# Splitting the cosmic web for more information

Yan-Chuan Cai
Institute for Astronomy
University of Edinburgh

KITP, UC Santa Barbara, 09 Feb 2023

PDF of the density field

(Planck)

Early Universe:
Gaussian

(SDSS galaxies)

Late-time Universe:
non-Guassian

early universe

late-time universe

$\delta = \rho / \rho_{mean} - 1$

PDF
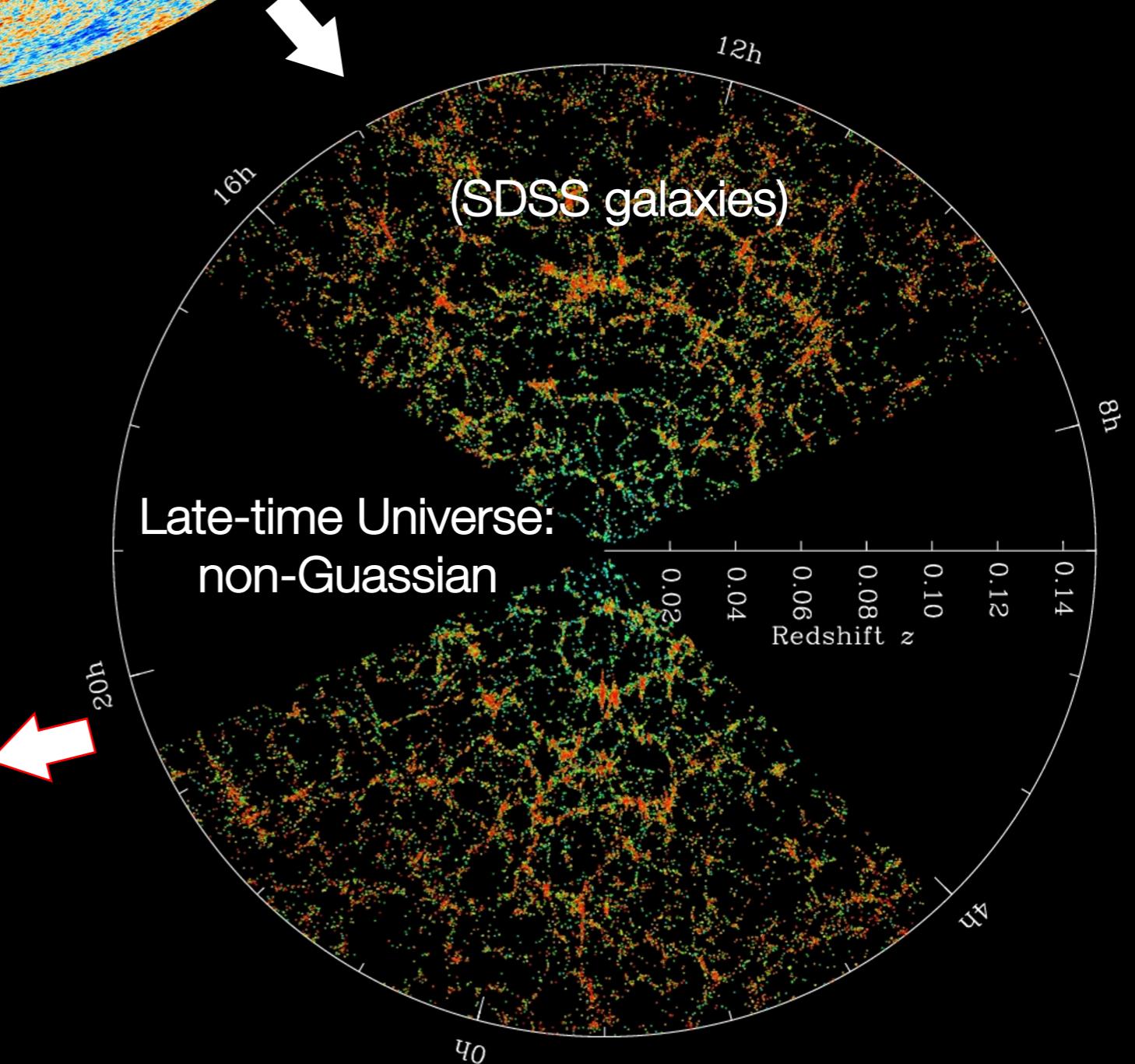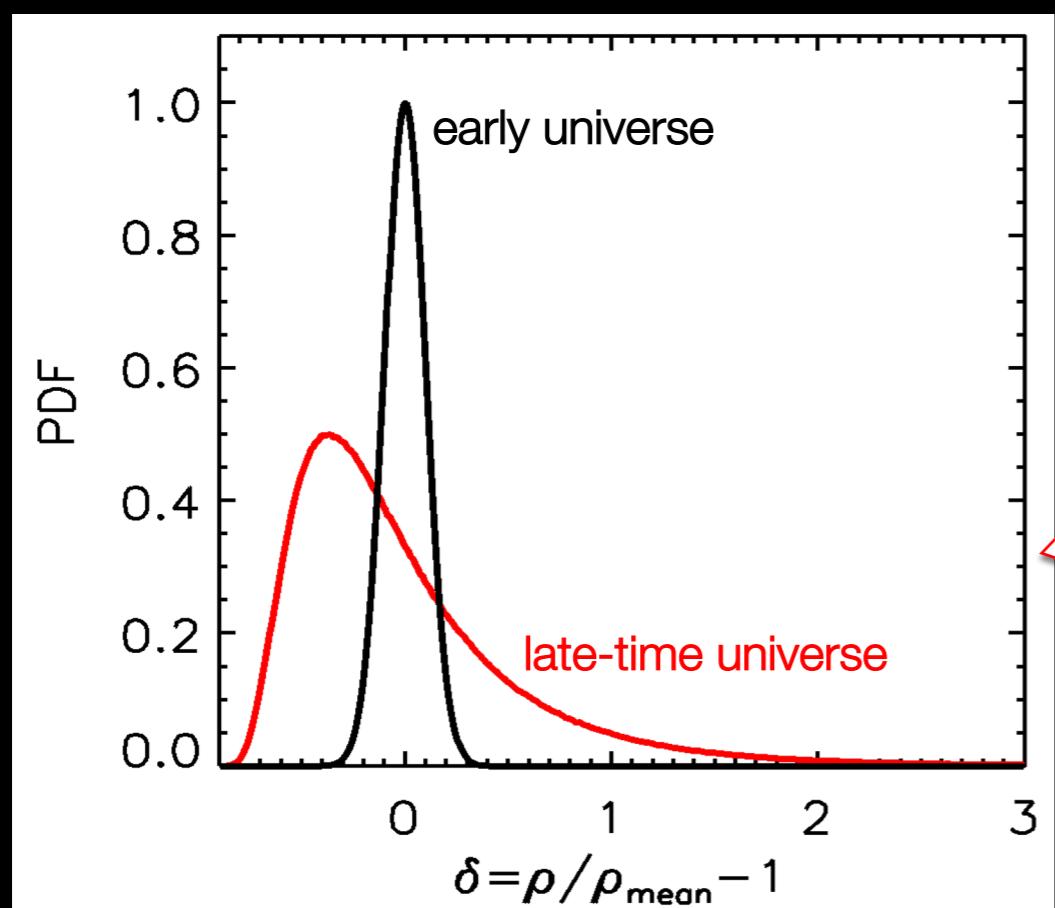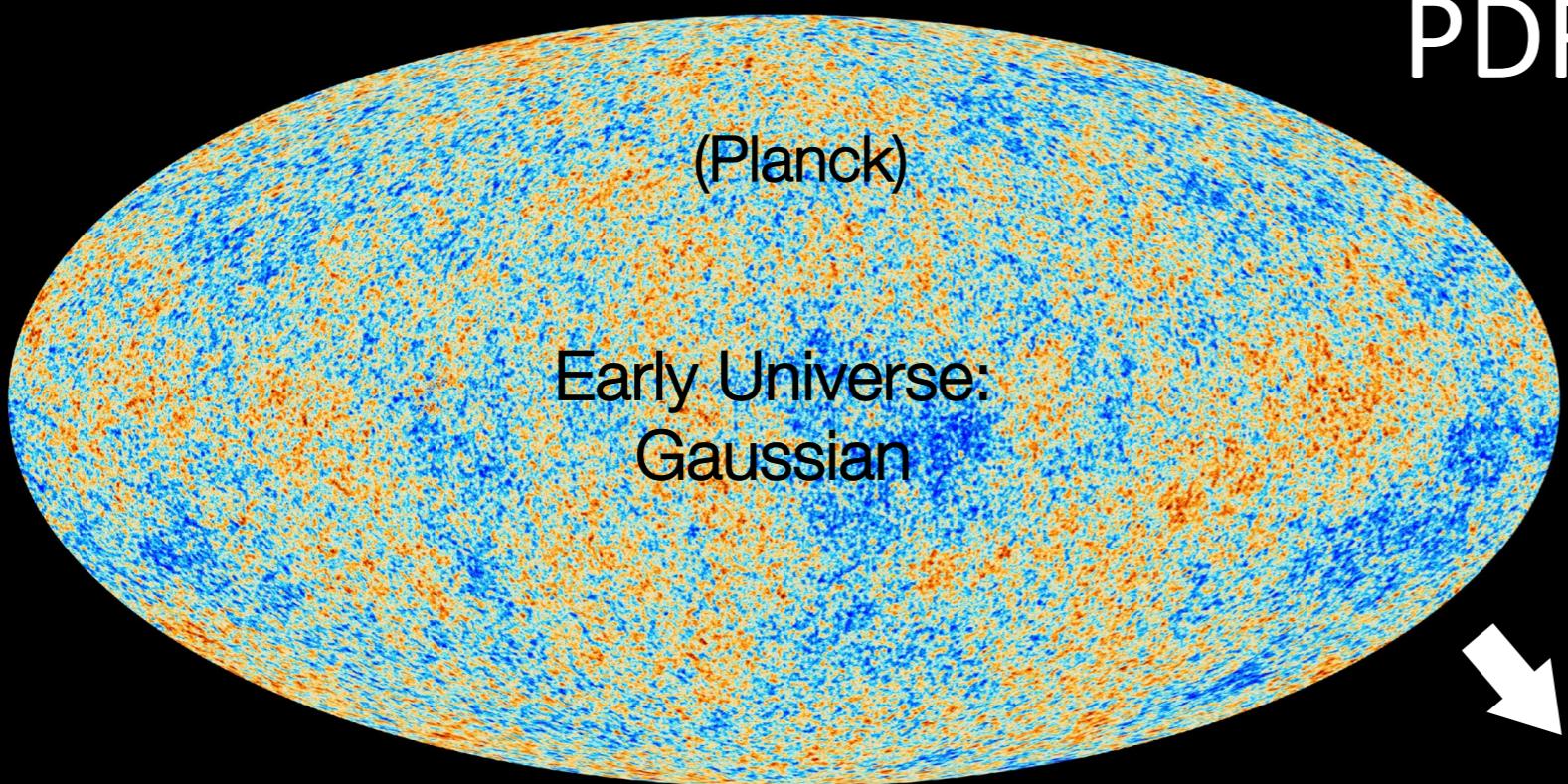
Variance of the density field

Angular scale

Early Universe

Late-time Universe

Gaussian, linear
Cosmic-variance limited

$$f \equiv \frac{d \ln \delta}{d \ln a} \approx \Omega_m^{0.55}$$

$P(k)$

Amplitude of fluctuation

6000 Mpc   600 Mpc   60 Mpc

large scale

small

Non-Gaussian,
non-linear

Spatial Frequency: k
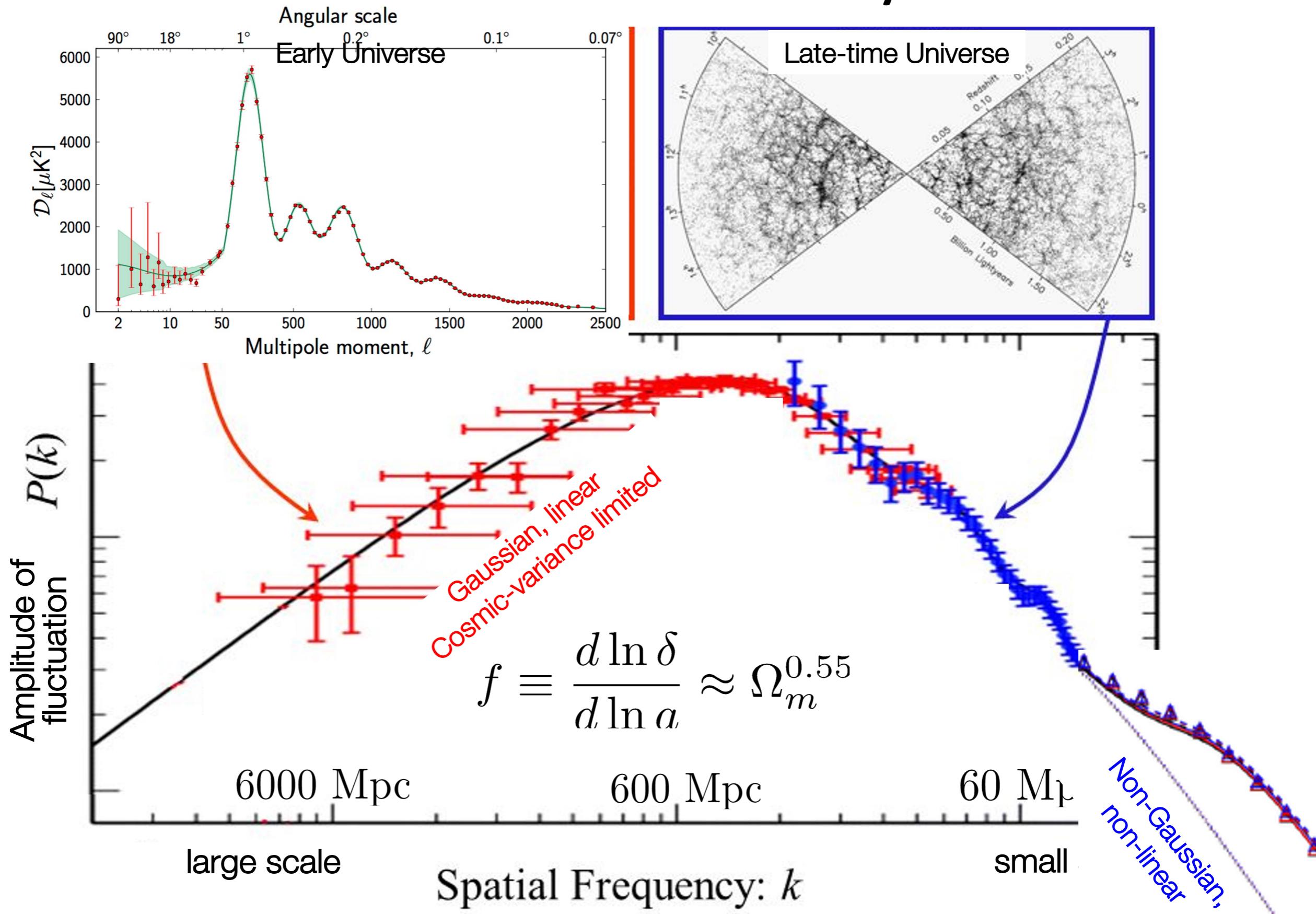
Redshift Space Distortion (RSD)

Real space:

Linear regime

Observer

$$\mathbf{s} = \mathbf{r} + \frac{v_{\parallel}}{aH}\hat{\mathbf{z}}$$

Redshift space:

Squashing effect

Observer
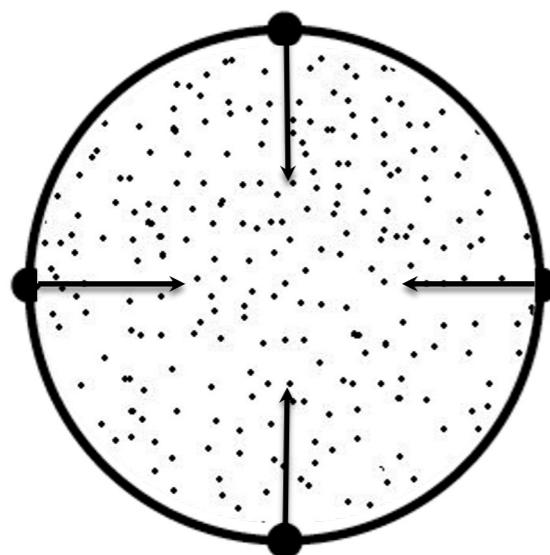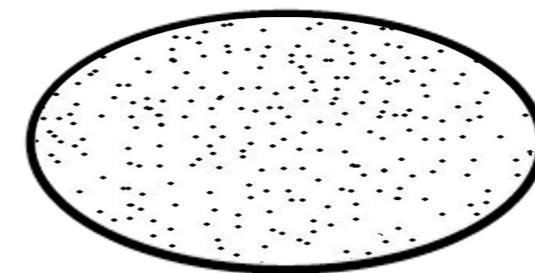
$$P_s = (b + f\mu^2)^2 P = (b/f + \mu^2)^2 f^2 P$$

Kaiser 1987

A measurement of the cosmological mass density from clustering in the 2dF Galaxy Redshift Survey

John A. Peacock[1], Shaun Cole[2], Peder Norberg[2], Carlton M. Baugh[2], Joss Bland-Hawthorn[3], Terry Bridges[3], Russell D. Cannon[3], Matthew Colless[4], Chris Collins[5], Warrick Couch[6], Gavin Dalton[7], Kathryn Deeley[6], Roberto De Propris[6], Simon P. Driver[8], George Efstathiou[9], Richard S. Ellis[9,10], Carlos S. Frenk[2], Karl Glazebrook[11], Carole Jackson[4], Ofer Lahav[9], Ian Lewis[3], Stuart Lumsden[12], Steve Maddox[13], Will J. Percival[1], Bruce A. Peterson[4], Ian Price[4], Will Sutherland[7,1], Keith Taylor[3,10]

141,000 galaxies   ~ 0.1 (Gpc)³

Growth rate parameter $\beta \equiv \Omega^{0.6}/b = 0.43 \pm 0.07$ (16%)

(considering $8\,h^{-1}\,\mathrm{Mpc} < r < 25\,h^{-1}\,\mathrm{Mpc}$)

SDSS-BOSS

1,198,006 galaxies   ~ 10 (Gpc)^3

fitting range $25\ h^{-1}\mathrm{Mpc} \leq s \leq 150\ h^{-1}\mathrm{Mpc}$

Derived Parameters

$f\sigma_8$	x	0.430 ± 0.054	0.452 ± 0.057	0.457 ± 0.052
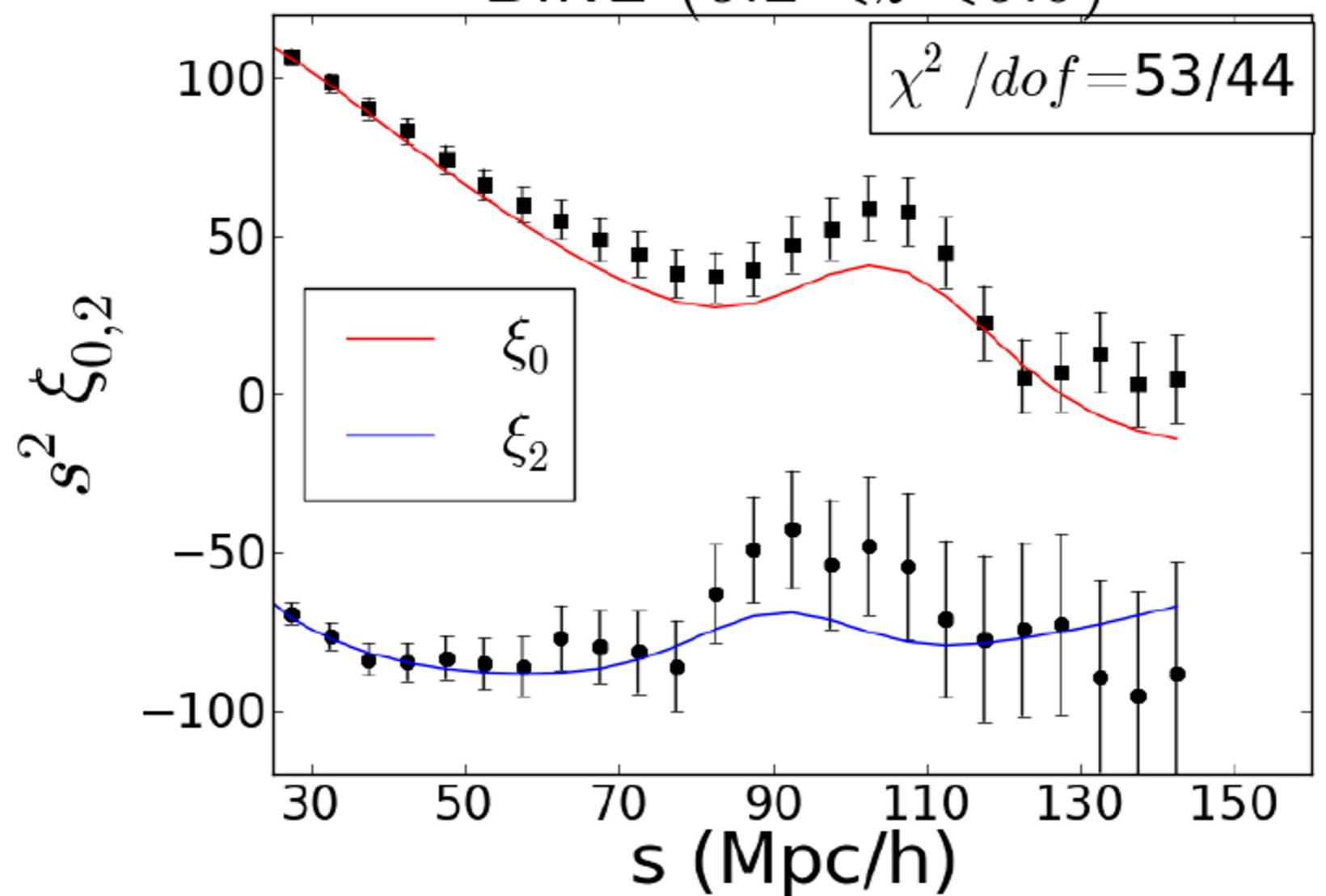
RSD model

$$\mathbf{s} = \mathbf{r} + \frac{v_\parallel}{aH}\hat{\mathbf{z}}$$

Observed redshift = cosmological redshift + peculiar velocity

$$1 + \xi^s(s_\perp, s_\parallel) = \int [1 + \xi(r)]\, \mathcal{P}(v_\parallel, \mathbf{r}) dv_\parallel$$

Peebles 1980

Observed galaxy distribution = true galaxy distribution ✳ velocity distribution

$$1 + \xi^s(s_\perp, s_\parallel) = \int (1 + \xi(r)) \frac{1}{\sqrt{2\pi\sigma_\parallel^2(r,\mu)}} \exp\left\{ -\frac{[v_\parallel - v_r(r)\mu]^2}{2\sigma_\parallel^2(r,\mu)} \right\} dv_\parallel$$

Fisher 1995

Observed galaxy distribution = true galaxy distribution ✳ **Gaussian** velocity distribution

$\log(\xi(s_\perp, s_\parallel) + 1)$

2PCF

$s_\parallel \ [\mathrm{Mpc}/h]$

$s_\perp \ [\mathrm{Mpc}/h]$
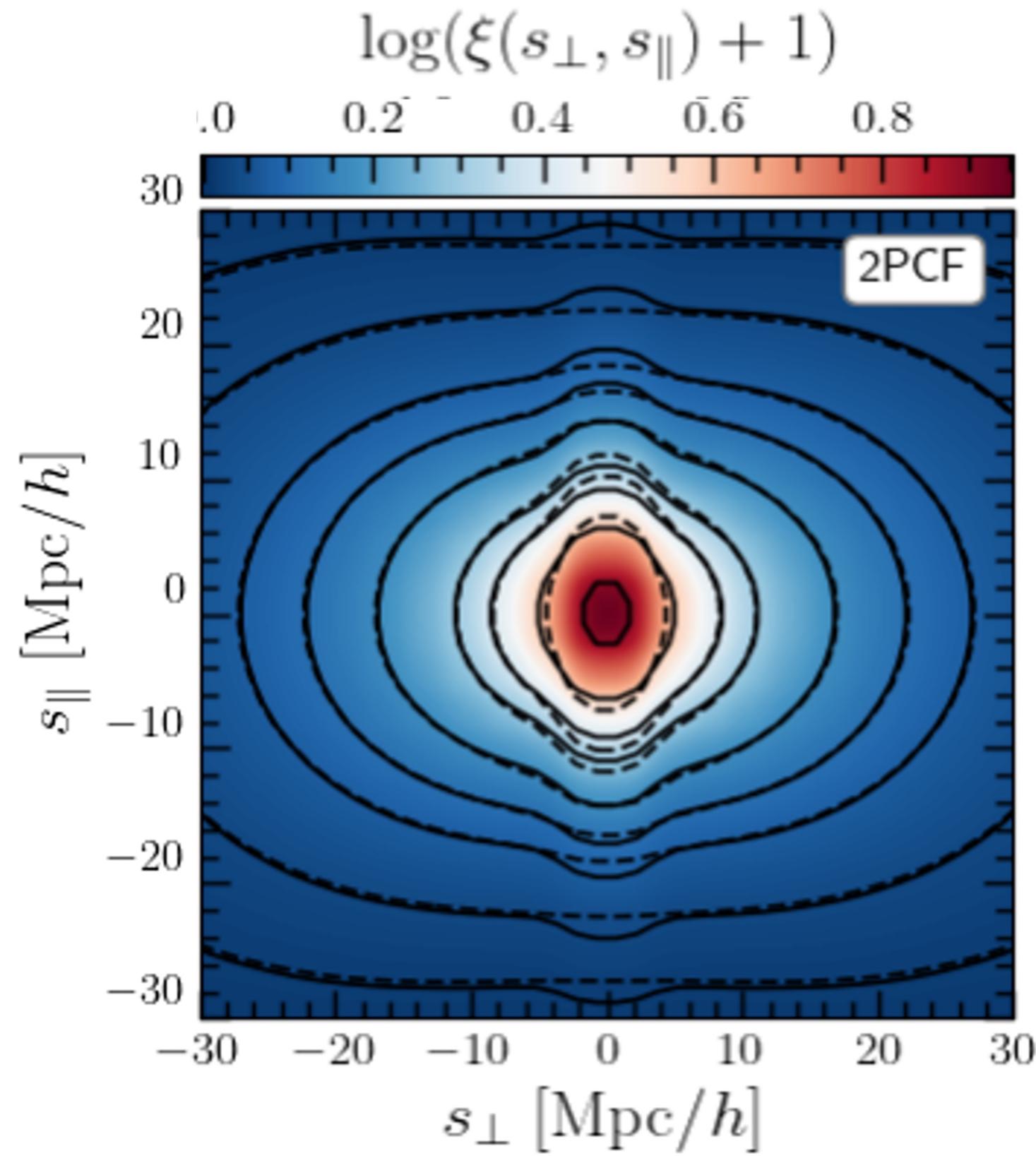
with $\left\{ \begin{array}{l} \xi(r) \\ v_r(r) \\ \sigma_\parallel^2(r, \mu) \end{array} \right.$

from simulation

+

Fisher95 model

See also Reid B. & White M., 2011, MNRAS, 417, 1913

RSD with split densities

125 Mpc/h
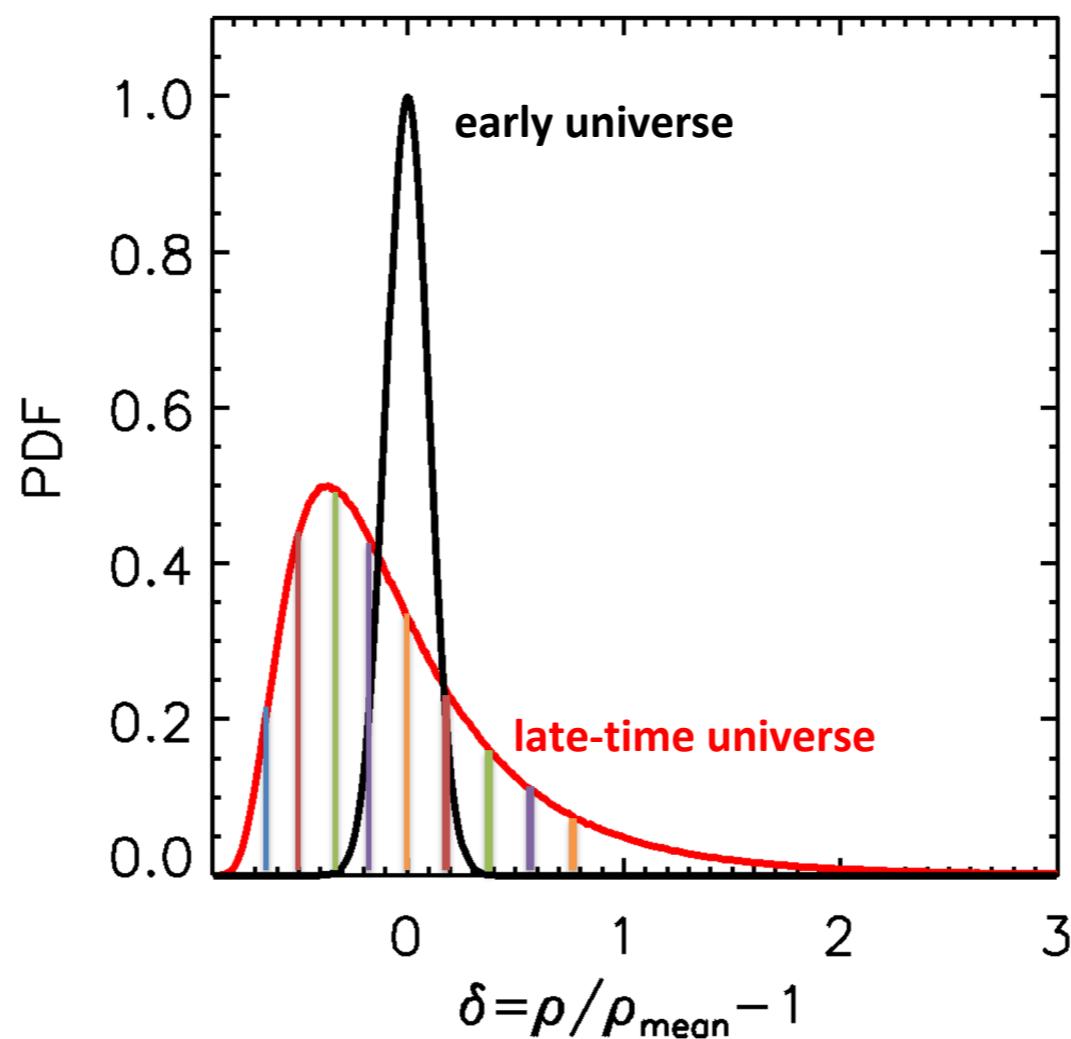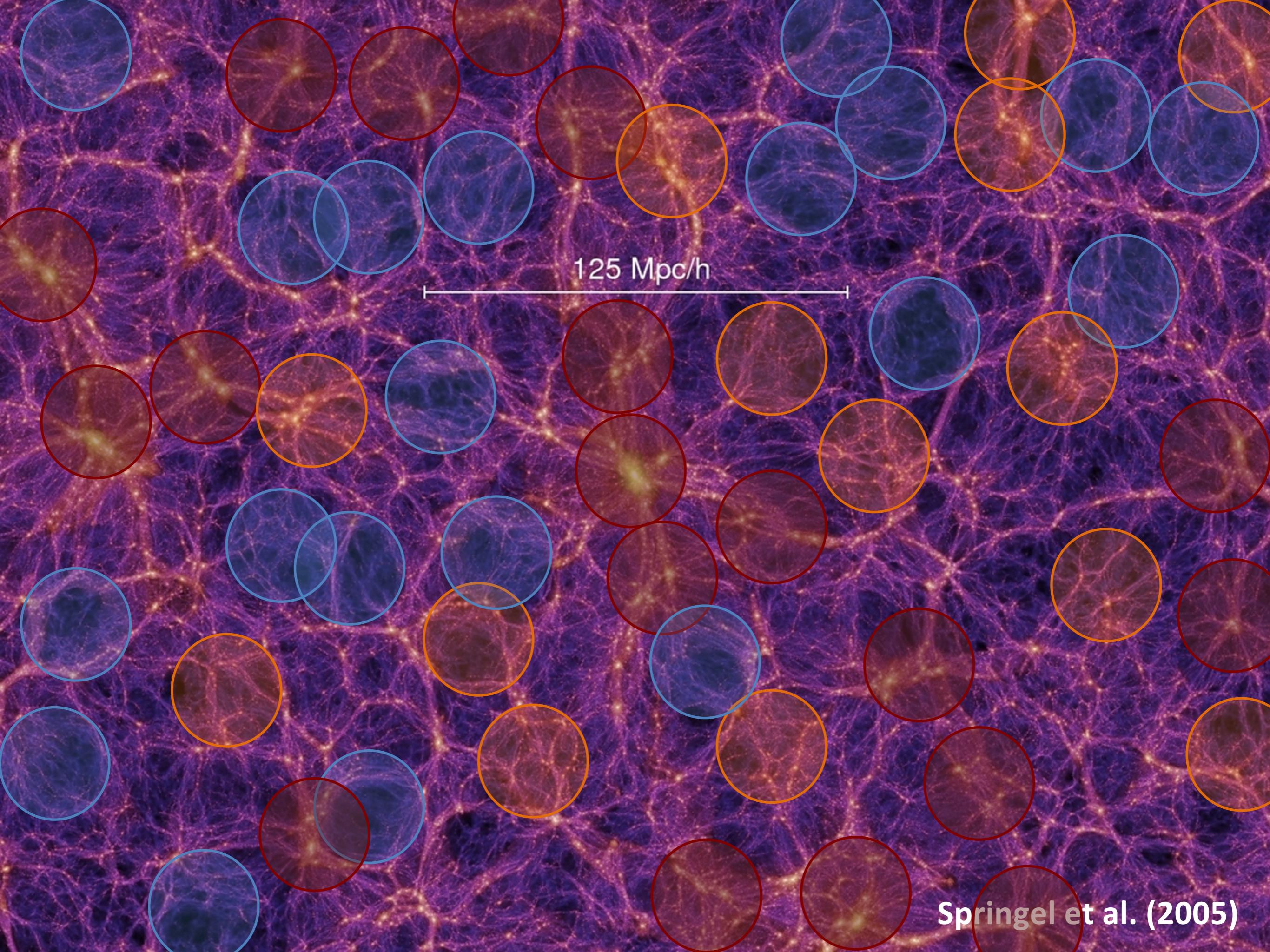
Springel et al. (2005)

E. Paillas, YC, N. Padilla, A. Sánchez 2021

$\overline{v}_r$: 173.6 km/s σ_v: 299.1 km/s Skewness: 0.15 **Low density (void)**	$\overline{v}_r$: 128.5 km/s σ_v: 308.3 km/s Skewness: 0.15	$\overline{v}_r$: 82.8 km/s σ_v: 319.9 km/s Skewness: 0.17
DS1	DS2	DS3
$\overline{v}_r$: 19.7 km/s σ_v: 334.4 km/s Skewness: 0.17	$\overline{v}_r$: -116.9 km/s σ_v: 373.8 km/s Skewness: 0.11 **high density (supercluster)**	$\overline{v}_r$: -238.6 km/s σ_v: 441.4 km/s Skewness: -0.51
DS4	DS5	2PCF
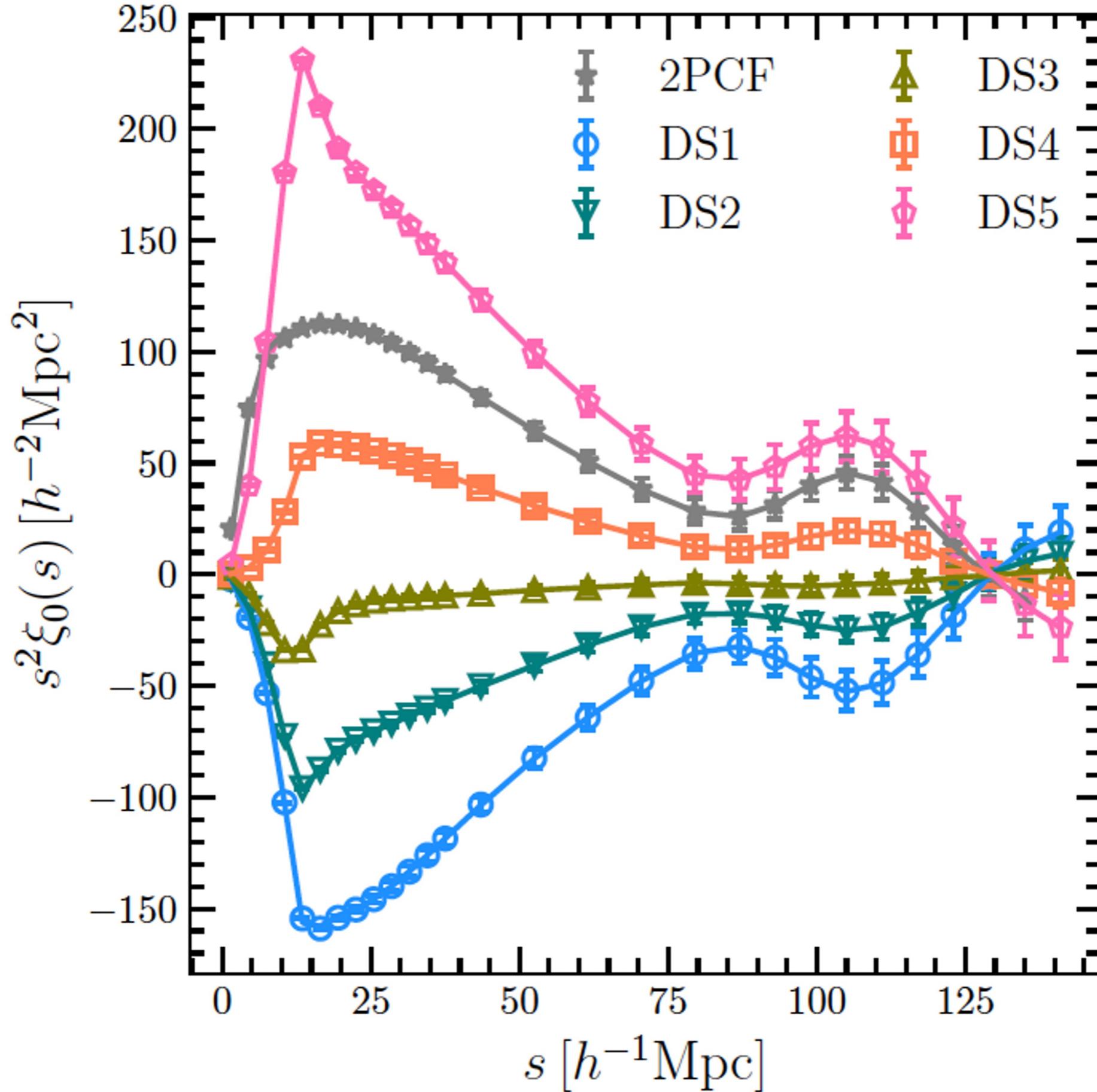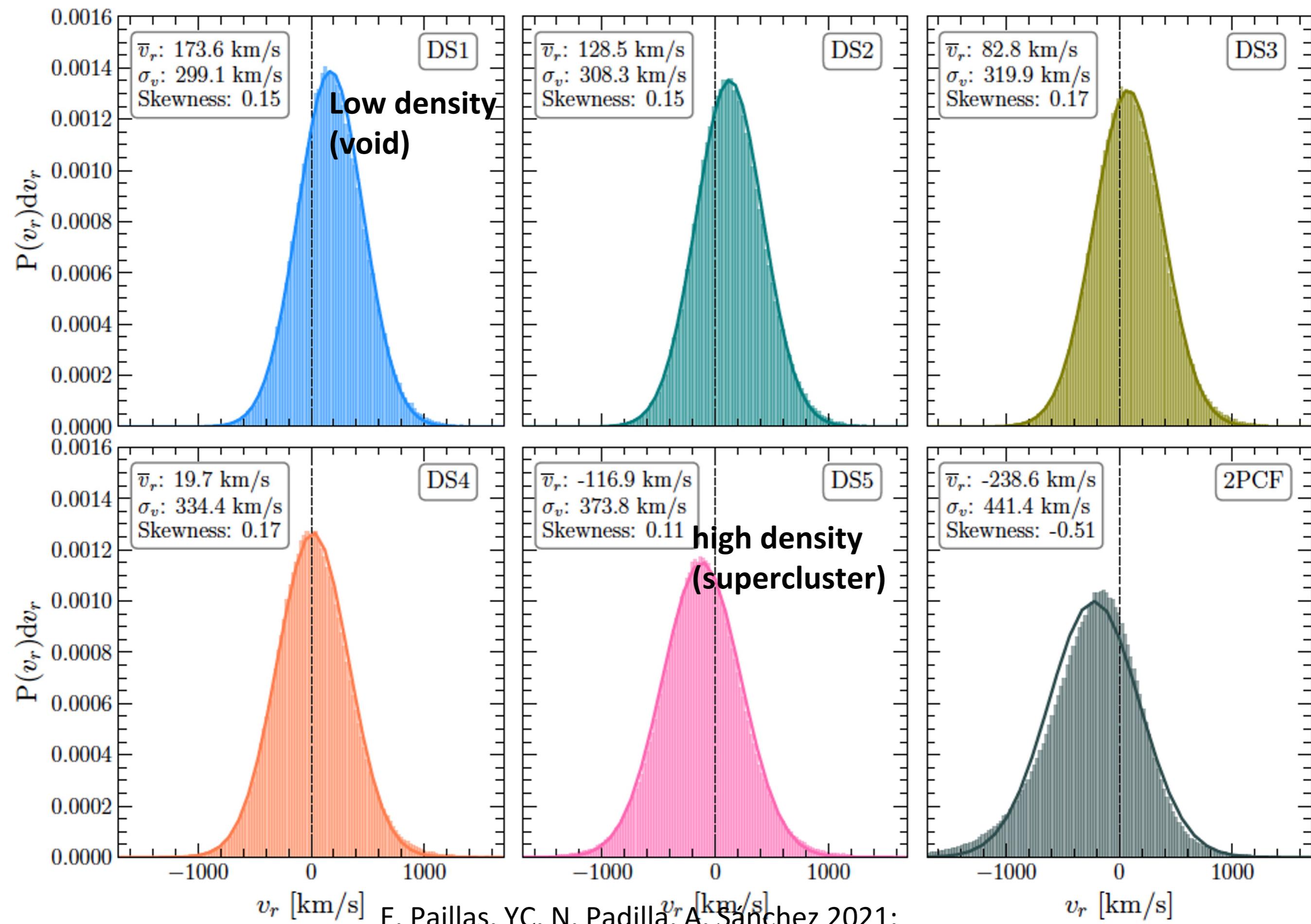
E. Paillas, YC, N. Padilla, A. Sánchez 2021;
See also Tinker J. 2007, MNRAS, 374, 477

$$v_r(r) = -\frac{1}{3}\frac{aHr\beta\bar{\xi}(r)}{1+\nu\xi(r)}$$

- ○ Galaxy
- - - Linear coupling
- —— Empirical coupling

E. Paillas, YC, N. Padilla, A. Sánchez 2021

E. Paillas, YC, N. Padilla, A. Sánchez 2021
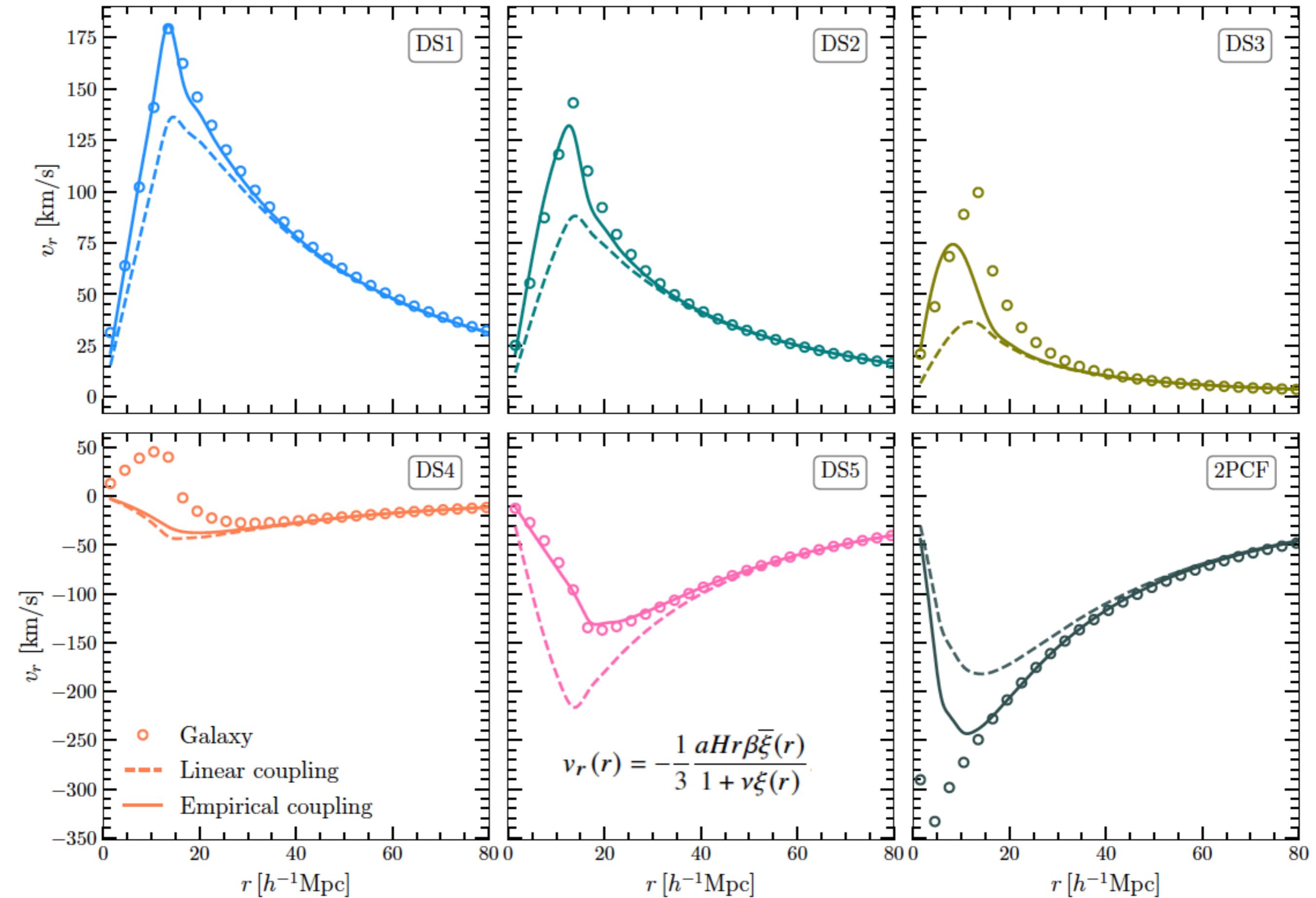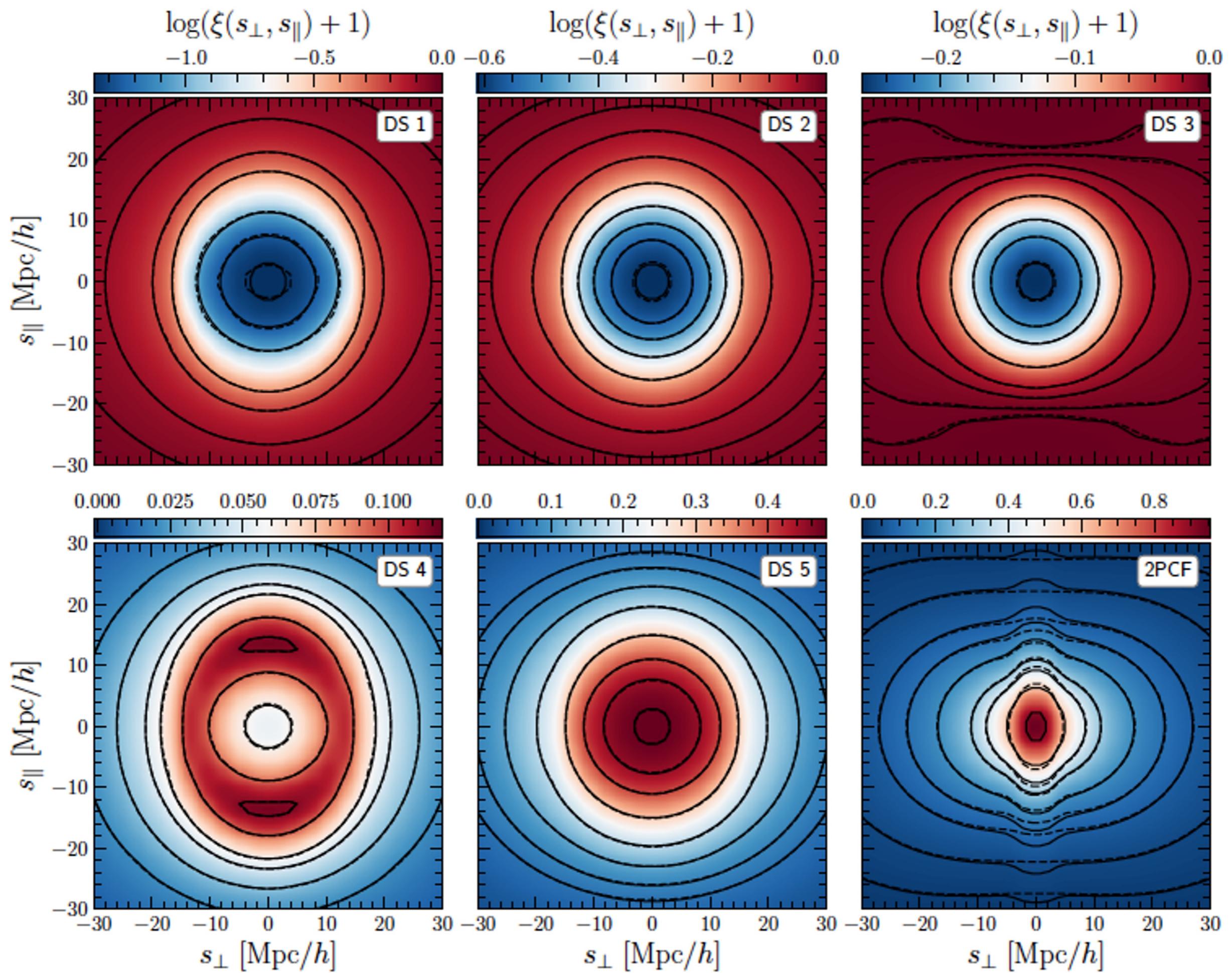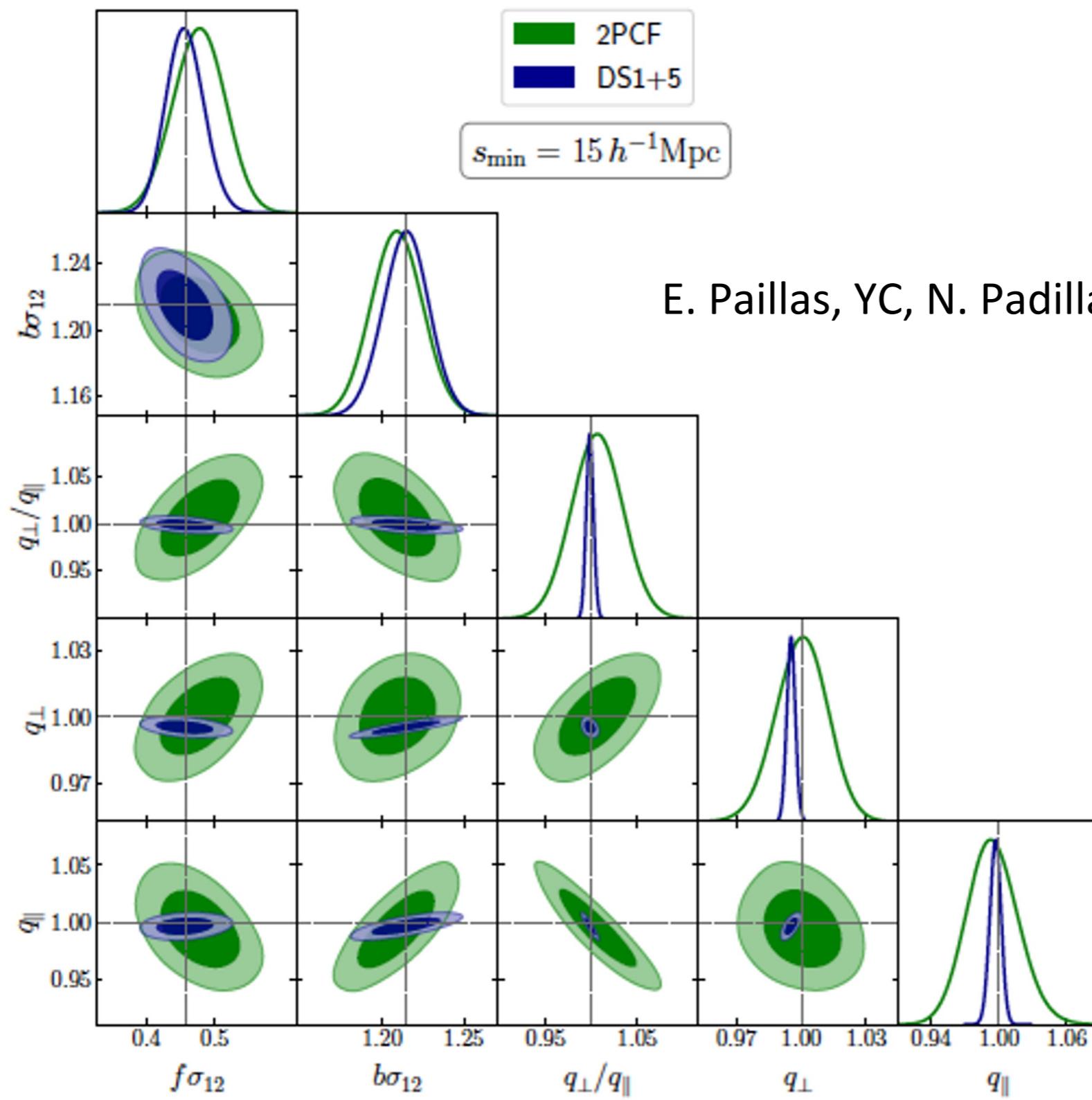
More information

E. Paillas, YC, N. Padilla, A. Sánchez 2021

Enrique Paillas

More information
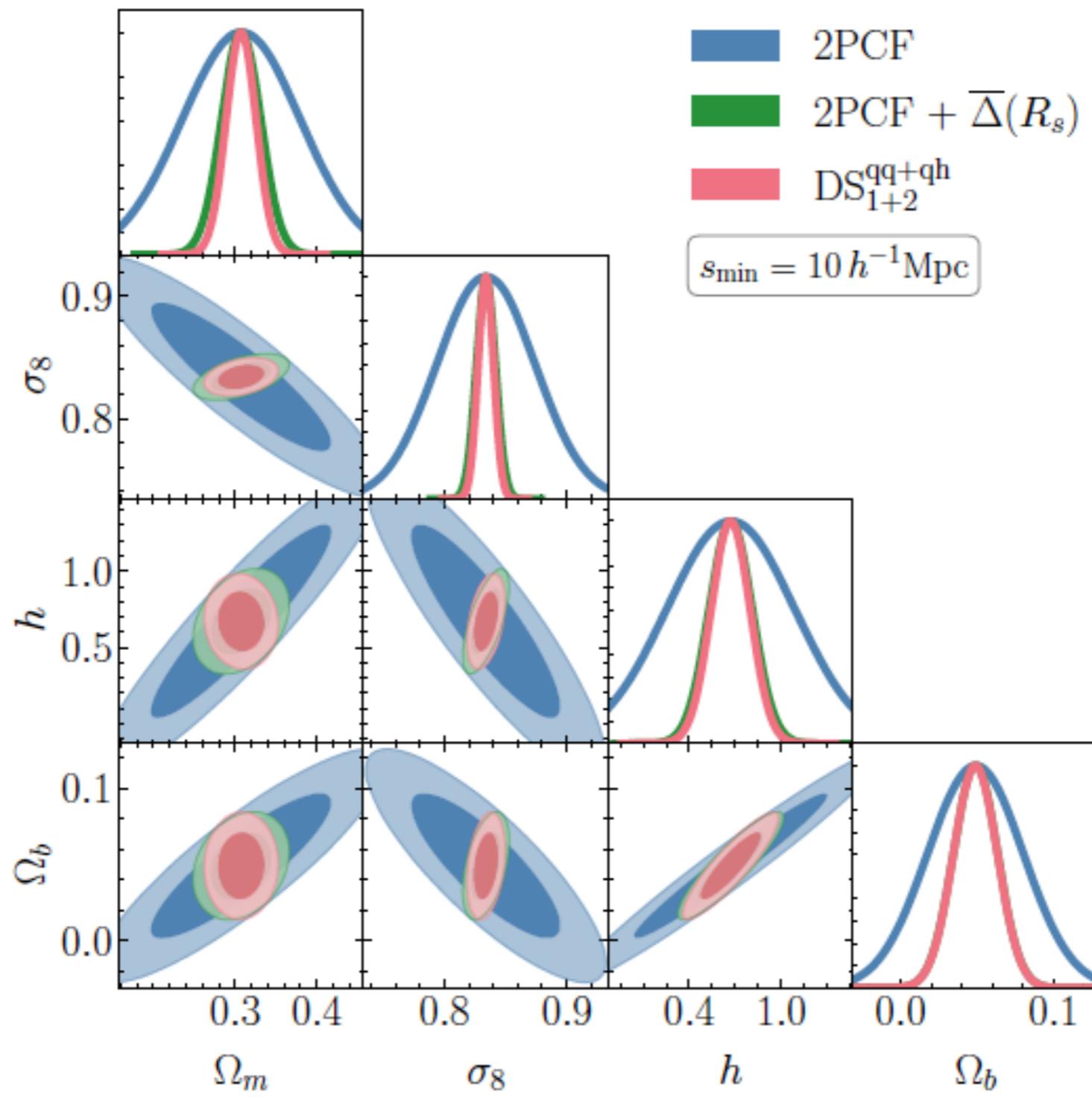
Legend:
- 2PCF
- 2PCF + $\overline{\Delta}(R_s)$
- DS_{1+2}^{qq+qh}
- $s_{min} = 10\,h^{-1}\mathrm{Mpc}$

Axes: Ω_m, σ_8, h, Ω_b

E. Paillas, C. Cuesta-Lazaro, P. Zarrouk, YC, et al. arXiv:2209.0431

Also true for 2D

Benjamin Giblin

Gaussian

Giblin B., YC & Hornois-Deraps 2023, MNRAS.tmp..315G, arXiv.2211.05708

Also true for 2D

Benjamin Giblin

Log-normal

Giblin B., YC & Hornois-Deraps 2023, MNRAS.tmp..315G, arXiv.2211.05708
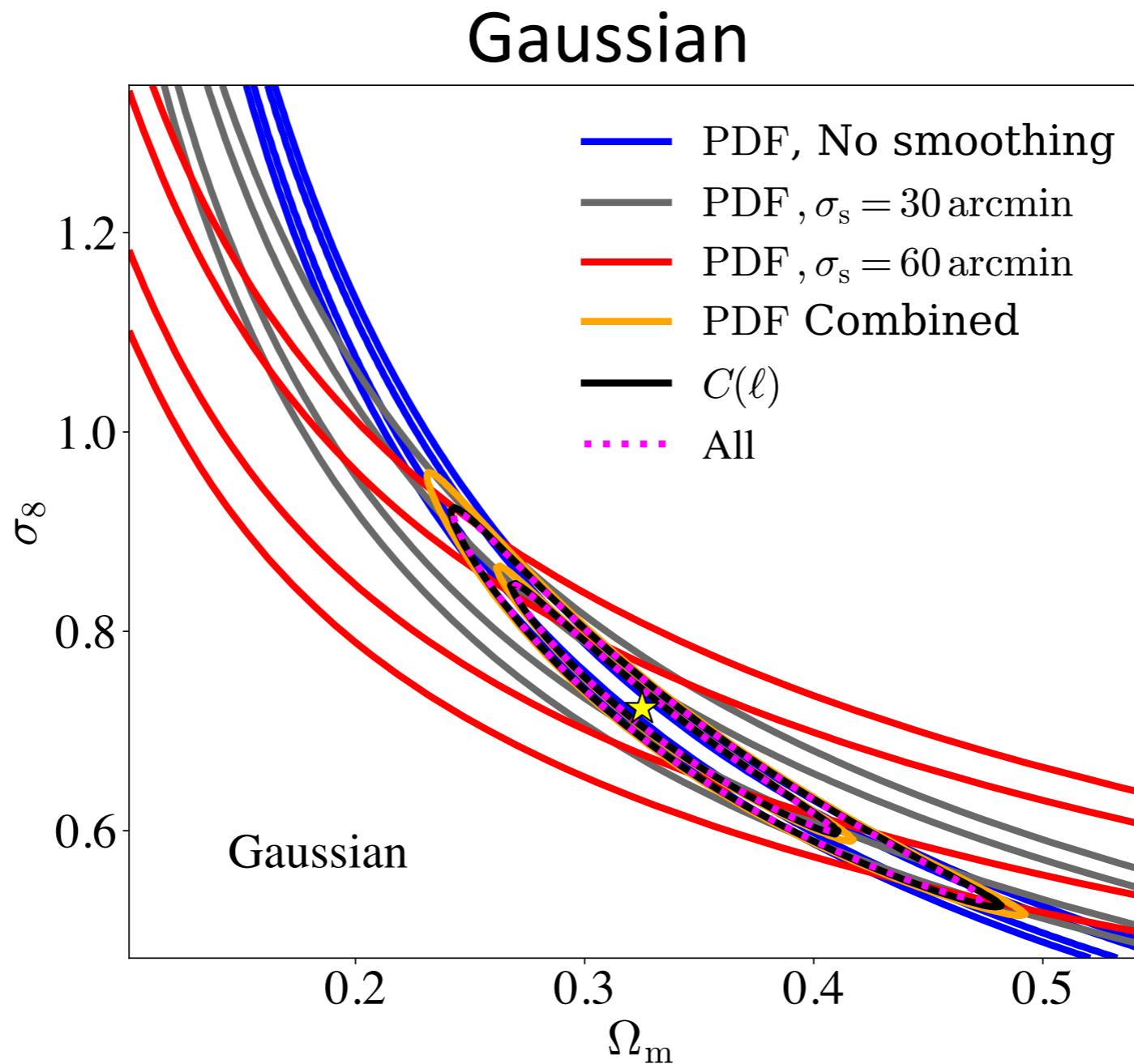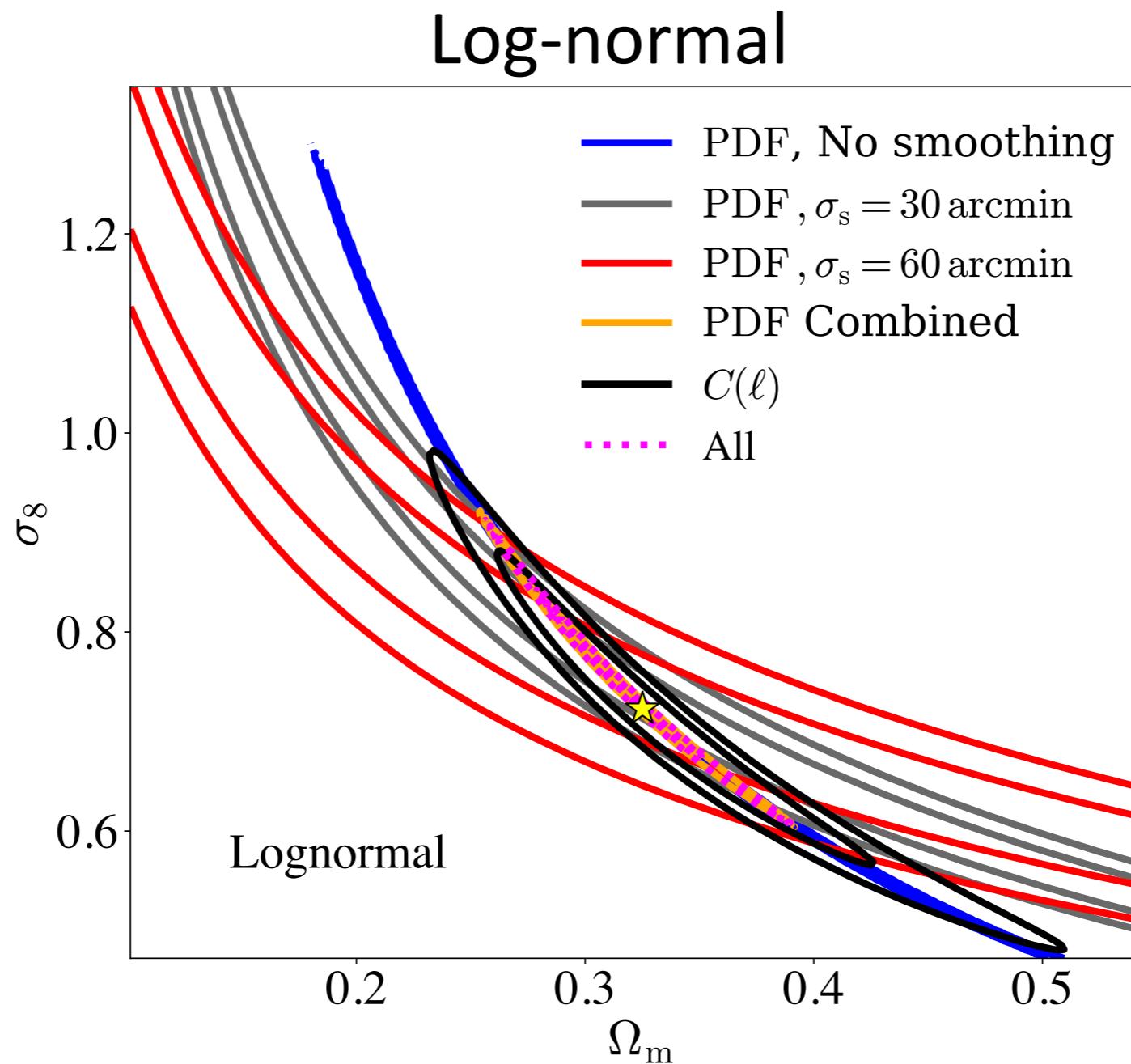
Modeling density-split clustering

➢ Density PDFs

➢ Real-space density profiles: $\xi(r)$

➢ Velocity distribution p(v)

In the Gaussian limit:

Streaming velocity profile $v(r)$

Velocity dispersion profile $\sigma_{\parallel}(r, \mu)$

Modeling split density clustering
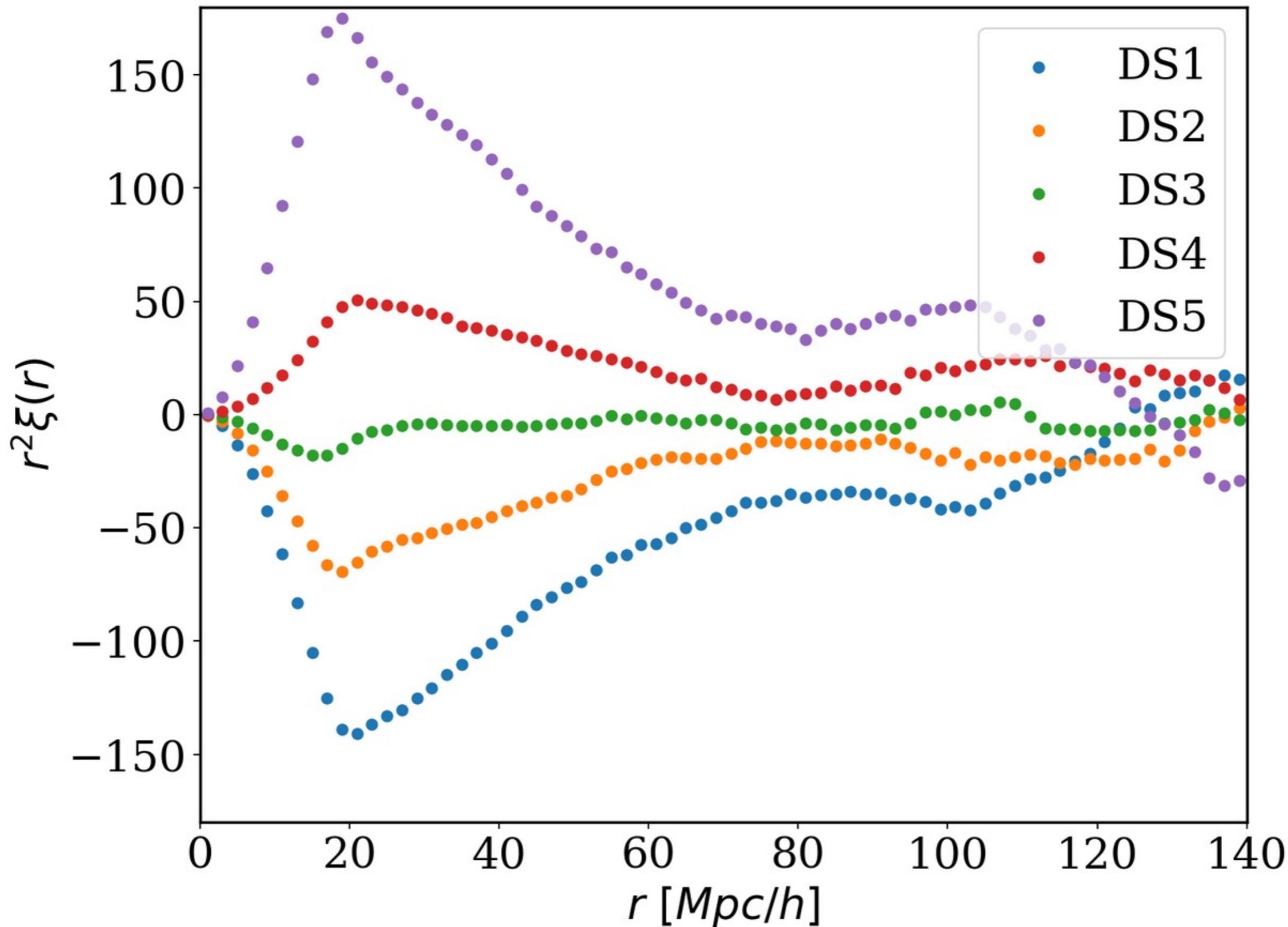
# Counts in Cells
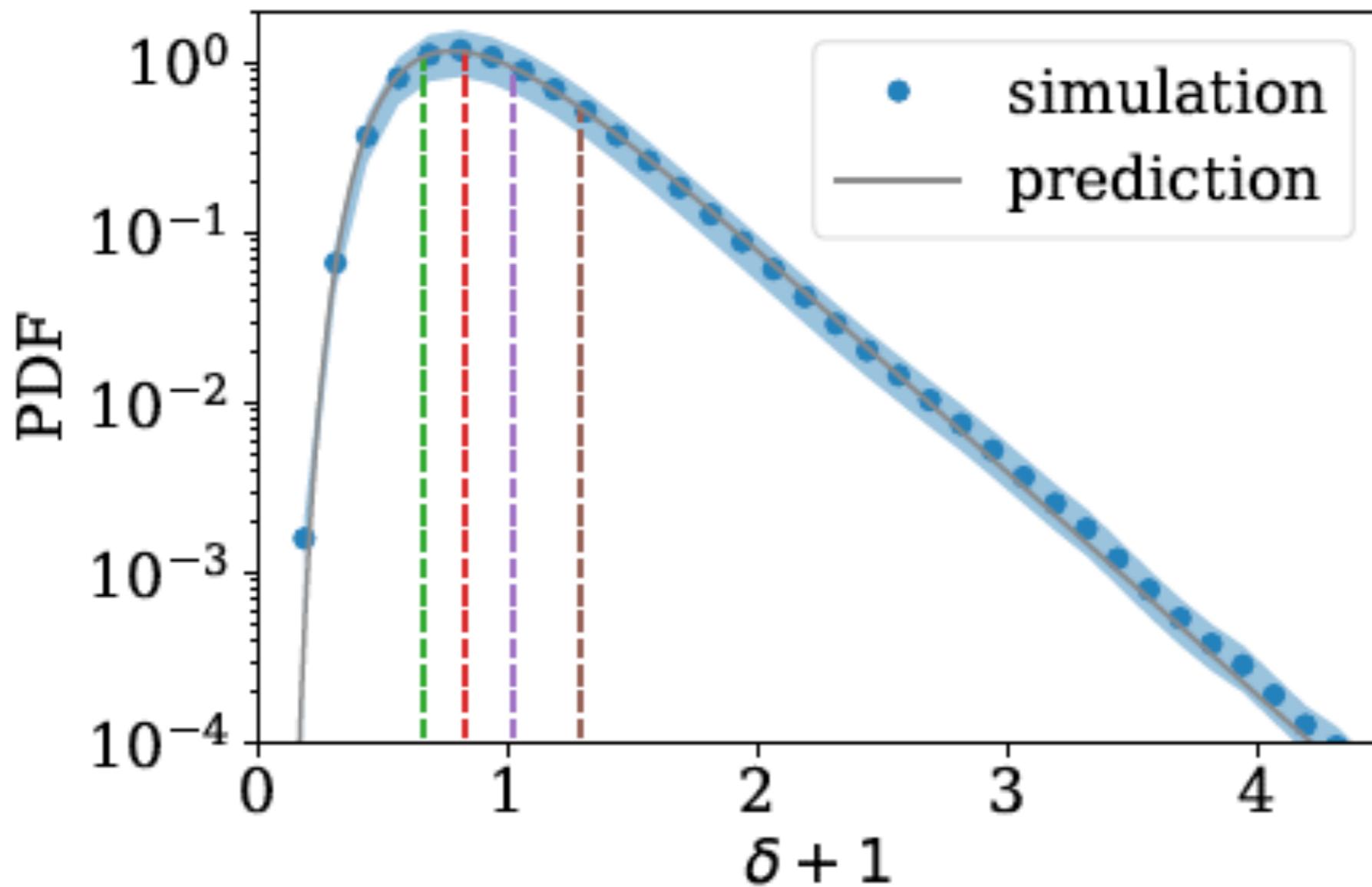
e.g. Uhlemann, C. et al. 2016, MNRAS.460.1529U

Conditioned correlation function
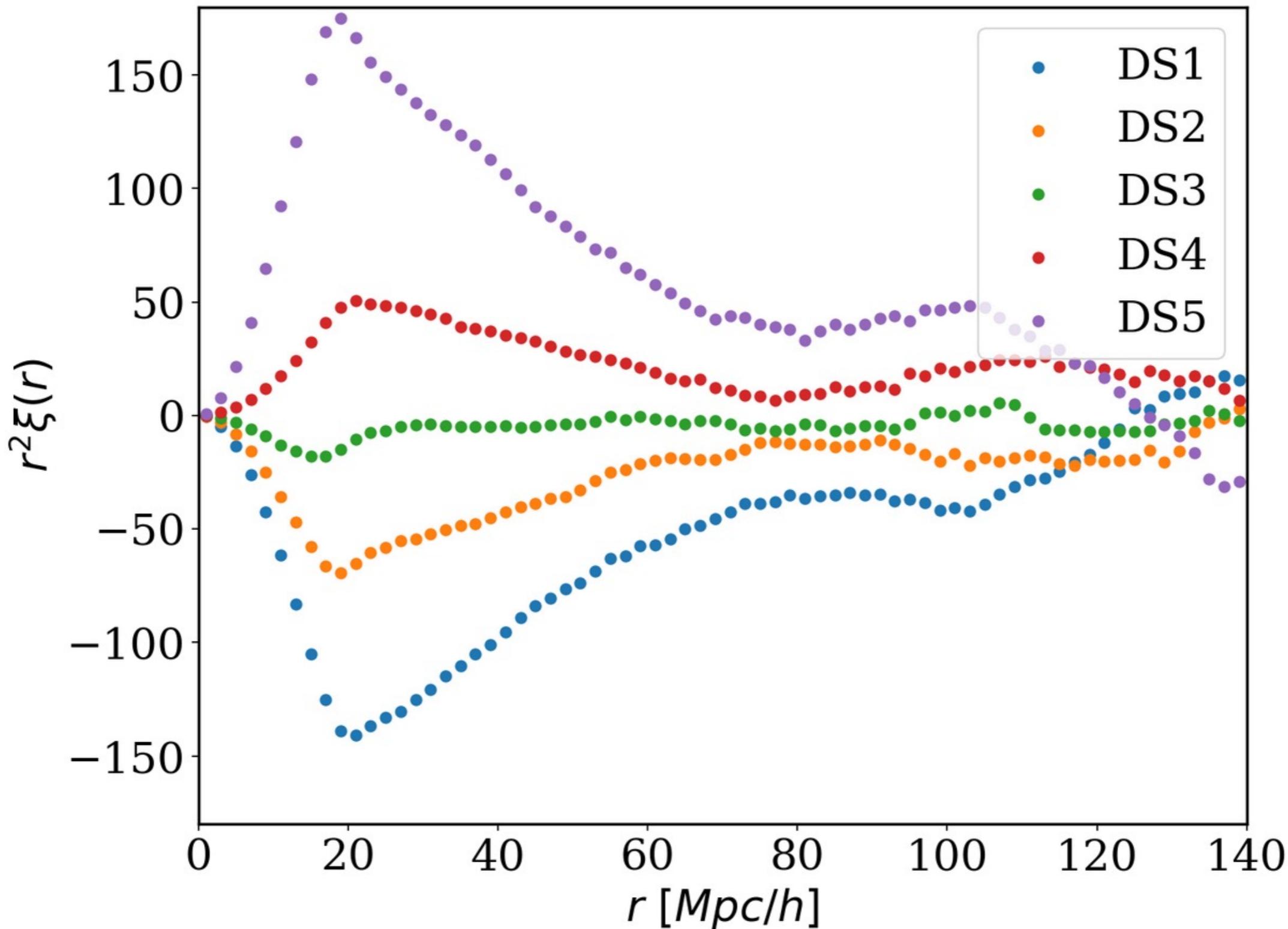
Conditioned correlation function
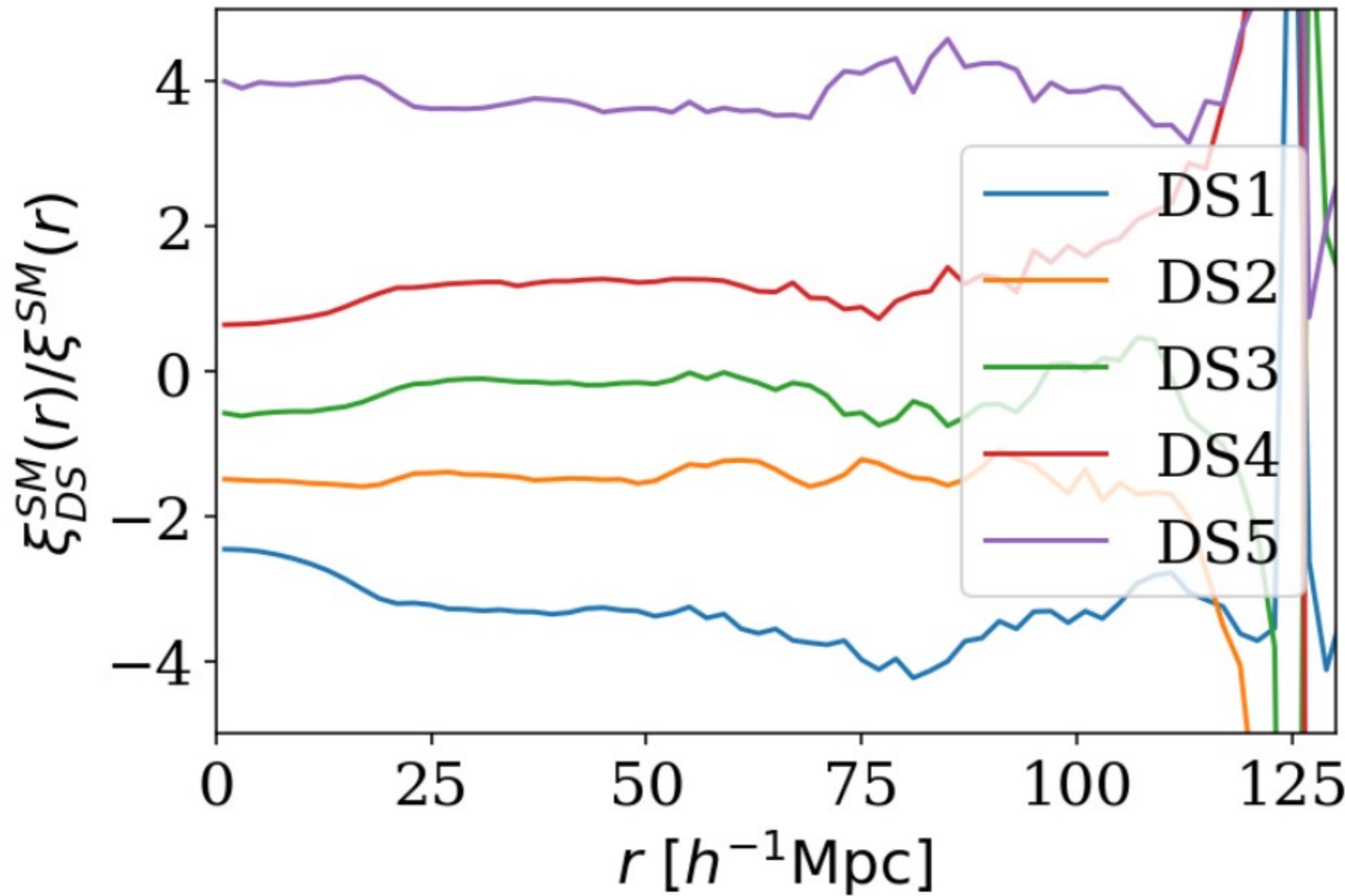
$$\xi_{\mathrm{DS}}(r, R) = \frac{\bar{\delta}_{\mathrm{DS}}(R)}{\sigma_{\mathrm{lin}}^2(R)} \xi_{\mathrm{lin}}(r, R)$$
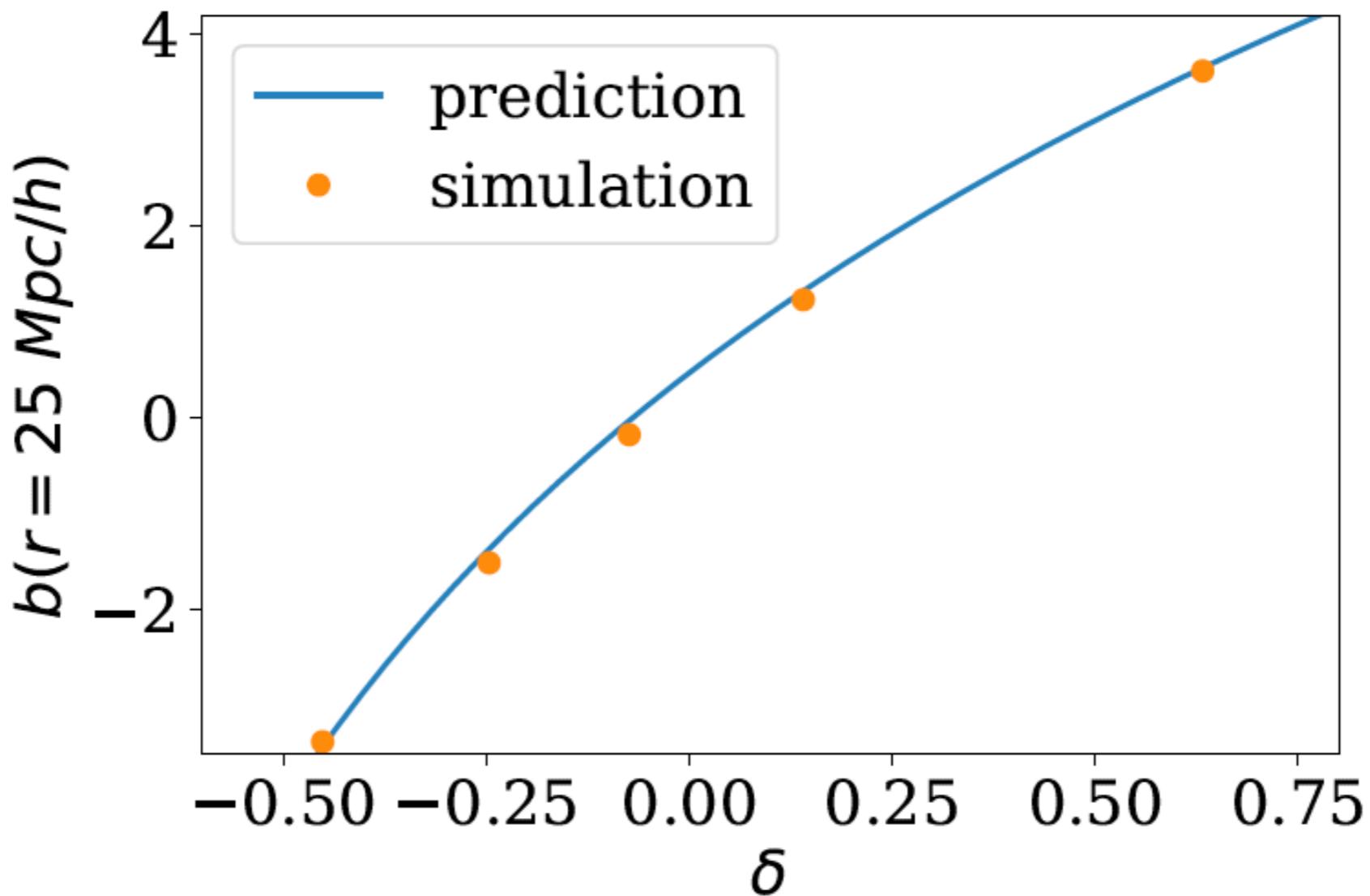

e.g.
Abbas & Sheth 2007, MNRAS.378..641A
Neyrinck, M. et al, 2018, MNRAS.478.2495N;
Hall, A., 2020, PhRvD.101d3519H
Repp & Szapudi, 2022, MNRAS.509..586R

YC et al. in prep.

Modeling density-split clustering
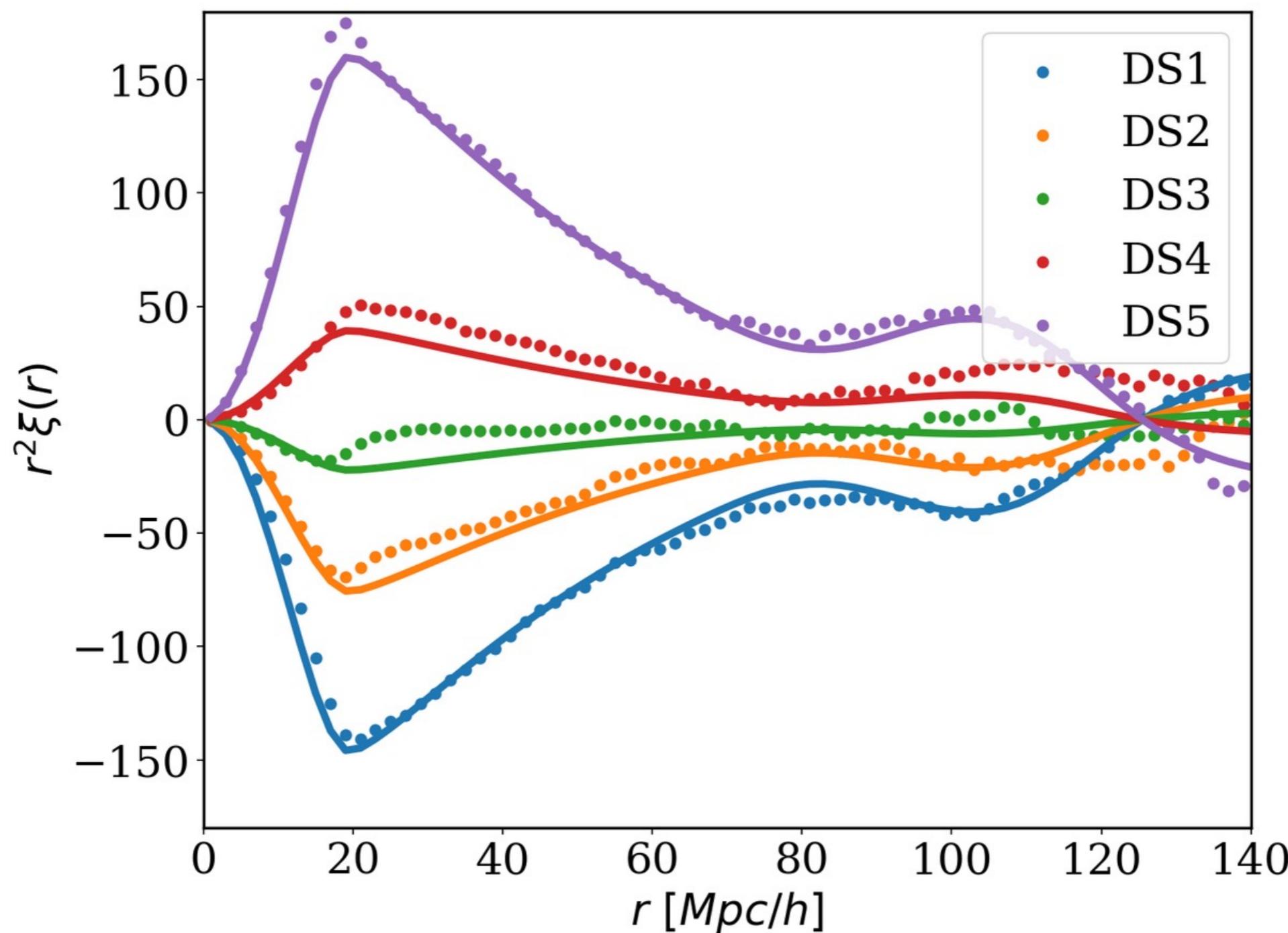
Strong clustering of underdense regions and the environmental dependence of clustering from Gaussian initial conditions

Ummi Abbas[1] and Ravi K. Sheth[2]★

[1]*Laboratoire D'Astrophysique de Marseille, Traverse du Siphon, B.P. 8, 13376 Marseille Cedex 12, France*
[2]*Department of Physics & Astronomy, University of Pennsylvania, 209 S. 33rd Street, Philadelphia, PA 19104, USA*

Nearest neighbour distributions: New statistical measures for cosmological clustering

Arka Banerjee [1,2,3]★ and Tom Abel[1,2,3]

[1]*Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, 452 Lomita Mall, Stanford, CA 94305, USA*
[2]*Department of Physics, Stanford University, 382 Via Pueblo Mall, Stanford, CA 94305, USA*
[3]*SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025, USA*

Indicator power spectra: surgical excision of non-linearities and covariance matrices for counts in cells

Andrew Repp [1,2]★ and István Szapudi[2]

[1]*Christian Liberty Academy, 16-675 Milo St., Kea'au, HI 96749, USA*
[2]*Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822, USA*

Summary

RSD with splitting densities:

- improves modelling accuracy
- contain more cosmological information

Conditioned correlation function

Environmental dependence clustering

Density-split clustering

kNN-CPDF

Multi-scale PDFs

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