Modeling Galaxy Surveys with the MICE simulations

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Main collaborators:
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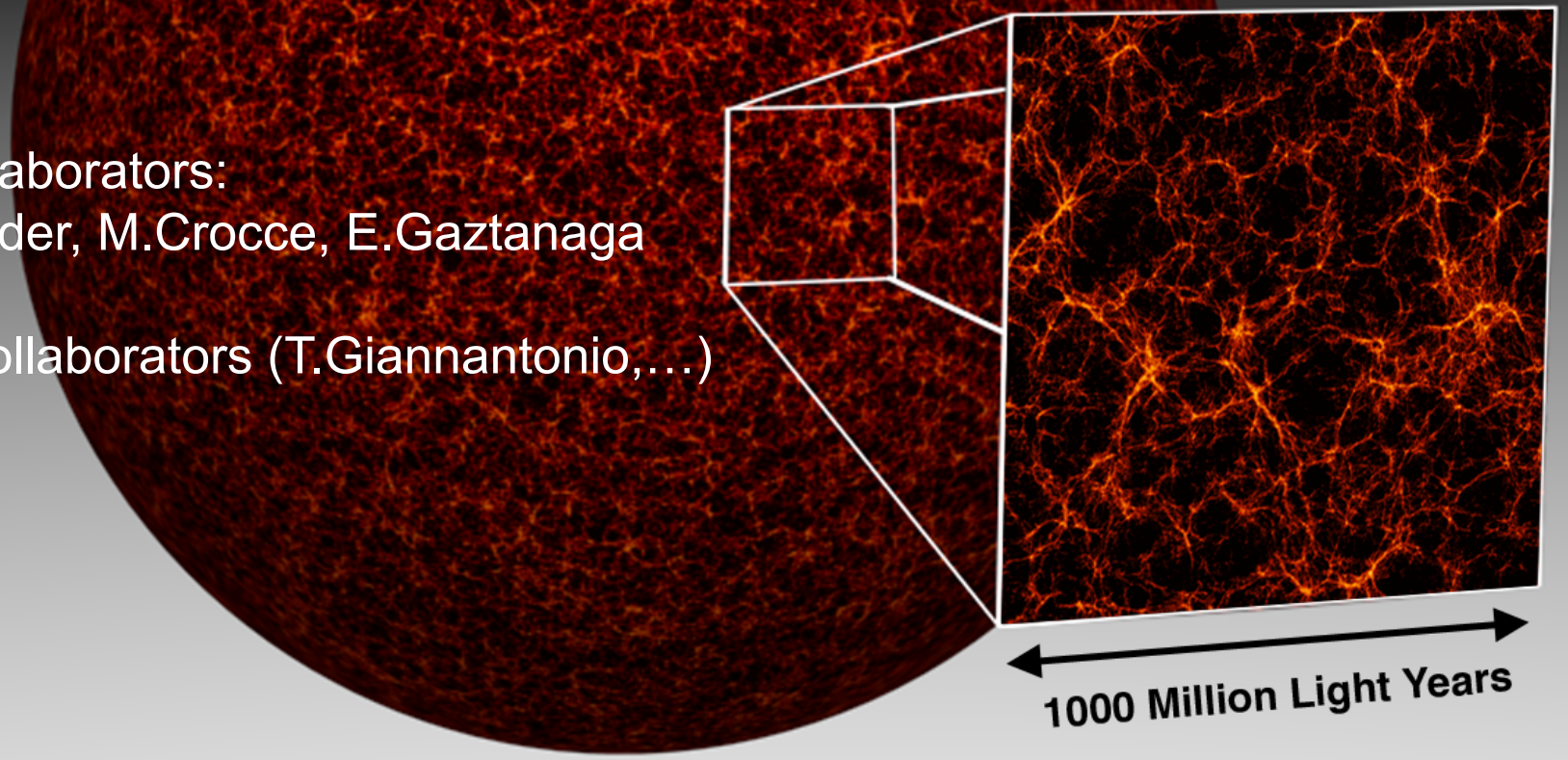
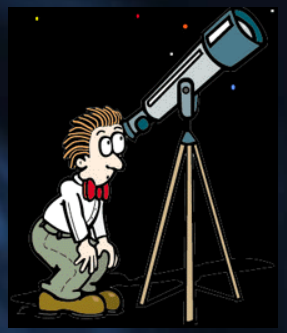
+ DES collaborators (T.Giannantonio,…)



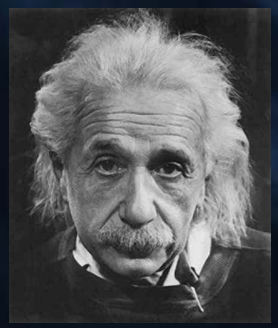
"Cosmic Triangle"



Observations

Theory

Numerical Simulations



Towards 1% accuracy in Dark-Matter statistics: Power Spectrum

(Courtesy of R.Smith)

Clustering on large-scales: using Perturbation Theory

- CDM Perturbation Theory:

Audren & Lesgourgues (2011): 1% precision for k<0.2 h/Mpc and z>2; 1% precision k<0.14 h/Mpc z=1. Released as part of CLASS

Crocce et al (2012): MPTBreeze: Fast code for evaluation of multi-point propagators: 2% precision for BAO scales; z<2.5 k<0.5 h/Mpc (LCDM)

Taruya et al (2012): REGPT-Fast: precision 1% for k<0.2 h/Mpc (WCDM)

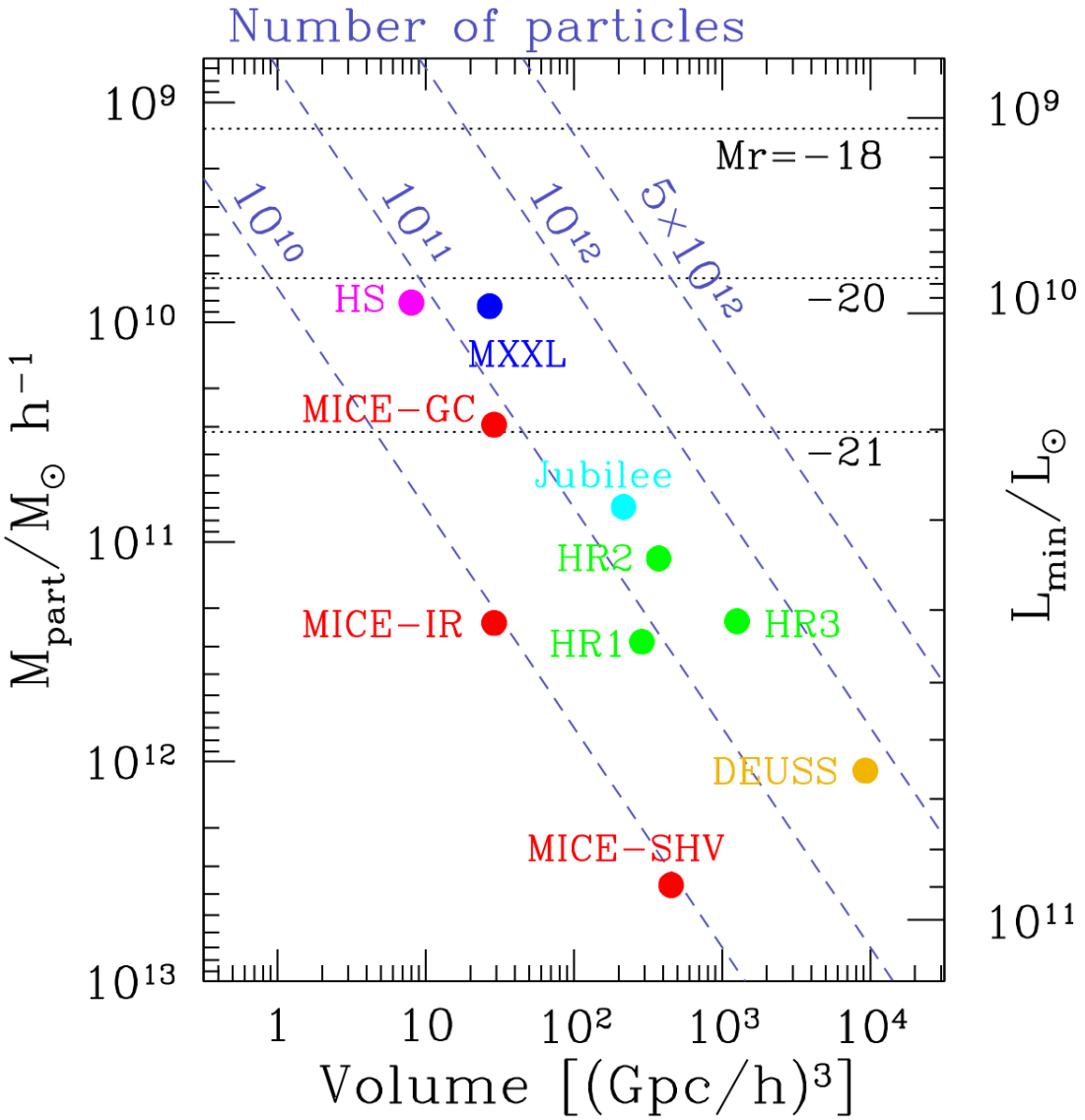
Analytic theory accurate enough (~1%) for BAO scales in real/redshift space

Beyond BAO scales (i.e r < 100 Mpc scales or k >0.2-0.3 Mpc^{-1}), harder to model with analytic theory…

→ Need for simulations to accurately model signal and covariance of observables

State of the art in Nbody simulations

MXXL: Angulo et al.
MICE: Fosalba et al.
Horizon Sim: Teyssier et al.
HR1,2,3: Kim et al.
DEUSS: Alimi et al.
Jubilee: Watson et al.



State of the art in Nbody simulations

Current simulations can model MilkyWay like galaxies (10^{10} $L_\odot$) over large volumes

MXXL: Angulo et al.
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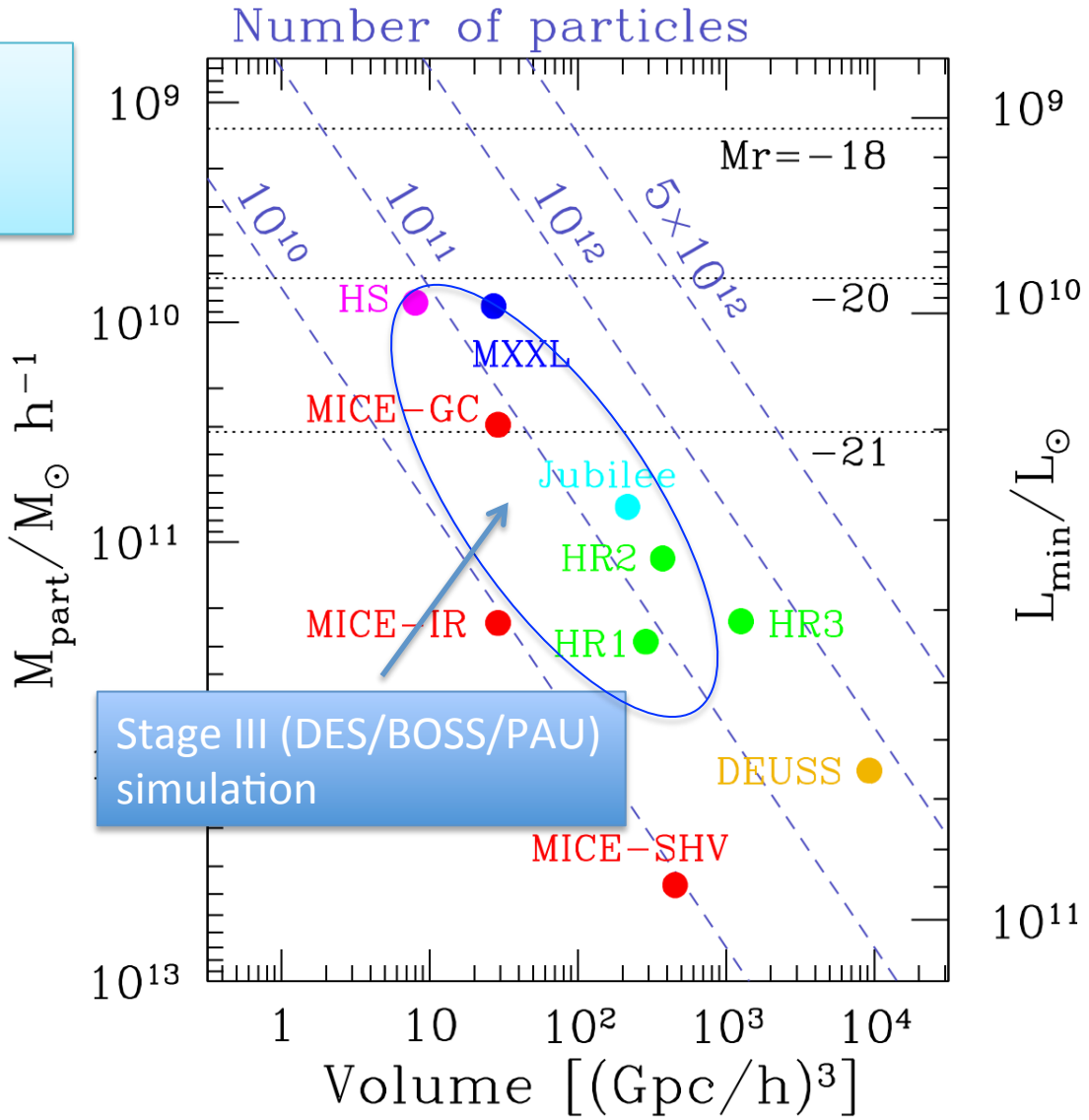

State of the art in Nbody simulations

MICE
Grand-Challenge
simulation

MXXL: Angulo et al.
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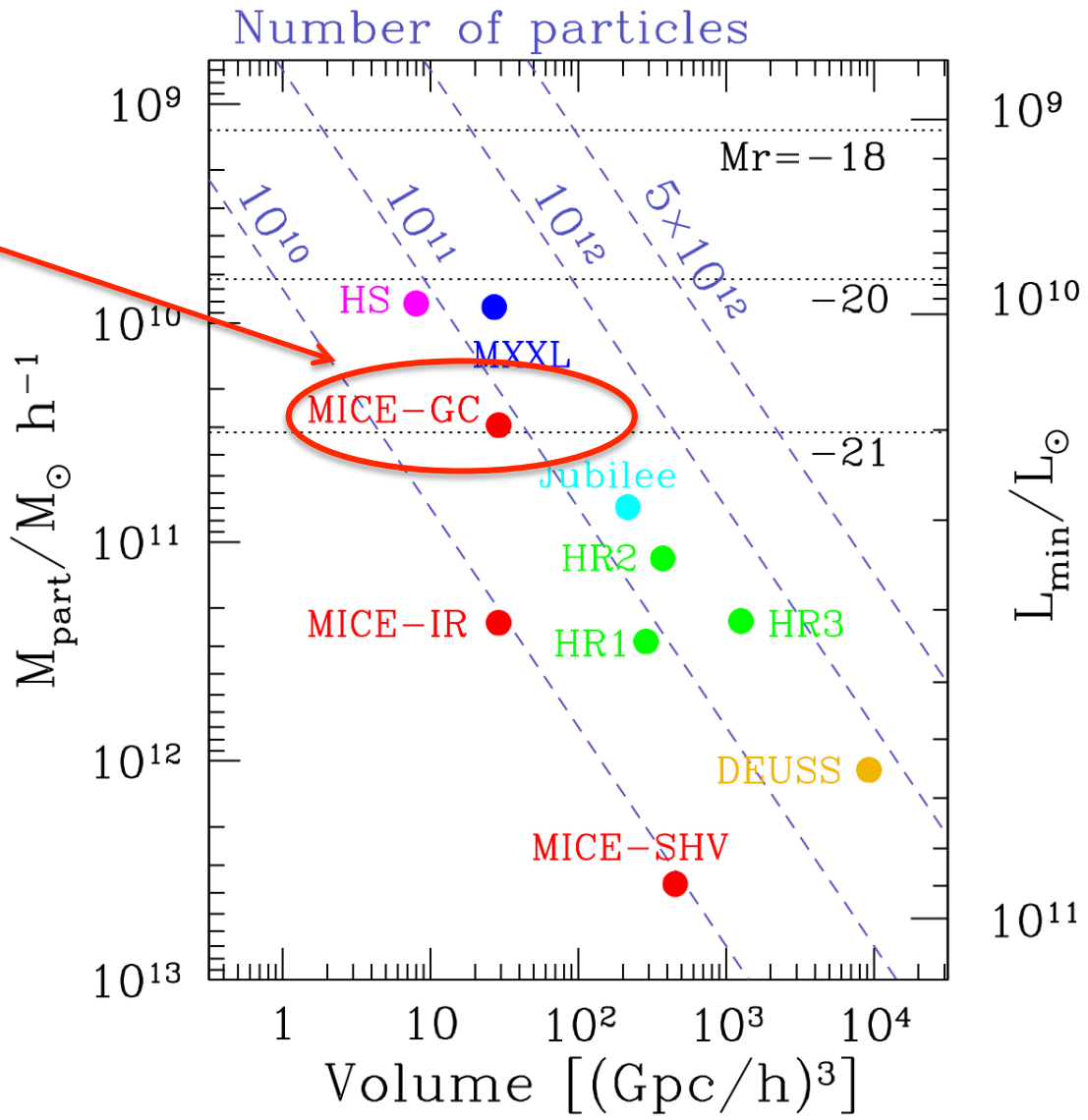


MICE

Marenostrum Institut de Ciències de l'Espai Simulations

project web: www.ice.cat/mice

What is MICE ?

➢ Project hosted at ICE to develop very large N-body simulations using the **Marenostrum** supercomputer (PRACE Tier-0) in Barcelona/Spain

 14+ million CPU hours allocated via open competition (since 2006)

 Used up to 4.000+ processors, 8 TB RAM

 GADGET2 code simulations with 10^9-10^{11} dark-matter particles in volumes ~ 1-500 Gpc^3

 ~50 Terabytes of simulated data stored at PIC (data storage center @ Barcelona) **PIC Team:** Carretero, Neissner, Tallada, Tonello

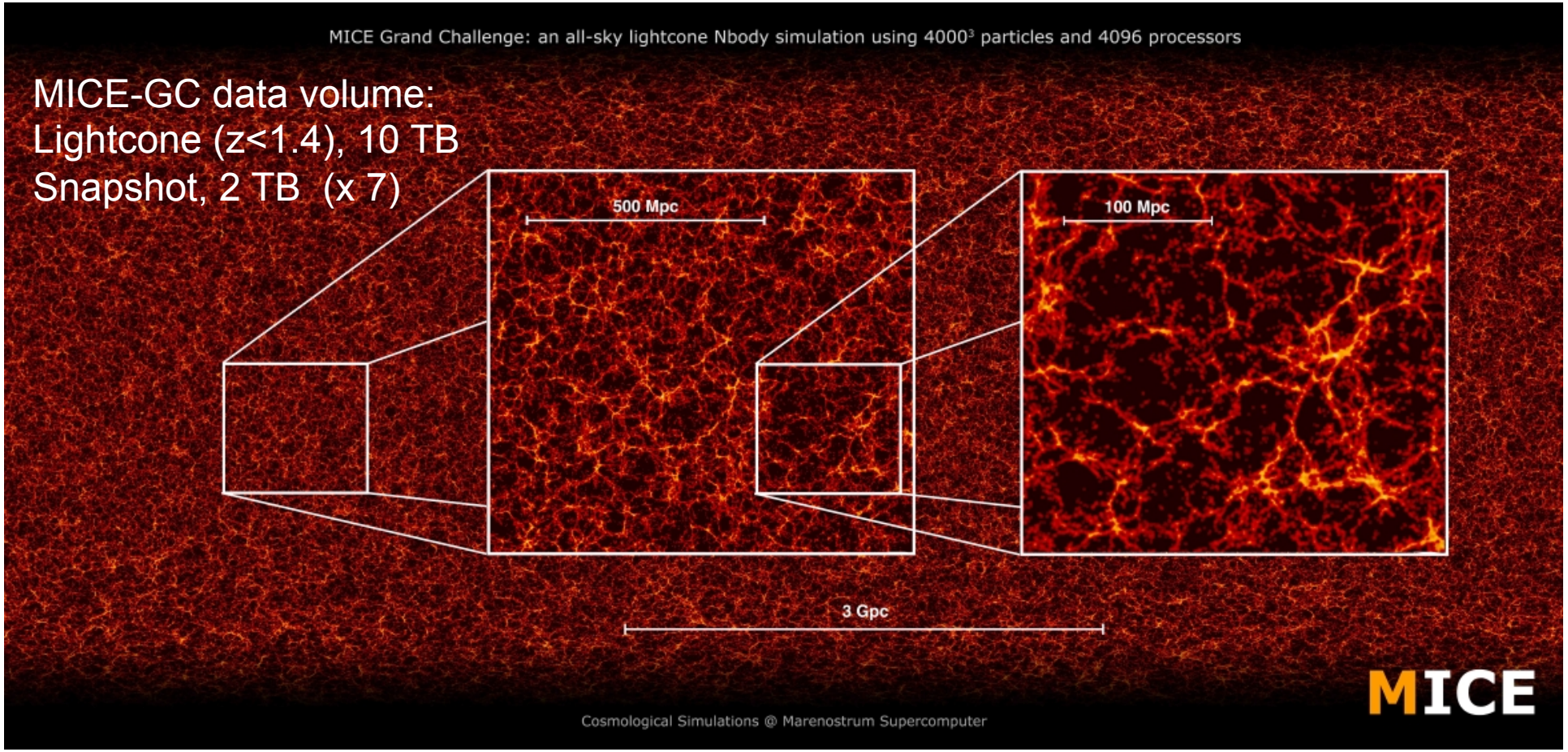
MICE Team: P.Fosalba, F.Castander, M.Crocce, E.Gaztañaga, M.Manera
Collaborators: A.Bauer, C.Bonnett, J.Carretero, K.Hoffman, A.Izard, A.Pujol, D.Reed, S.Serrano

MICE-Grand Challenge simulation

Developed at Marenostrum @ BSC, used Gadget2, 4100 cores, 3 M-hours

70 billion particles in a 3 Gpc/h box (50 kpc/h soft length)

Samples 5 decades in dynamic range



MICECAT: galaxy mock from MICE-GC

- ✓ Built on MICE *Grand Challenge* *simulation*
  70 billion particles, 3 Gpc/h box, $m_p=3\times10^{10}\ M_\odot$
- ✓ 3D Lightcone (up to z=1.4), 2D LC up to z=100 (all sky CMB Lensing map)
- ✓ FoF halos with b=0.2: 150 million halos per octant, for $N_p>10$
- ✓ 1 octant (5000 sq.deg.), up to z<1.4, with 200 Million HOD galaxies.
  we can model galaxies down to $M_r < -18$

  Adjust HOD parameters:
  ★ Match LF and color-magnitude diagram to SDSS (low-z)
  ★ Observed SDSS clustering vs. Luminosity and Color

- ✓ **Data publicly available @ Cosmohub.pic.es:**
  * magnitudes (multiple bands), halo mass, photo-z, SEDs, colors, shapes,..
  * Lensing properties for galaxies: Convergence, Shear, Lensed positions

MICE-GC simulation papers

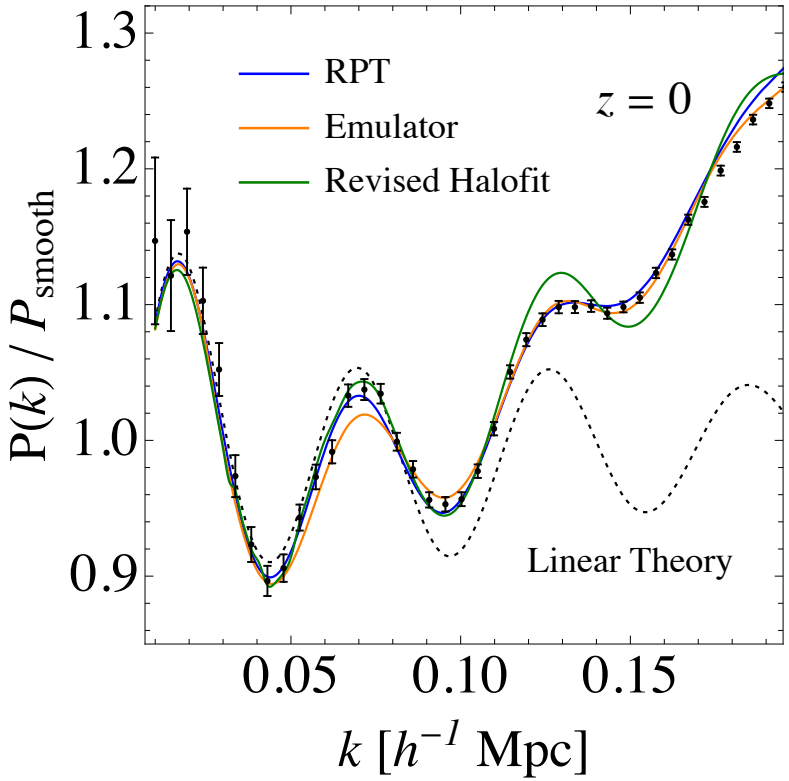
Paper I: Dark-matter clustering [Fosalba et al. 2015a, **MNRAS, 448, 2987**]
Paper II: Halo and galaxy clustering [Crocce et al., **arXiv:1312.2013**]
Paper III: Galaxy lensing mocks [Fosalba et al. 2015b, **MNRAS, 447, 1319**]

HOD galaxy mock method [Carretero et al. 2015, **MNRAS, 447, 646**]
Higher-order clustering [Hoffmann et al. 2015, **MNRAS, 447, 1724**]

Dark-Matter clustering: large-scales

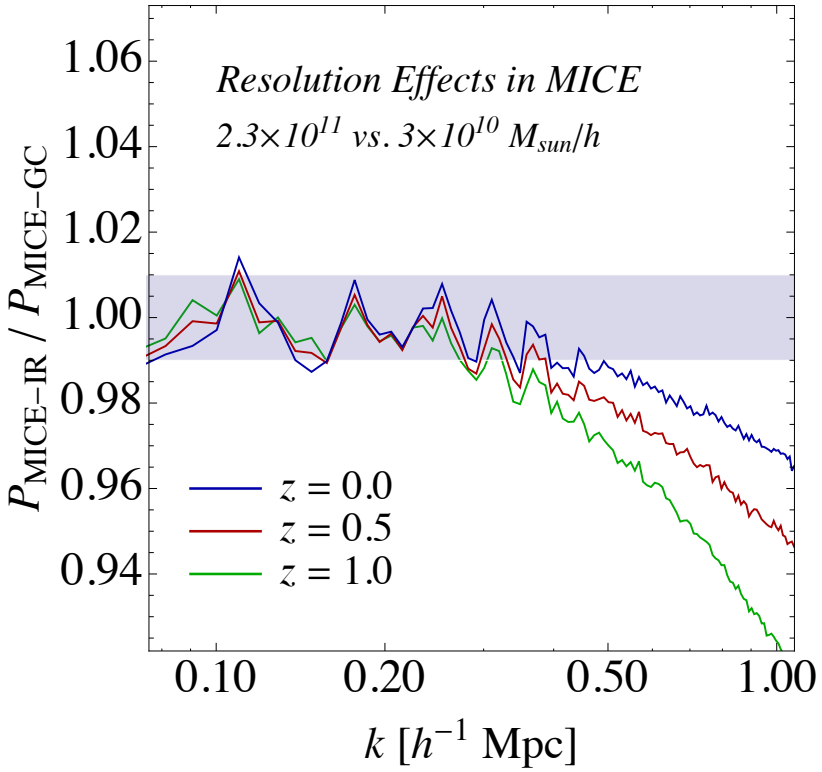
Fosalba et al 2015 [MNRAS, 448, 2987]

P(k) at BAO scales



✓ Agreement with hi-res numerical fits (Heitmann et al 2013; Takahashi et al 2012) within **2%** accuracy

Mass Resolution Effects



✓ **5-10%** resolution effects at k>1 h/Mpc

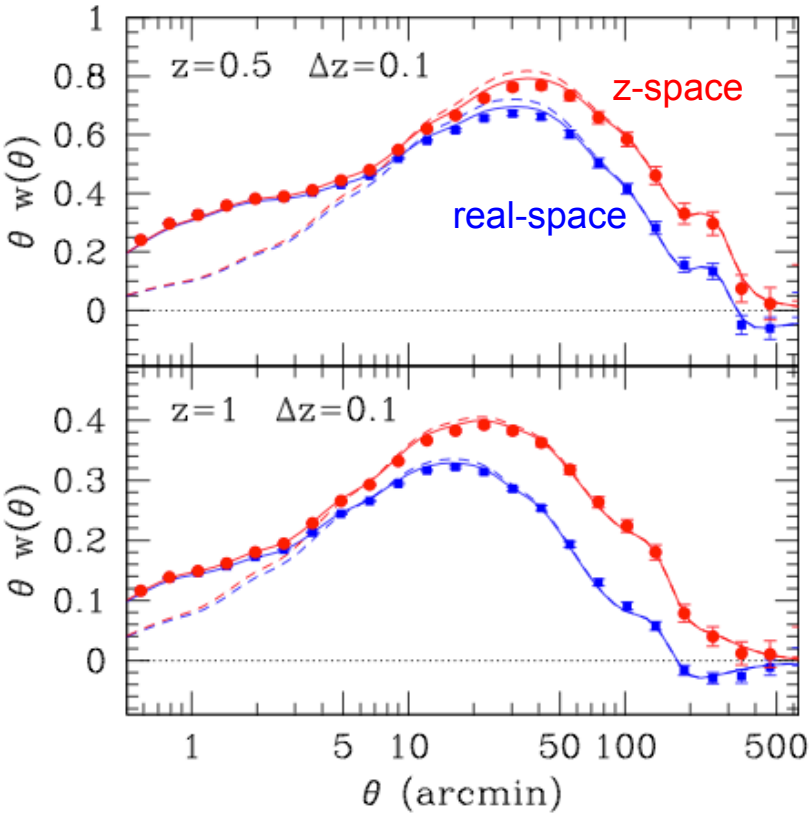
✓ increase with redshift

Similar effects seen in the 2PCF and 3PCF

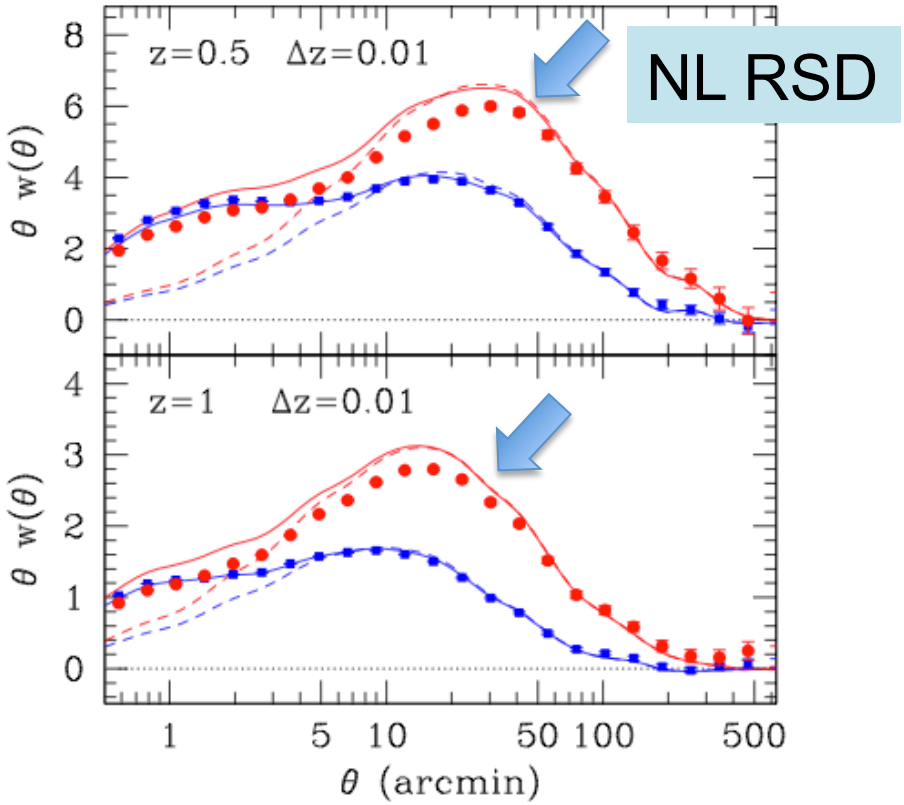
Dark-Matter clustering: redshift space distortions

Fosalba et al. 2015 [MNRAS, 448, 2987]

Redshift accuracy of **photometric** galaxy surveys (e.g, DES)



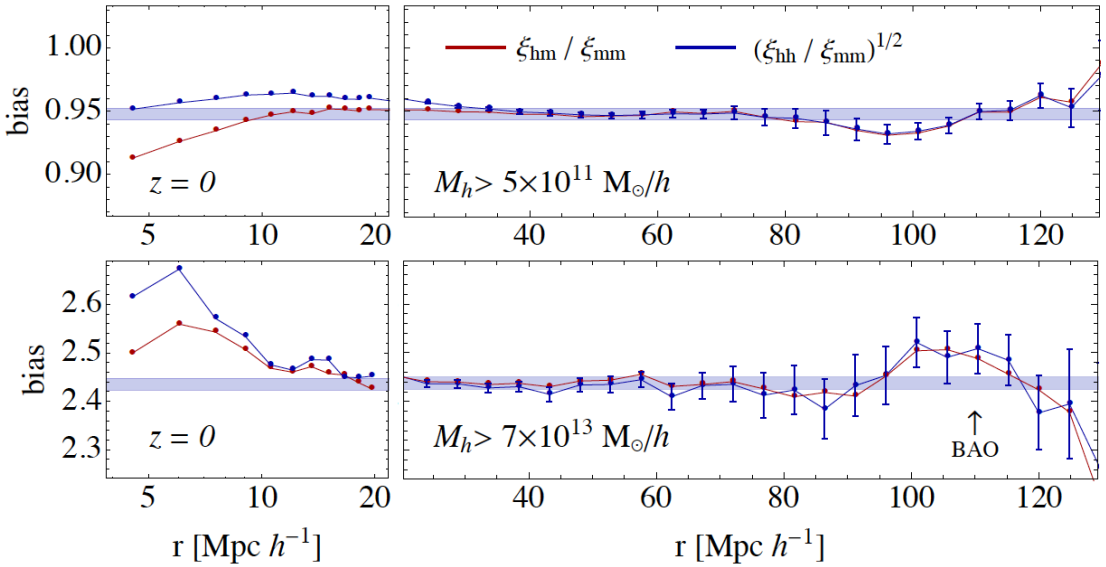
Redshift accuracy of **spectroscopic** surveys (BOSS/DESI)



- RSD effects more important as redshift accuracy of galaxy survey increases
- **Non-linear RSD** effects visible at 1 deg. Scales, even at z=1 (**~20 Mpc/h**)

Halo and Galaxy bias: small and large scales

Crocce et al. [MNRAS in press, **arXiv:1312.2013]**



Halos

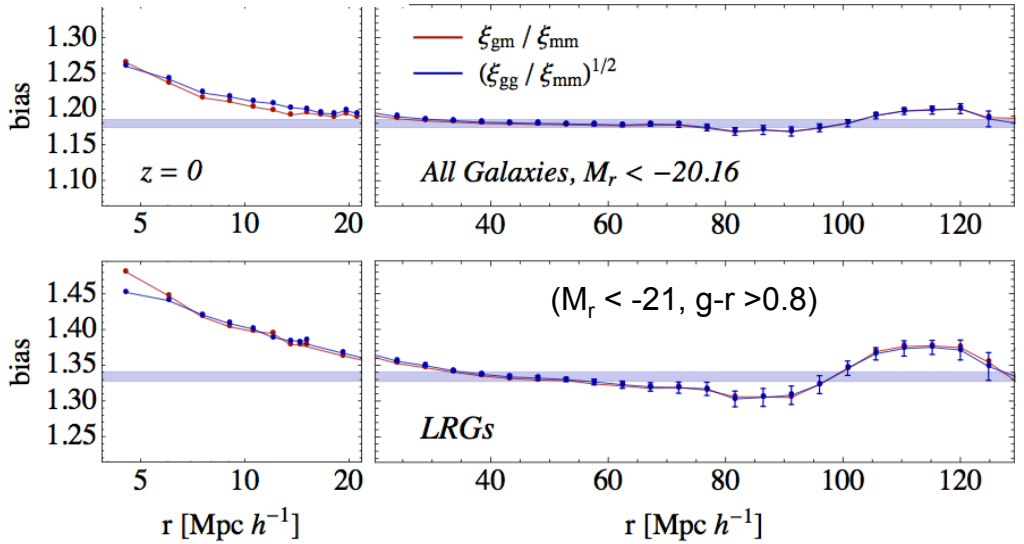
Large scales (> 20 Mpc/h):
Decrement (2%) for low mass,
excess (5%) for large mass halos

Small scales (< 20 Mpc/h):
bias becomes steadily scale dependent.
b_2 changes sign as mass increases

Galaxies
(centrals + satellites)

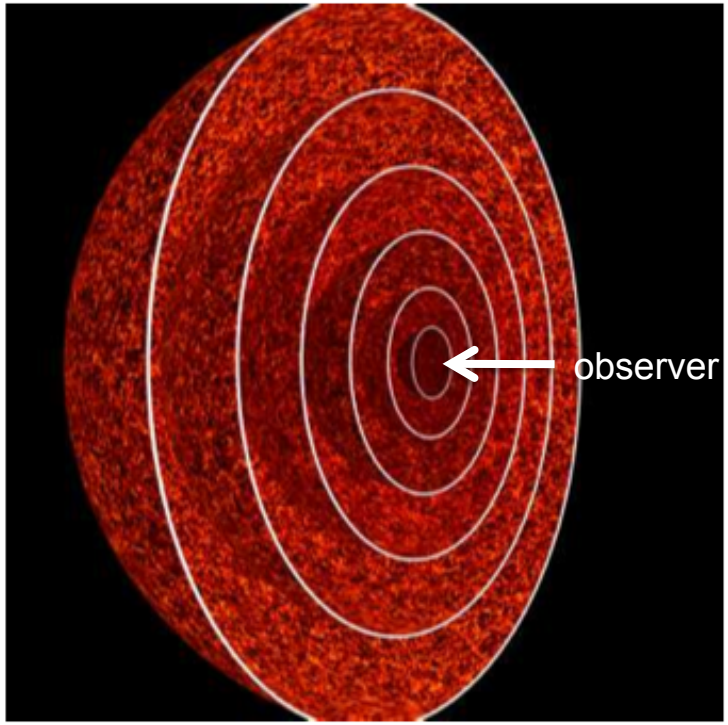
3D (spectro-z survey)

Scale dependence:
- ✓ similar to halos on large-scales
- ✓ NL bias always positive



Weak Lensing observables

"The onion universe: all sky light-cone simulations in spherical shells"
Fosalba et al. 2008, [MNRAS, 391, 435]



For the convergence field:

$$\kappa(\theta) = \frac{3H_0^2\Omega_m}{2c^2} \int dr\ \delta(r,\theta) \frac{(r_s - r)r}{r_s\ a}$$

..discrete sum over
Lightcone shells…

$$\kappa(i) = \frac{3H_0^2\Omega_m}{2c^2} \sum_j \delta(i,j)\ \frac{(r_s - r_j)r_j}{r_s a_j}\ dr_j$$

- Valid *in the Born approximation (ie, linear/uncorrelated deflections)*
  1% accurate at arcmin scale (as compared to full ray-tracing sims)

- *Simple relations (in harmonic space) to model other lensing observables (shear, flexion, etc.)*

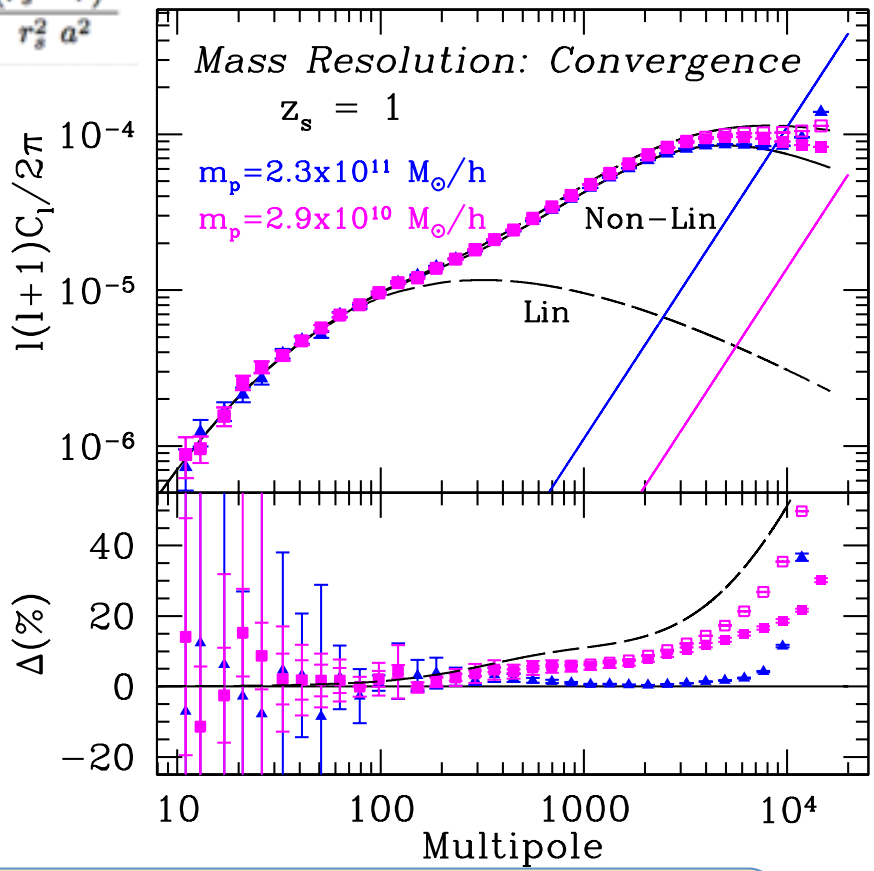
Weak Lensing: Convergence power

Fosalba et al. 2015 [MNRAS, 447,1319]

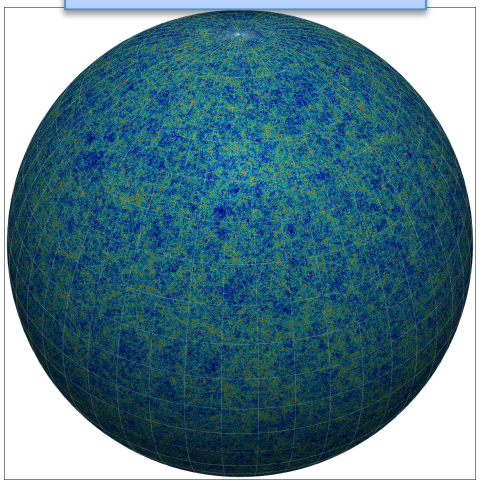
$$C_\ell(\kappa) = \frac{9H_0^4\Omega_m^2}{4c^4} \int dr\ P(k,z)\frac{(r_s-r)^2}{r_s^2\ a^2}$$

Symbols - MICE
MICE-IR
MICE-GC

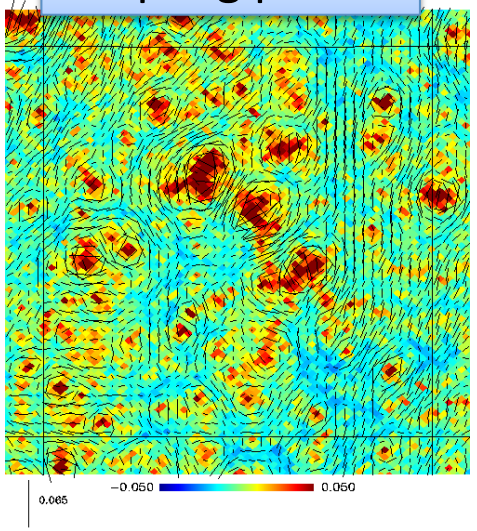
Lines - Fits
Solid: Smith et al 2003
Dashed: Takahashi 2012



All-sky maps



1 sq.deg patch



Lensing Halos < 3x10^{11} M$_\odot$ give 10-20 % contribution to lensing power at < 10 arcmin scales (multipoles > 1000)

Fosalba et al. 2015

MICE simulations for DES-SV

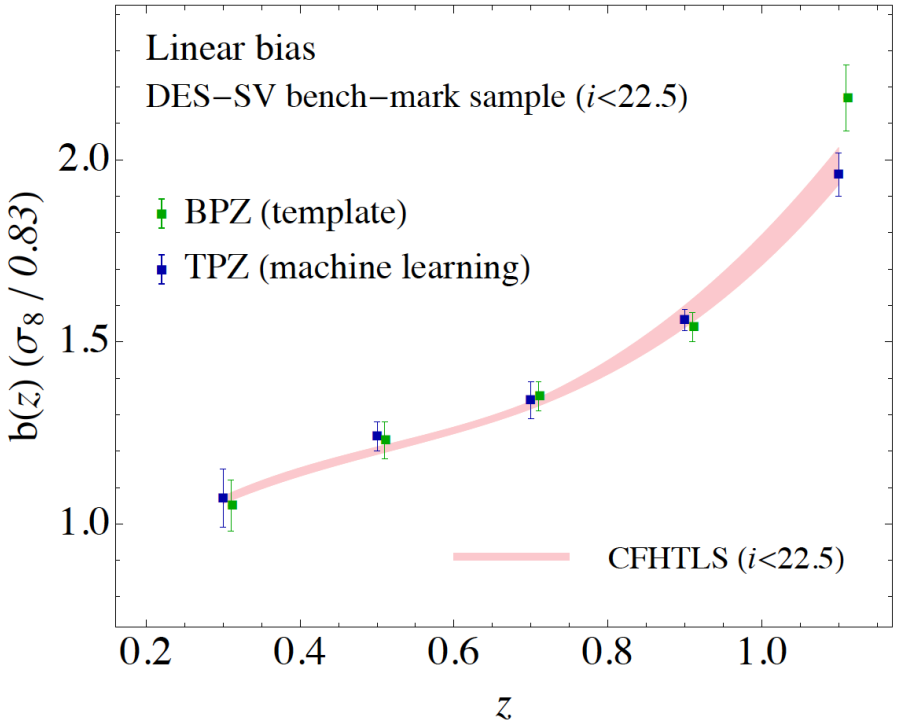
2point galaxy clustering [Crocce et al. 2015a, **arXiv:1507.05360**]

DESxCMB lensing [Giannantonio et al. 2015, **arXiv:1507.05551**]

DES-SV clustering: data vs simulations

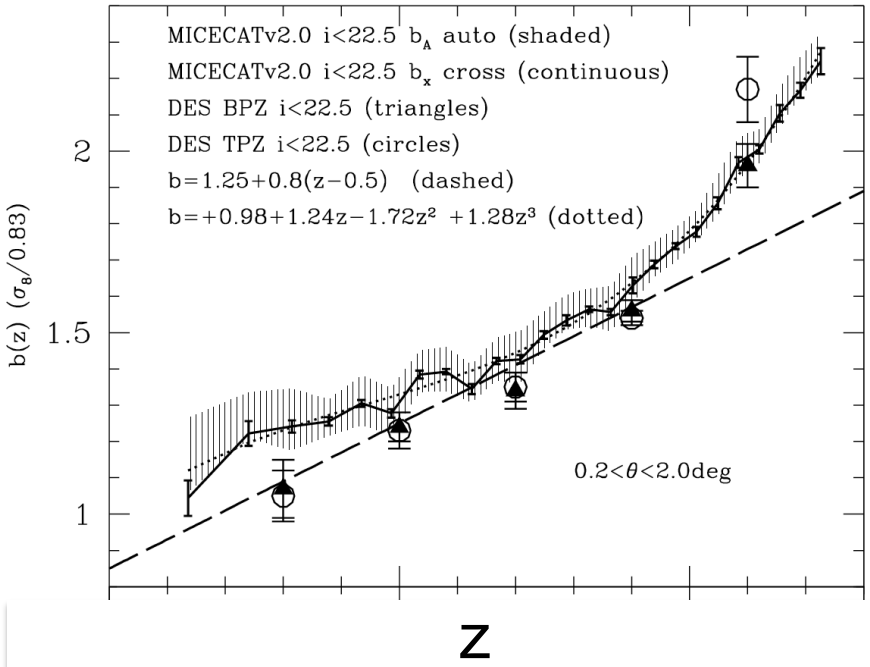
Crocce et al. 2015, arXiv:1507.05360

DATA: b(z) in 5 z-bins, width Δz =0.2



DATA vs SIMULATIONS

MICE: shaded region



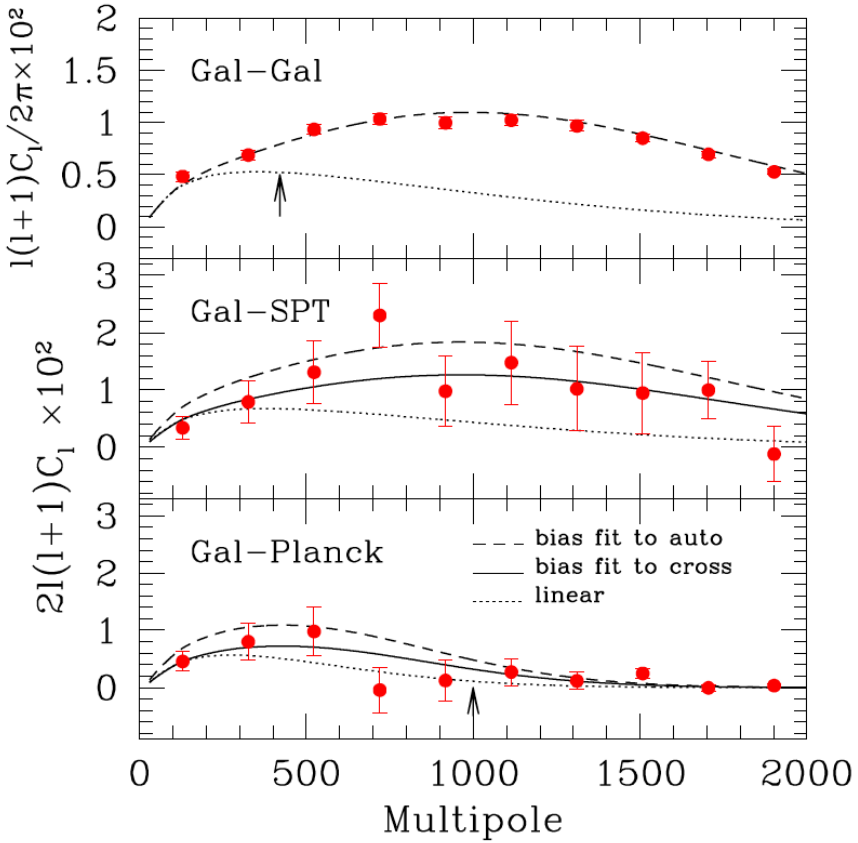
- Steep raise at z>1 expected from HOD mocks (~ flux-limited surveys)
- Larger bias expected at low-z (systematics? sample variance ?)

DESxCMB Lensing: data vs simulations

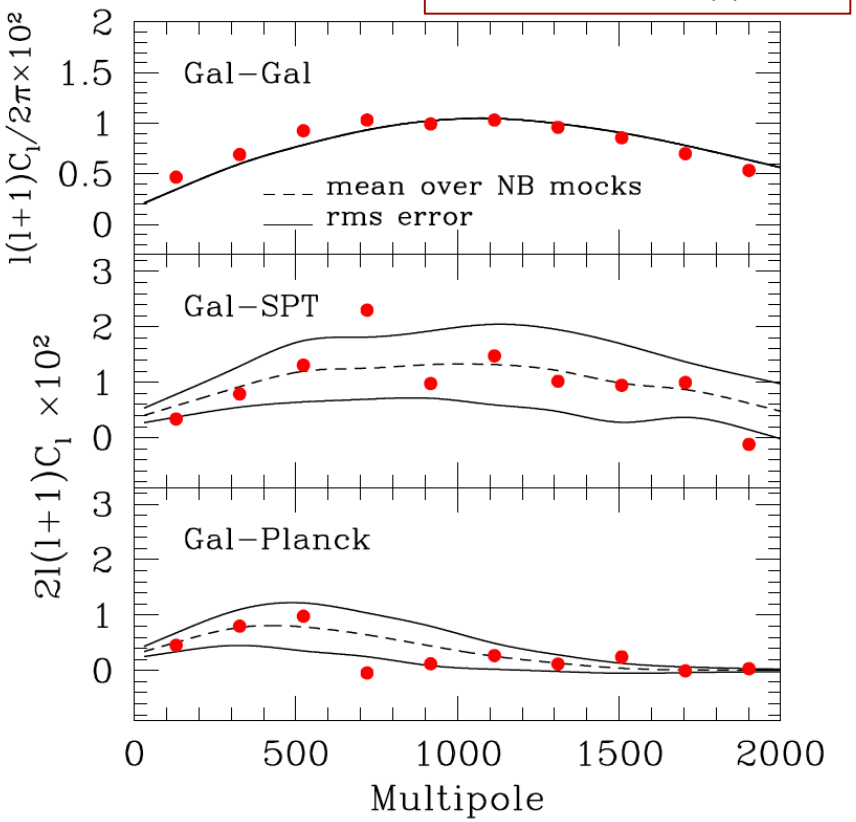
Giannantonio, Fosalba et al. 2015, arXiv:1507.05551

100 mocks (SV patches out of all-sky simulations) Sampling "galaxies" from the DM distribution in the LC with the DES n(z)

DATA full sample 0.2< z <1.2



SIMULATIONS

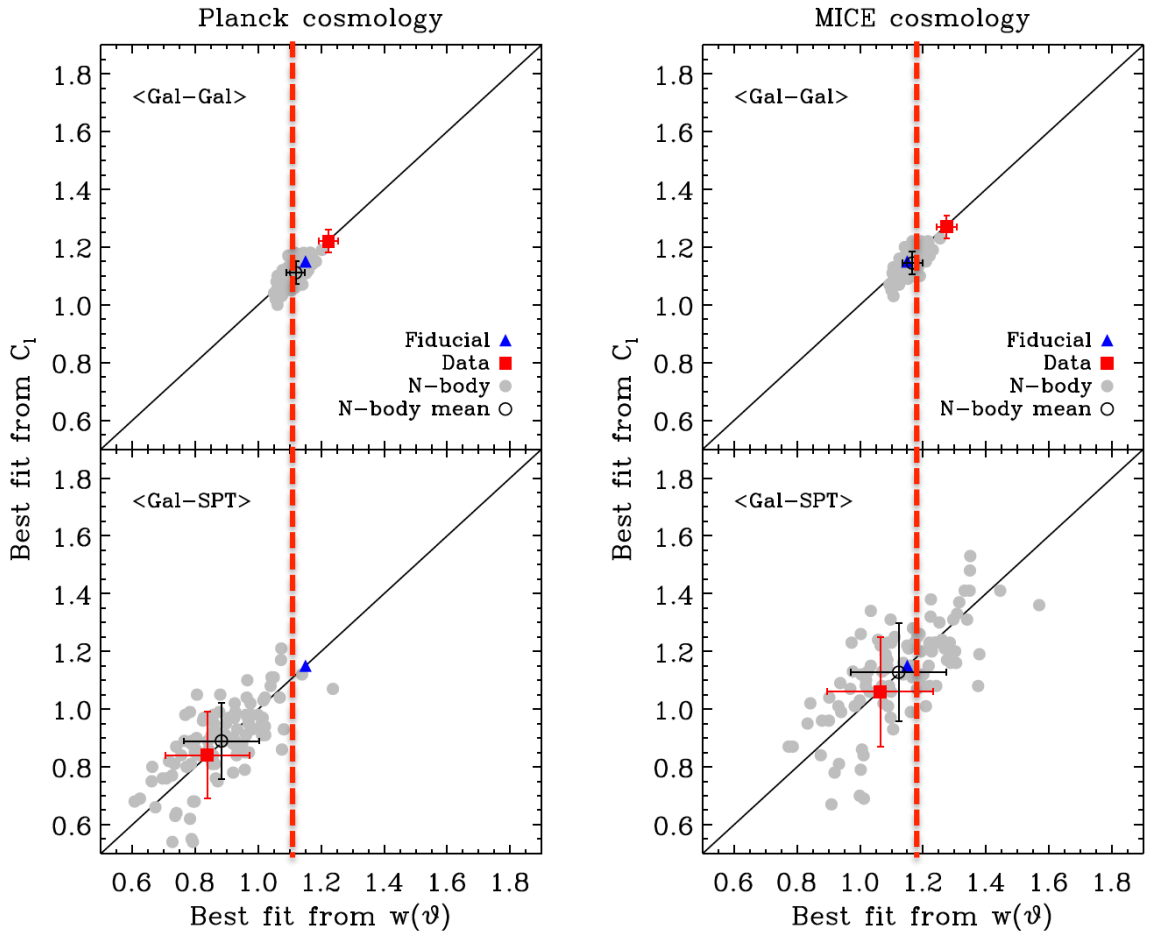


- Galaxy ACF is consistent with measurement from mocks
- Consistently lower galaxy bias from Gal-CMB reproduced by sims

DESxCMB Lensing: mismatch ACF/CCF

Giannantonio, Fosalba et al. 2015, arXiv:1507.05551

~2-sigma tension



Full-sample
0.2 < z <1.2

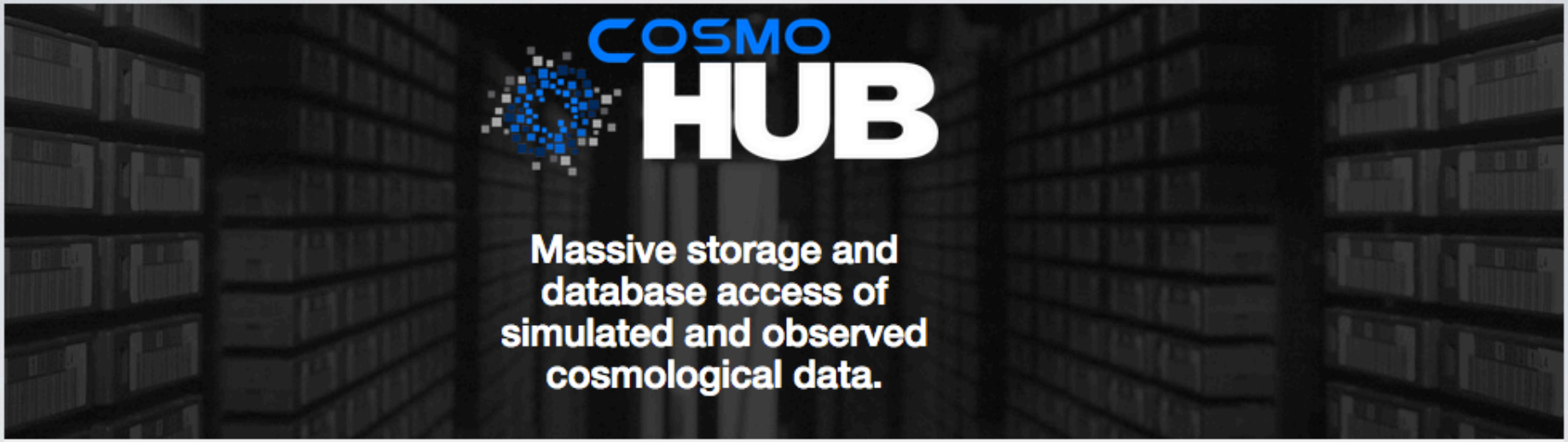
< 1-sigma tension

[sigma is DESxCMB stat. errorbar]

- Cross-consistency between linear galaxy bias from ACF and CCF follows mocks
- Mismatch between ACF/CCF depends on assumed underlying cosmology…*suggests DESxSPT prefers lower values of $\sigma_8\Omega_m$ than best-fit Planck2015 cosmology*

The MICE light-cone halo and galaxy public catalog

http://cosmohub.pic.es



Supporting projects:

PAU

Euclid consortium esa

MICE
Marenostrum Institut de Ciències de l'Espai Simulations

DARK ENERGY SURVEY

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CosmoHUB Statistics

- 180 users
- 330 batch downloads
- 150 prebuilt downloads
- 182 GB disk space
- 313.805.516 objects

P.Fosalba

MICE

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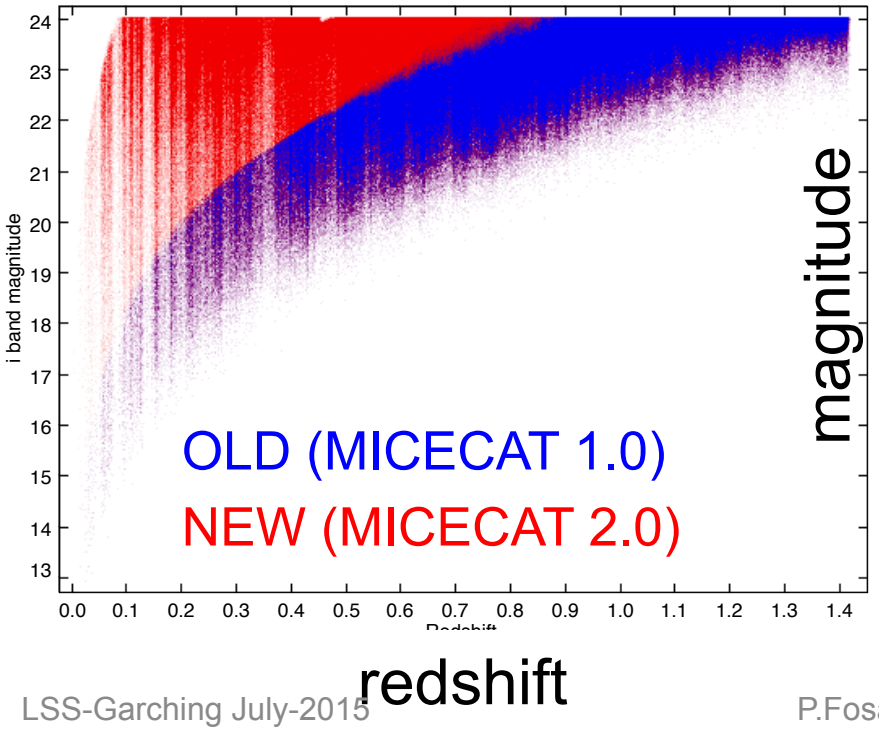
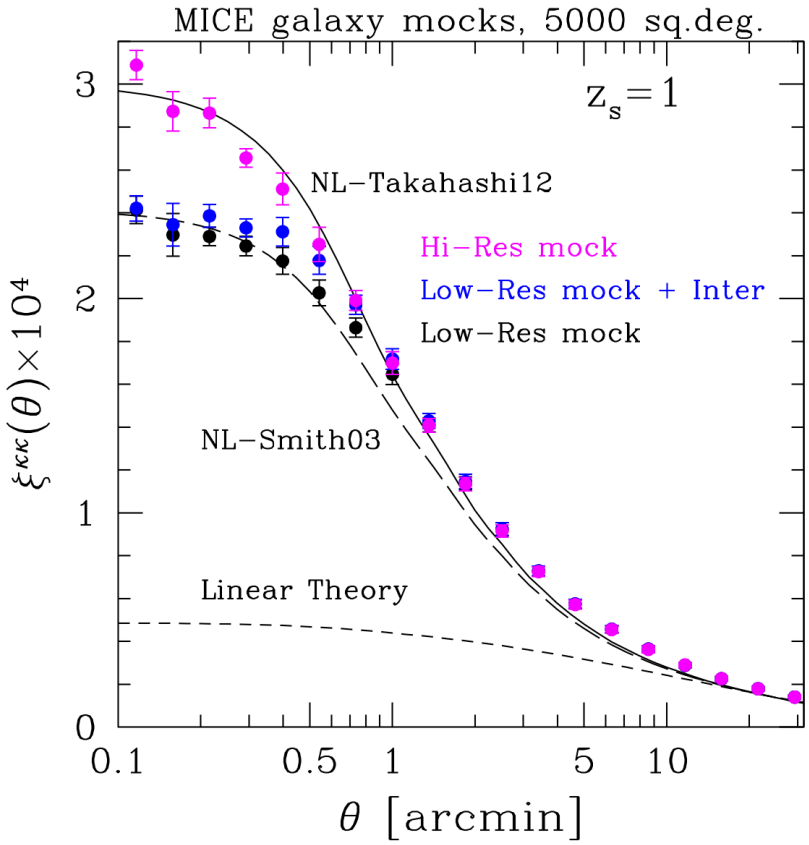
MICE galaxy mocks

Recent developments

- ✓ Increased completeness: i<24 to z=1.4
- ✓ Improved lensing resolution (< 1 arcmin)
- Deeper: 3D lightcone to z=3 (ongoing, MICECAT 3.0)
- Intrinsic alignments (ongoing, MICECAT3.0)





Back-up Slides

HOD galaxy assignment

Luminosity We populate halos with one central and maybe some satellite galaxies (HOD) $\langle N_{sat} \rangle = (M/M_1)^{\alpha}$
Luminosities set to match the r - band luminosity of SDSS

Color We assign (g-r) color using the color bi-modality at fixed M_r

Clustering We place centrals at the halo centers and satellites following an NFW profile with bulk + virial velocity decomposition.
Tune HOD by computing projected correlation function as a function of color and magnitude and comparing with observations.