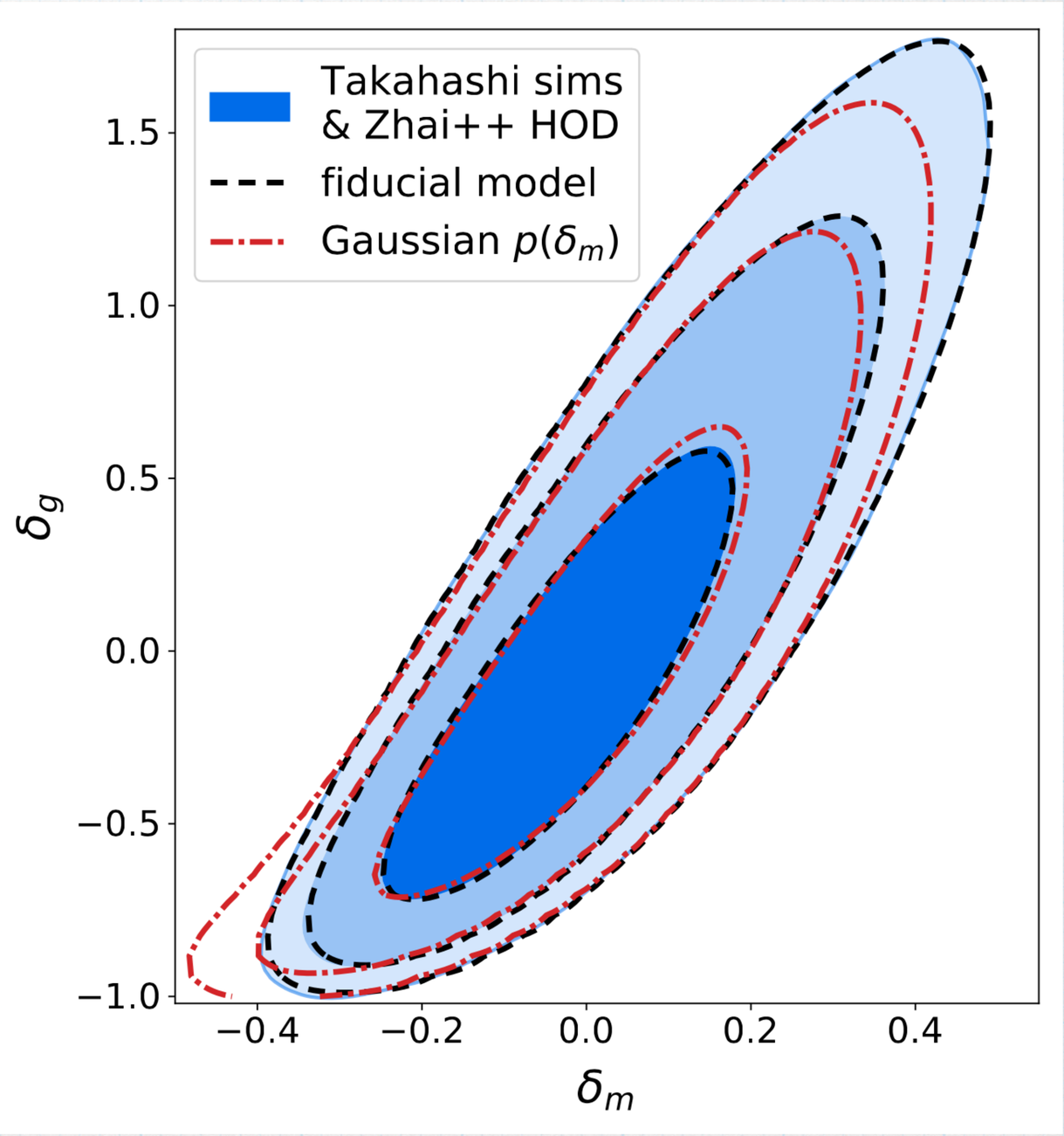
Conclusions & Outlook

- PDF technology is catching up with 2-point statistics
  → PNG
  → Lagrangian bias expansion
  → Neutrino and DE physics

- Full shape of PDF very powerful in measuring cosmology
  → even with 4-parameter bias model!

- Potential to break degeneracies of 3x2pt. What I expect to be most promising: 2-point functions + PDF on one scale

- Many of our tools are already publicly available in the **CosMomentum** package: https://github.com/OliverFHD/CosMomentum



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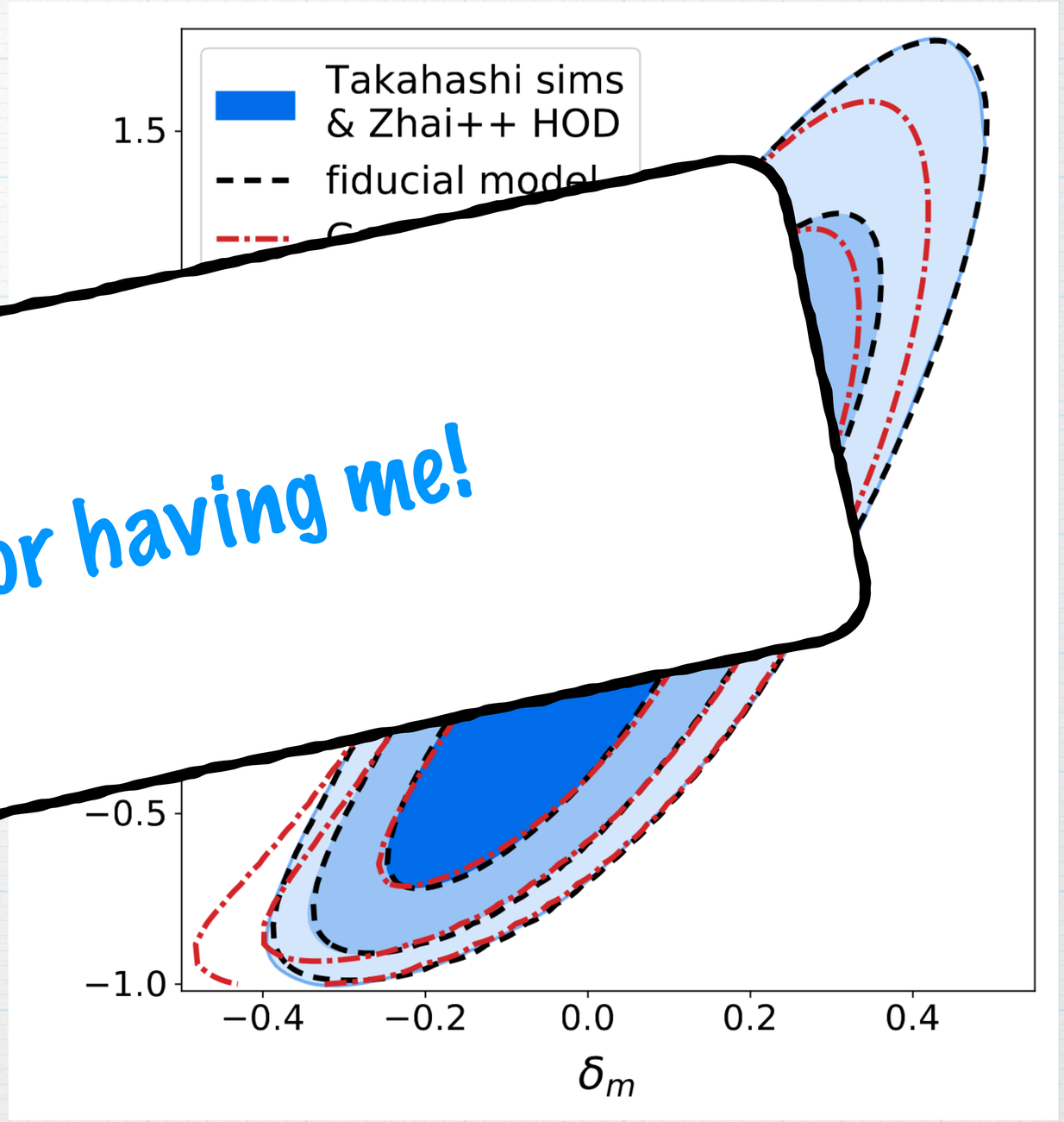

Thanks a lot for having me!