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&

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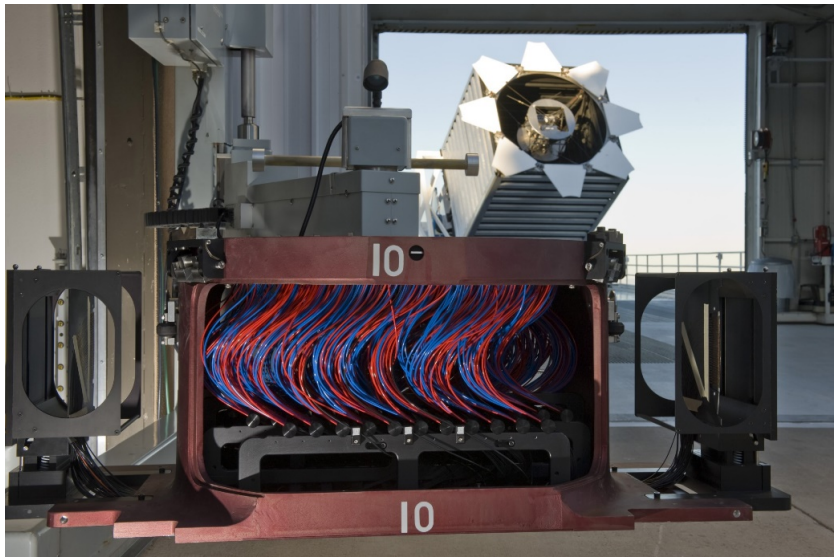
On behalf of the eBOSS clustering working group

QSO clustering with the SDSS-IV eBOSS survey

28th Rencontres de Blois

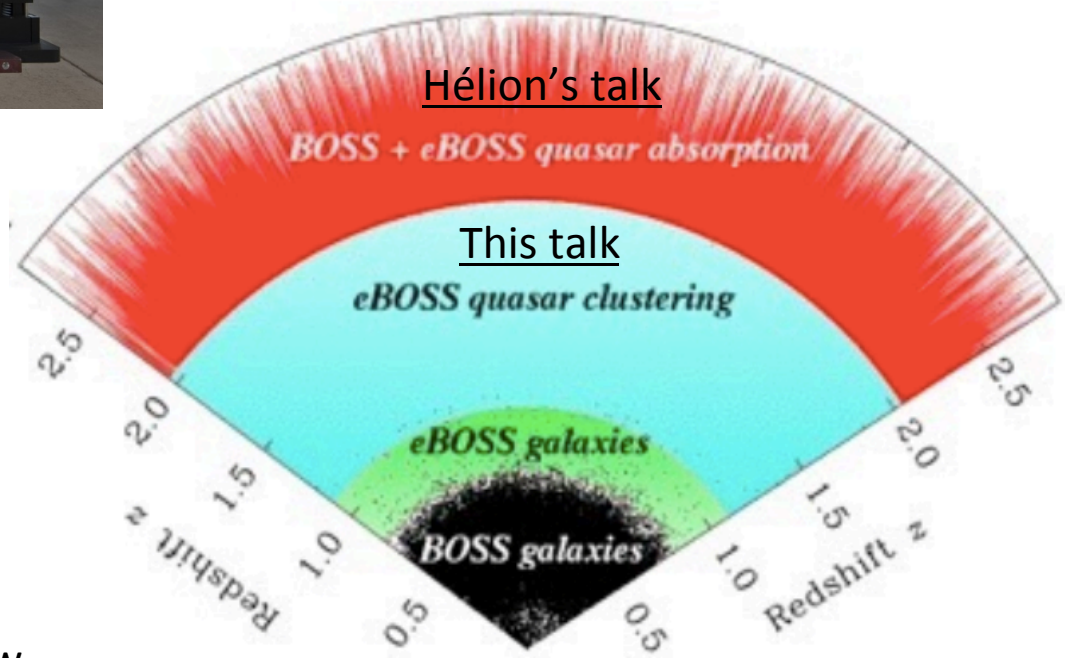
Particle Physics and Cosmology

SDSS-IV eBOSS survey



Data SDSS-IV

- 2.5m telescope, New Mexico, USA
- Survey: 2014-2019
- Spectrograph eBOSS

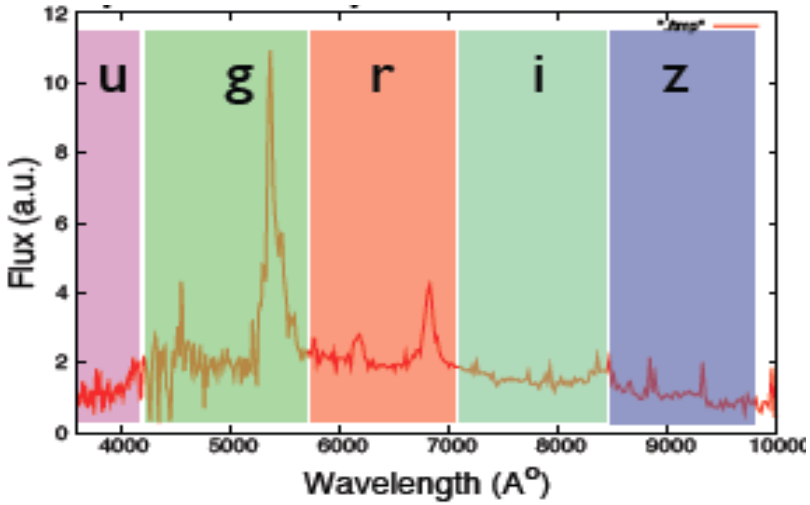


3D matter distribution

Different tracers

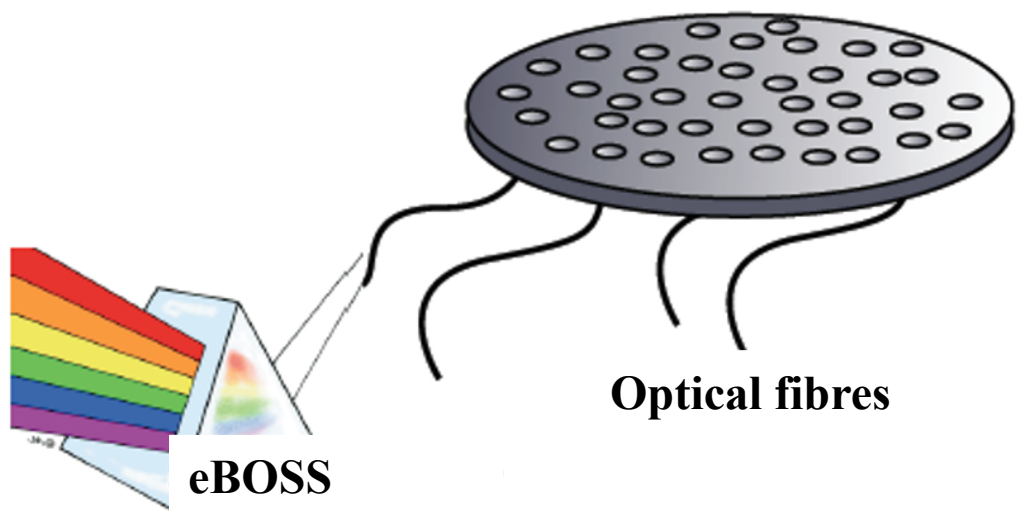
- Luminous red galaxies (LRGs): 350,000 at $z > 0.6$
- Emission line galaxies (ELGs): 190,000 at $0.6 < z < 1.0$
- Low-Redshift Quasars (QSOs): 470,000 at $0.9 < z < 2.2$
- Lyman-α forest (Lyα): 50,000 new, re-ob 70,000

SDSS-IV eBOSS spectrograph



Targets

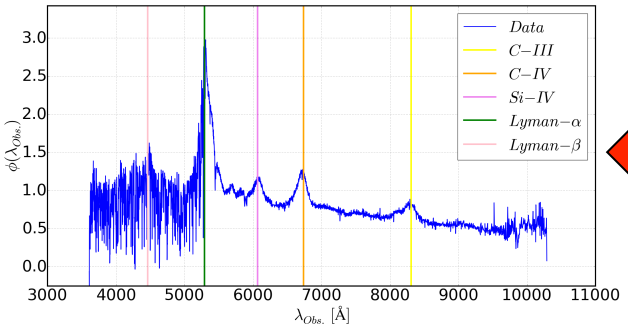
SDSS J112253.51+005329.8
SDSSp J120441.73-002149.6
SDSSp J130348.94+002010.4
SDSSp J141205.78-010152.6
SDSSp J141315.36+000032.1
....



Optical fibres

eBOSS spectrograph

Spectra



Clustering with eBOSS

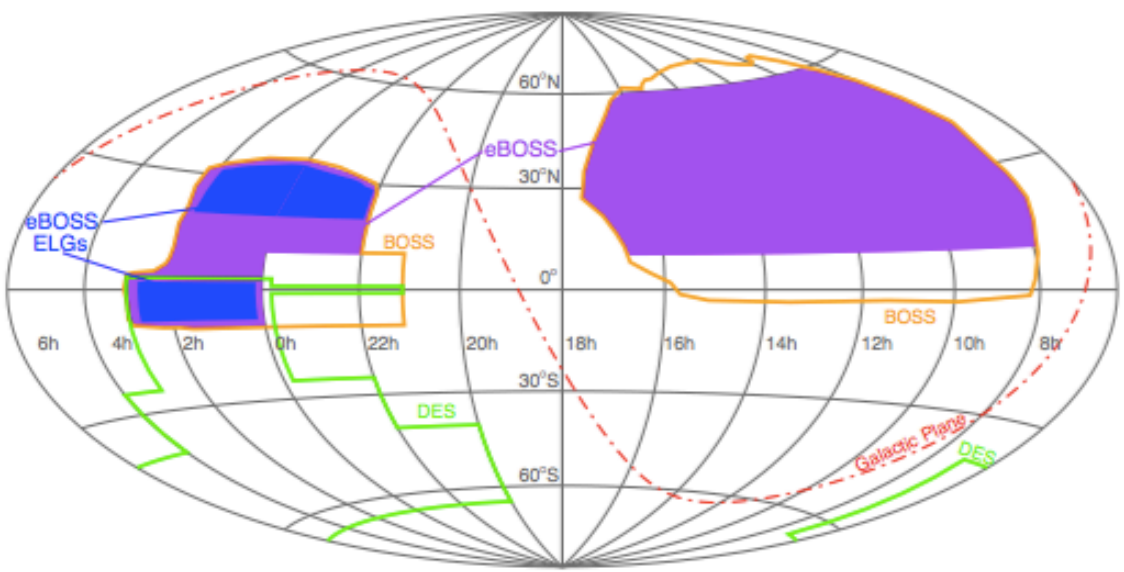
2-point correlation function ξ

Clustering strengh = number of pairs of galaxies (or other tracers) beyond random

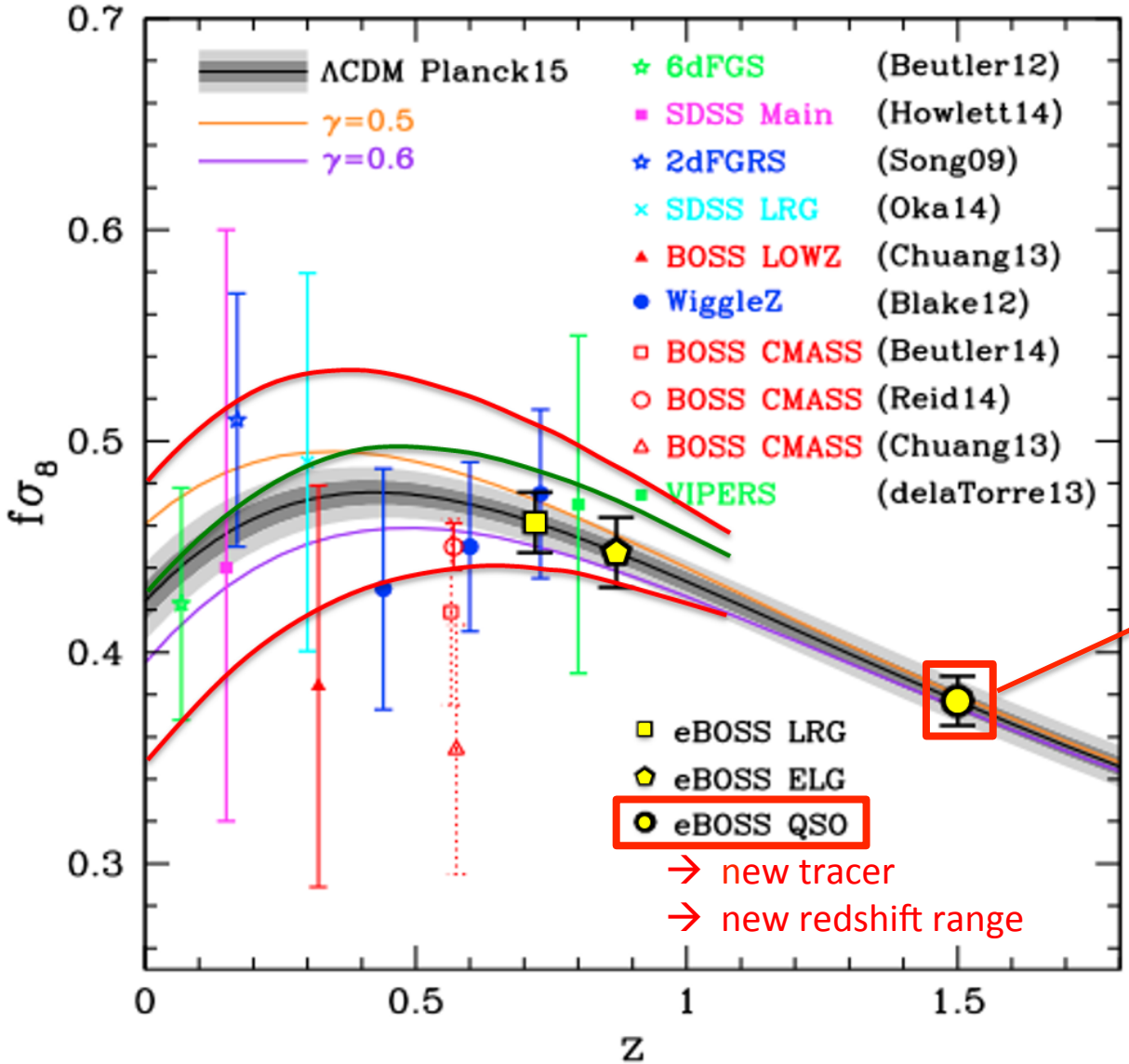
$$dP = \rho_0^2 \left[1 + \xi(r)\right] dV_1 dV_2$$

Biased tracers: $\xi_{tracer} = b^2\, \xi_{matter}$

Tracer name	density [deg^{-2}]	area [deg^2]	redshift range	BAO α [%]	growth rate $f\sigma_8$ [%]	bias systematic
LRG	40	7500	$0.6 < z < 0.9$	1.0	3.1	<0.5%
QSO	70	7500	$0.9 < z < 2.2$	1.7	3.1	
Ly$_\alpha$ QSO	8	7500	$2.15 < z < 3.15$	1.1		
ELG	150	1500	$0.7 < z < 1.2$	2.0	3.7	<0.2%

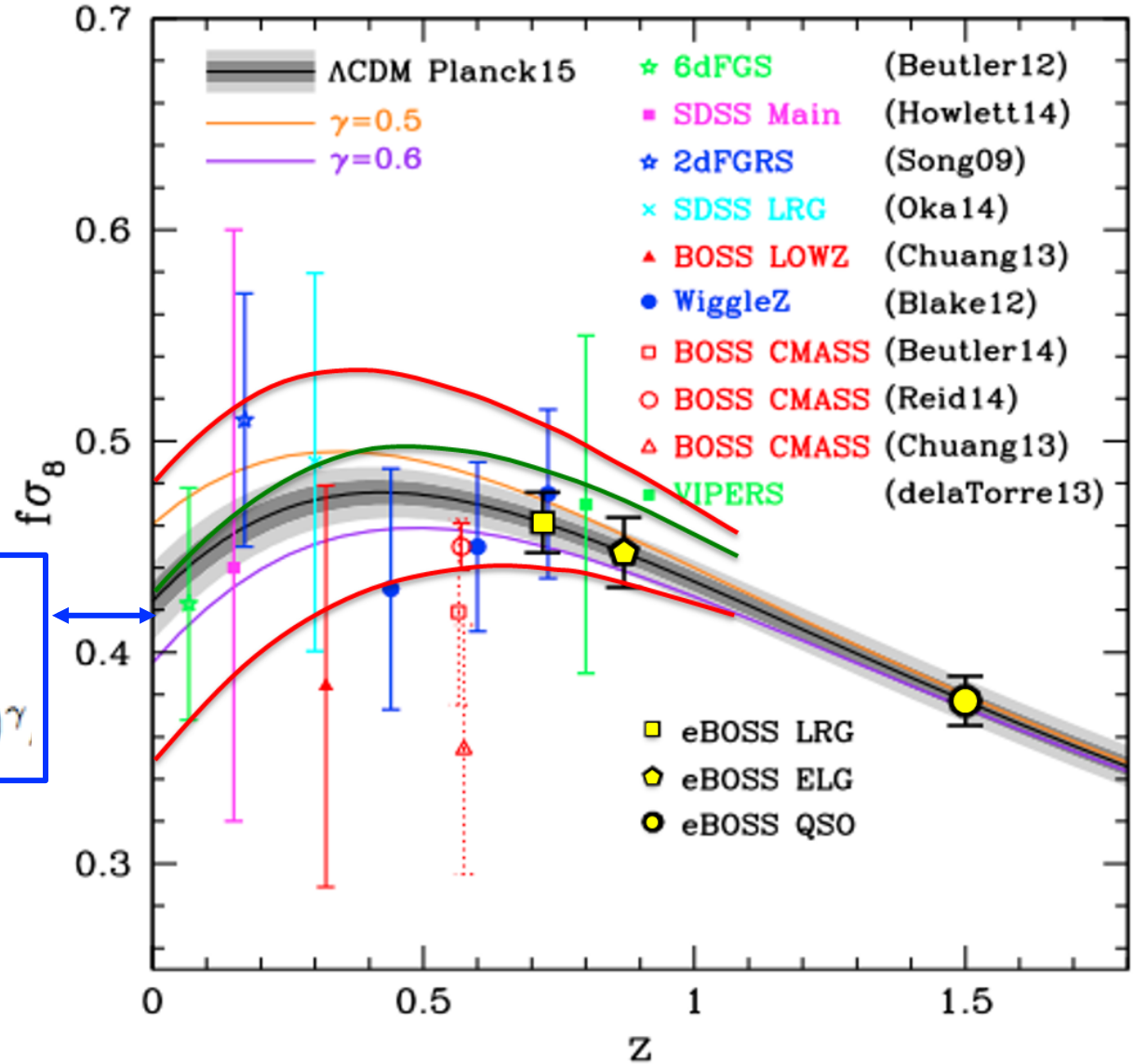


eBOSS RSD measurements



Expected precision with eBOSS

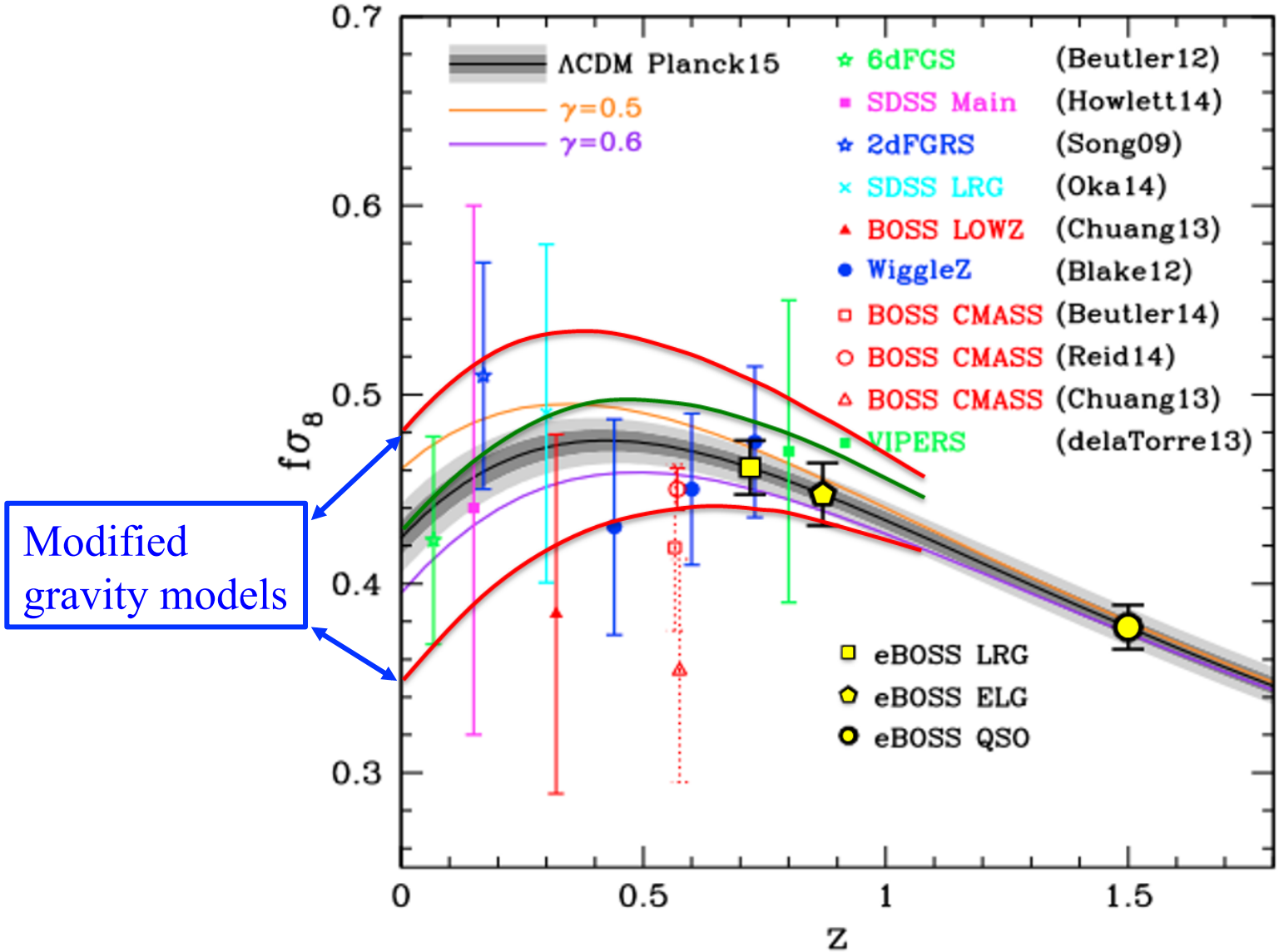
eBOSS RSD measurements



General relativity

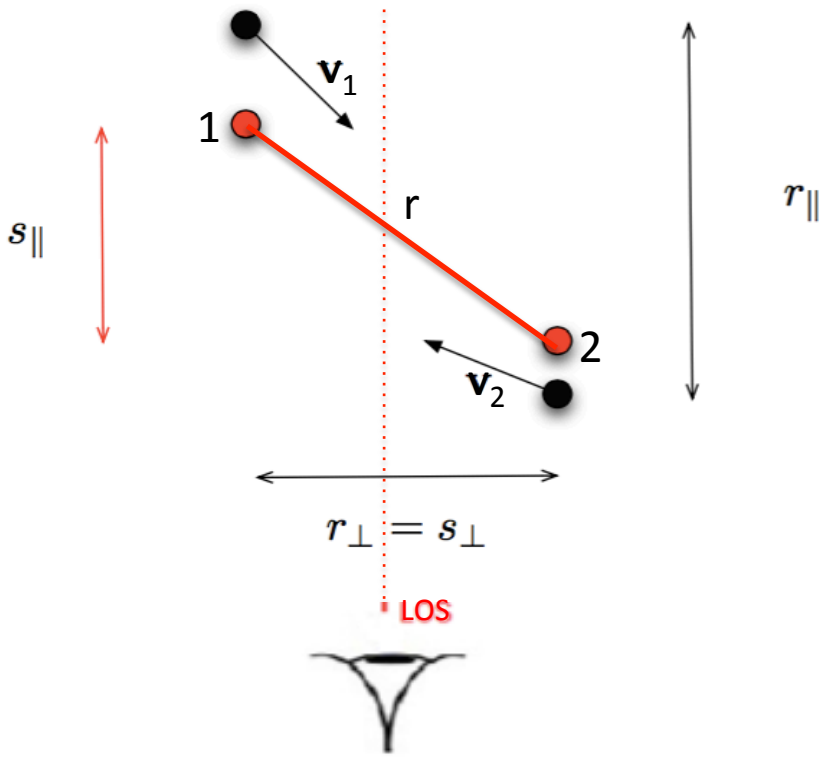
$f(a) = \Omega_m(a)^\gamma$

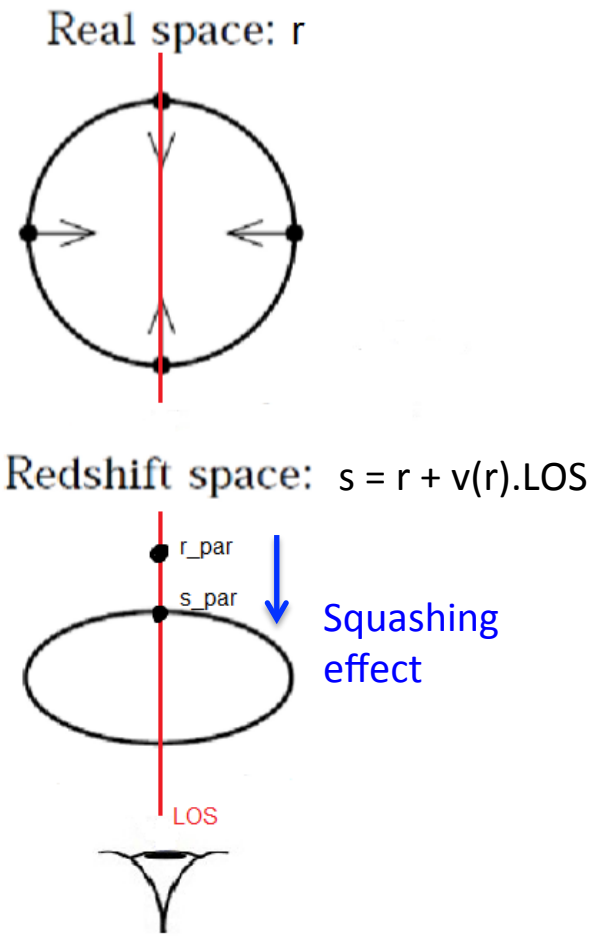
eBOSS RSD measurements



RSD: What does it mean?

→ Observed redshift depends on both Hubble expansion and "peculiar velocity"

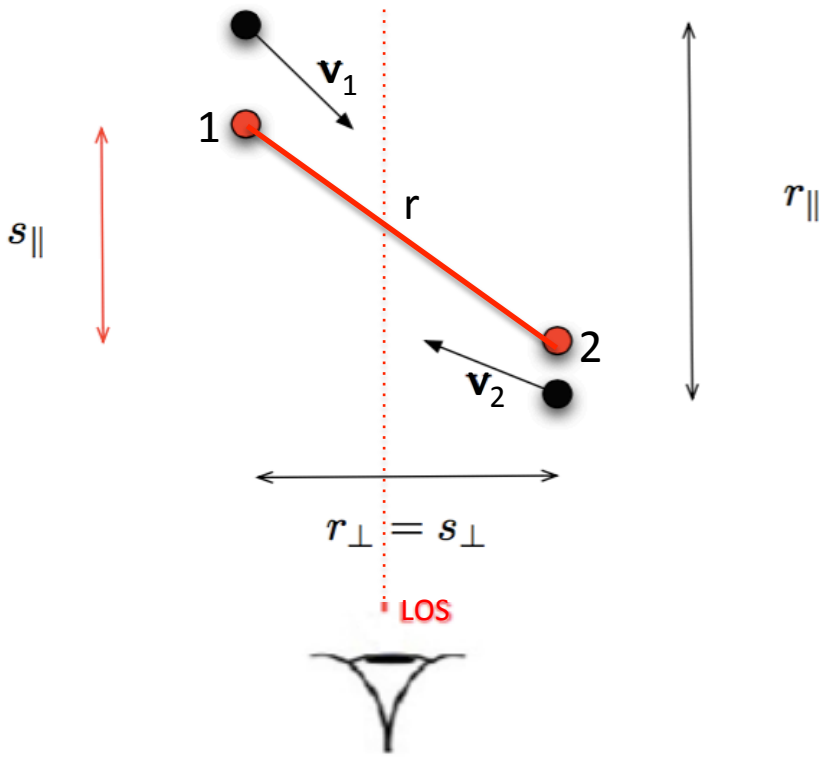


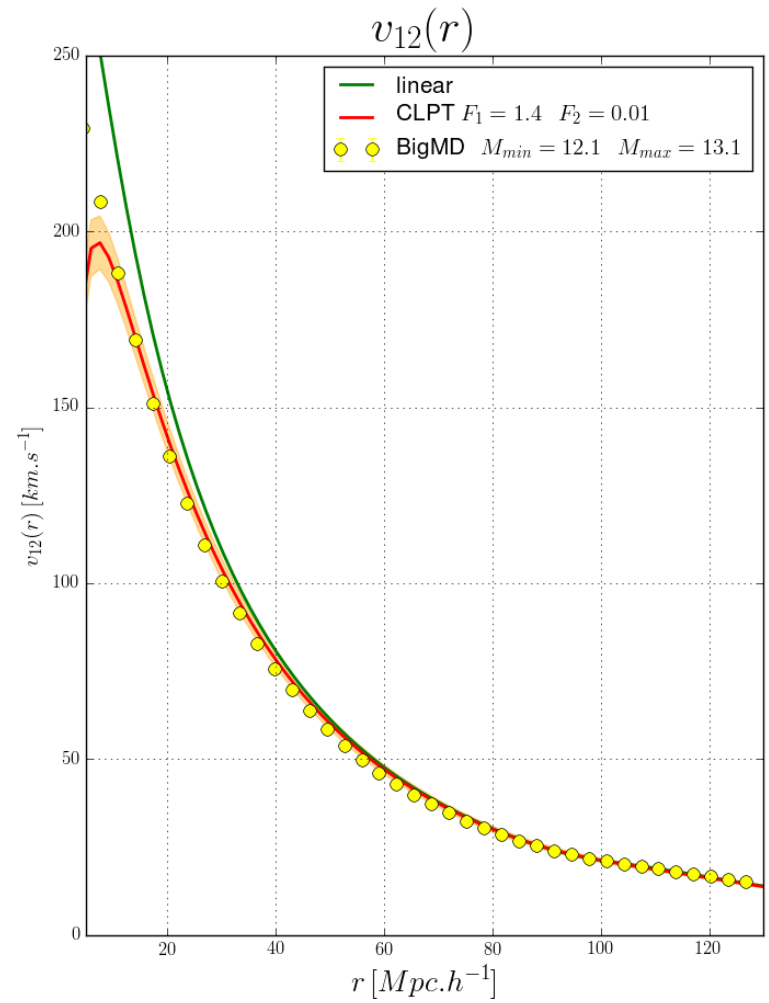


→ Mean infall velocity $v_{12}(r) = (v_2 - v_1).r$

RSD: What does it mean?

→ Observed redshift depends on both Hubble expansion and "peculiar velocity"





→ Mean infall velocity $v_{12}(r) = (v_2 - v_1).r$

RSD models

Gaussian Streaming (GS) model

$$1 + \xi_g(s_\parallel, s_\perp) = \int dr_\parallel \, [1 + \xi_g(r)] P(s_\parallel - r_\parallel, v_{12}, \sigma_{12}^2)$$

Redshift space

Real space

RSD models

Gaussian Streaming (GS) model

$$1 + \xi_g(s_\parallel, s_\perp) = \int dr_\parallel \, [1 + \xi_g(r)] P(s_\parallel - r_\parallel, v_{12}, \sigma_{12}^2)$$

- Linear-GS model

→ linear prediction for $\xi(r)$, v_{12} and σ_{12} that are injected into a GS model

- CLPT-GS model

→ Convolution Lagrangian Perturbation Theory (CLPT, Wang et al. 2013, Carlson et al., 2012) prediction for $\xi(r)$, v_{12} and σ_{12} that are injected into a GS model

$$A = A_0 + \langle F' \rangle A_{10} + \langle F'' \rangle A_{01} + \langle F' \rangle^2 A_{20} + \langle F' \rangle \langle F'' \rangle A_{11} + \langle F'' \rangle^2 A_{02}$$

bias parameters: unknown

$b = 1 + \langle F' \rangle$

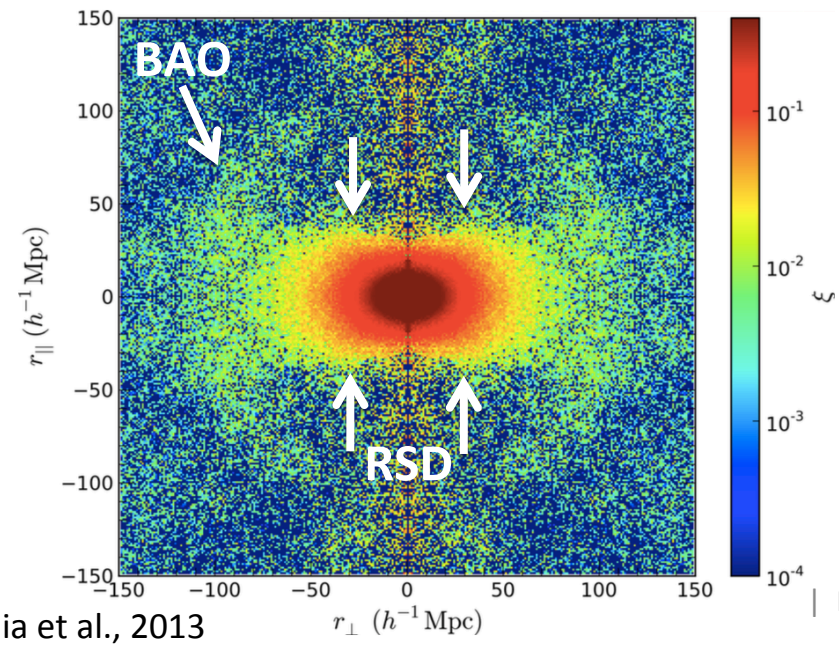
How to extract $f\sigma_8$?

$\xi_0^{Data}(s)$
$\xi_2^{Data}(s)$

Multipoles: $$\xi_l(s) = \frac{2l+1}{2}\int_{-1}^{1} d\mu\, \xi(s,\mu) P_l(\mu)$$

Where $P_0(\mu) = 1$ and $P_2(\mu) = \frac{1}{2}(3\mu^2 - 1)$: Legendre decomposition

→ **Monopole ξ_0 related to $b\sigma_8$**
→ **Quadrupole ξ_2 related to $b\sigma_8$ and $f\sigma_8$**



Samushia et al., 2013

How to extract $f\sigma_8$?

$\xi_0^{Data}(s)$
$\xi_2^{Data}(s)$

Fit $b\sigma_8$ and $f\sigma_8$

$\xi_0^{model}(s)$
$\xi_2^{model}(s)$

How to extract $f\sigma_8$?

$\xi_0^{Data}(s)$
$\xi_2^{Data}(s)$

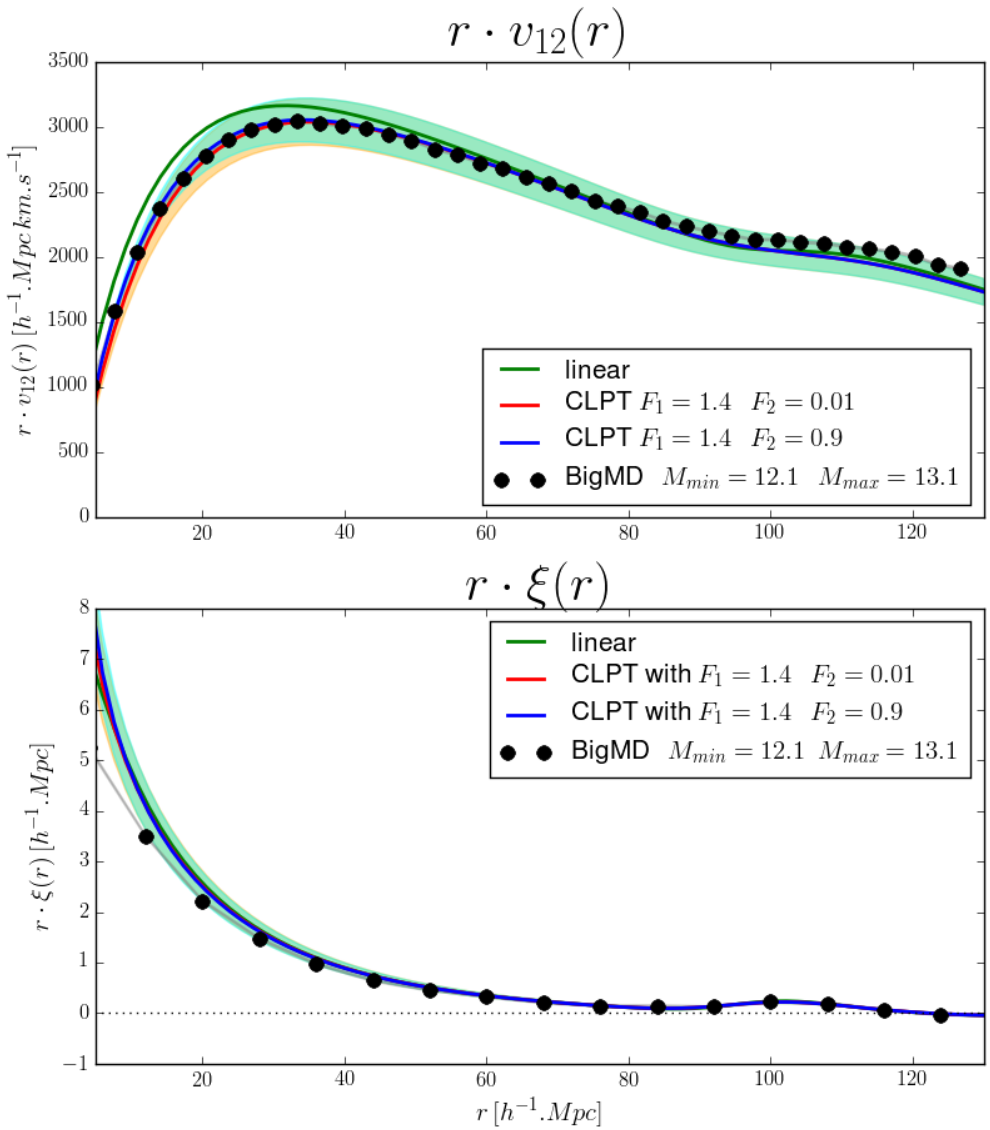
Fit $b\sigma_8$ and $f\sigma_8$

$\xi_0^{model}(s)$
$\xi_2^{model}(s)$

Check <F'> and <F''>

N-body simulations
- Dark matter halos that host QSO
- Clustering in real space

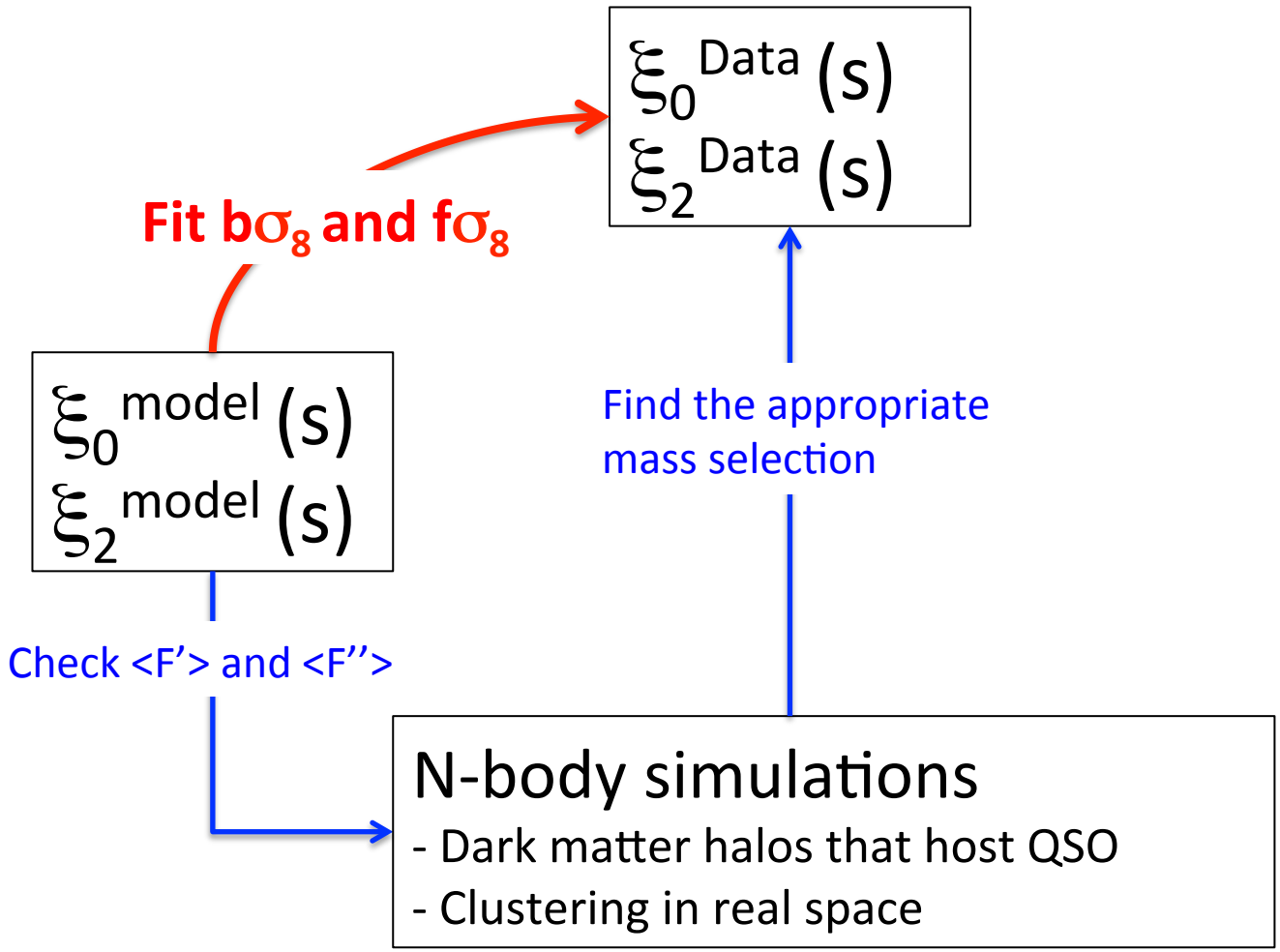
Test CLPT validity using N-body simulations



1. To form dark matter halos in a MultiDark simulation[1] for a given set of cosmological parameters
2. To apply mass selection to select halos which can host the astrophysical objects of interest
3. To calculate velocity and clustering statistics of these «fictive » population to test RSD models

[1] http://www.multidark.org/

How to extract $f\sigma_8$?



How to extract $f\sigma_8$?

$\xi_0^{Data}(s)$
$\xi_2^{Data}(s)$

Fit $b\sigma_8$ and $f\sigma_8$

$\xi_0^{model}(s)$
$\xi_2^{model}(s)$

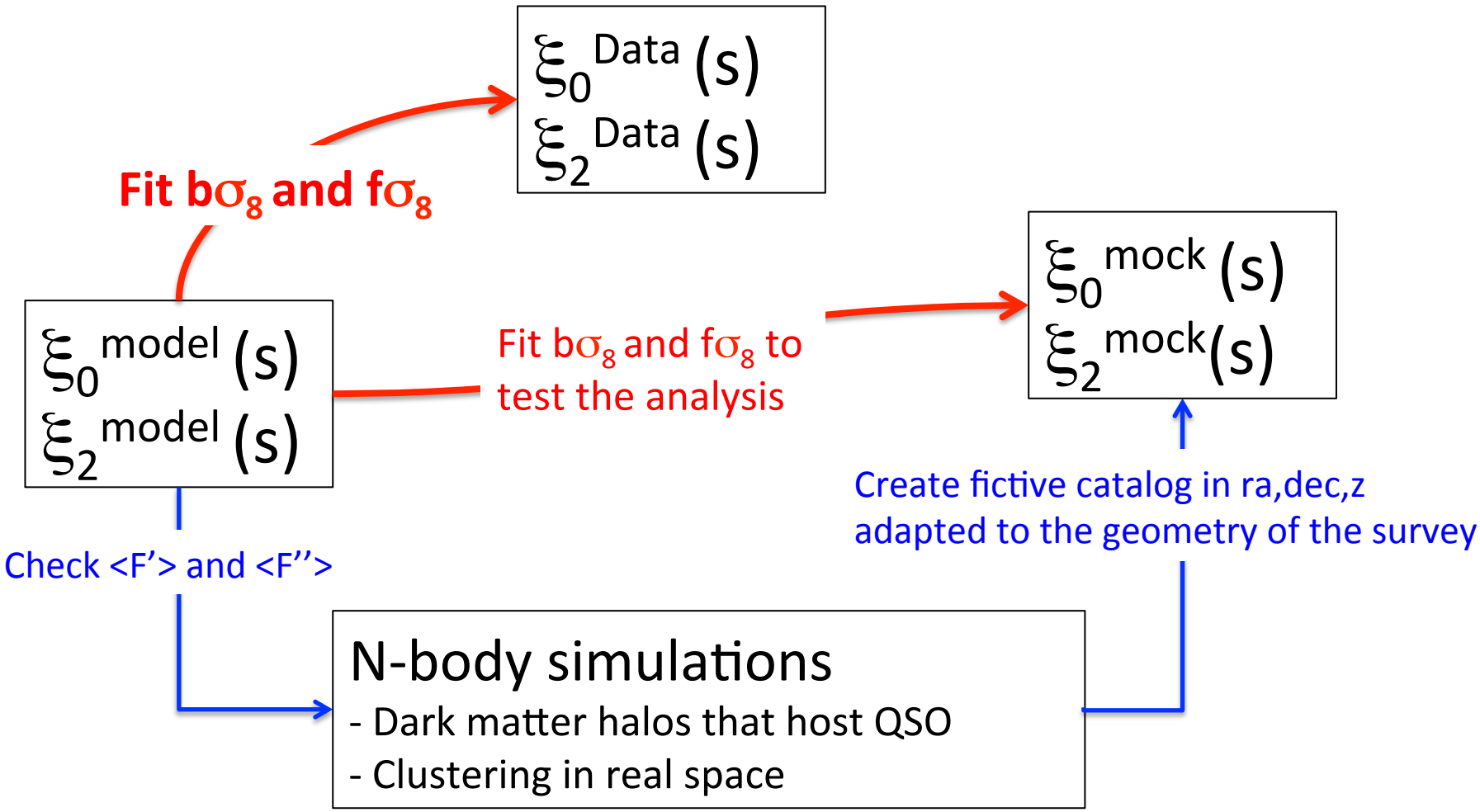
Check <F'> and <F''>

$\xi_0^{mock}(s)$
$\xi_2^{mock}(s)$

Create fictive catalog in ra,dec,z adapted to the geometry of the survey

N-body simulations
- Dark matter halos that host QSO
- Clustering in real space

How to extract $f\sigma_8$?



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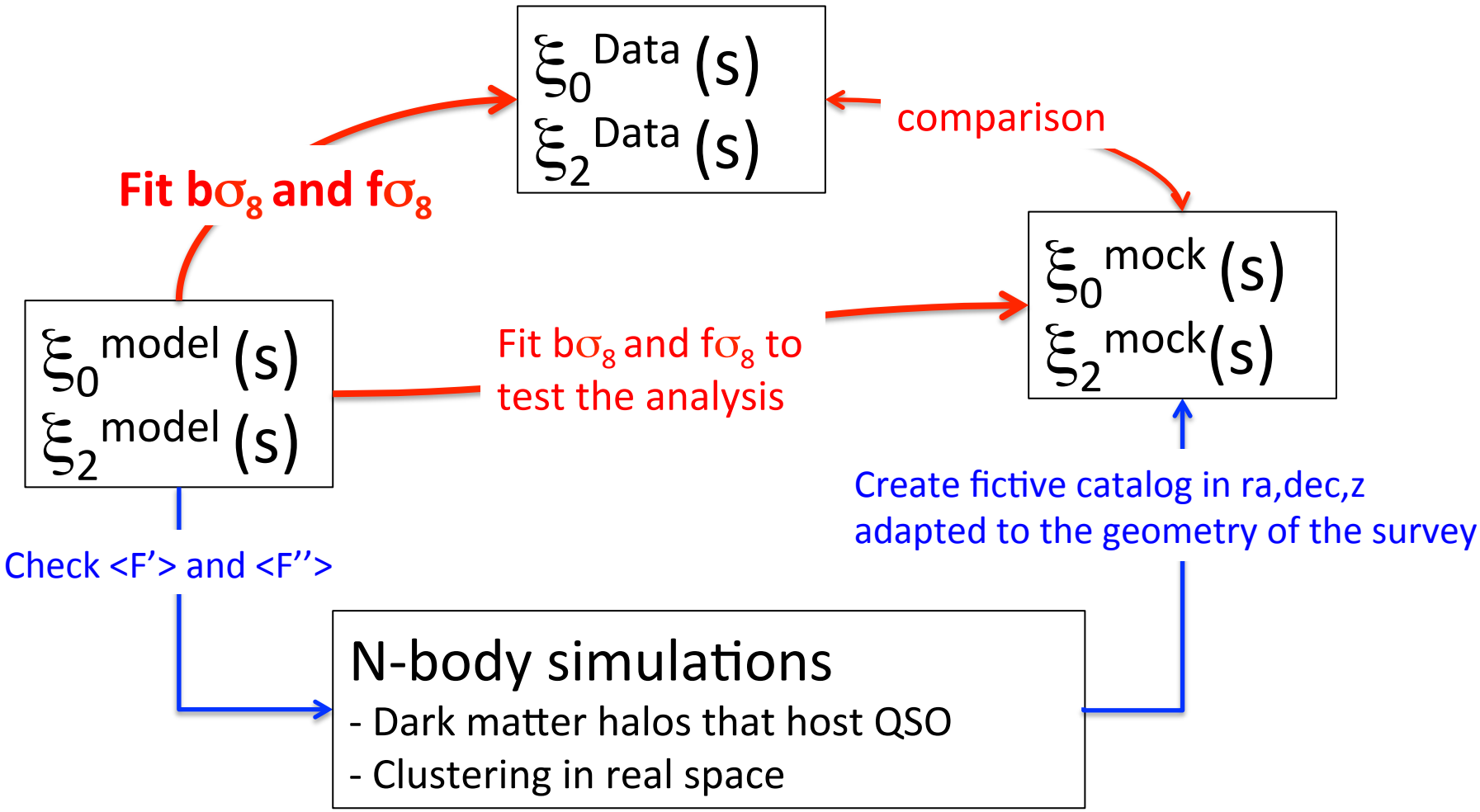

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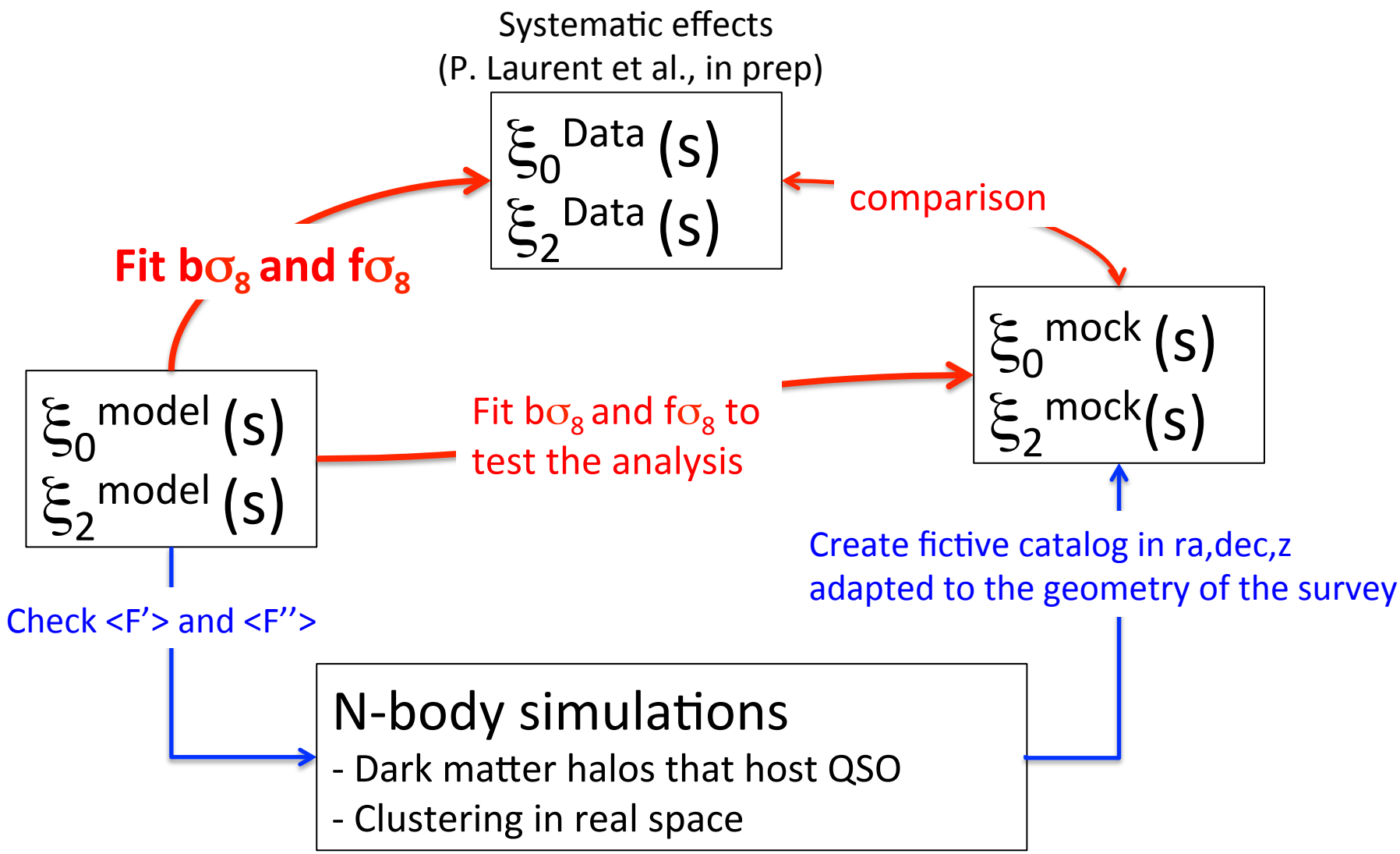
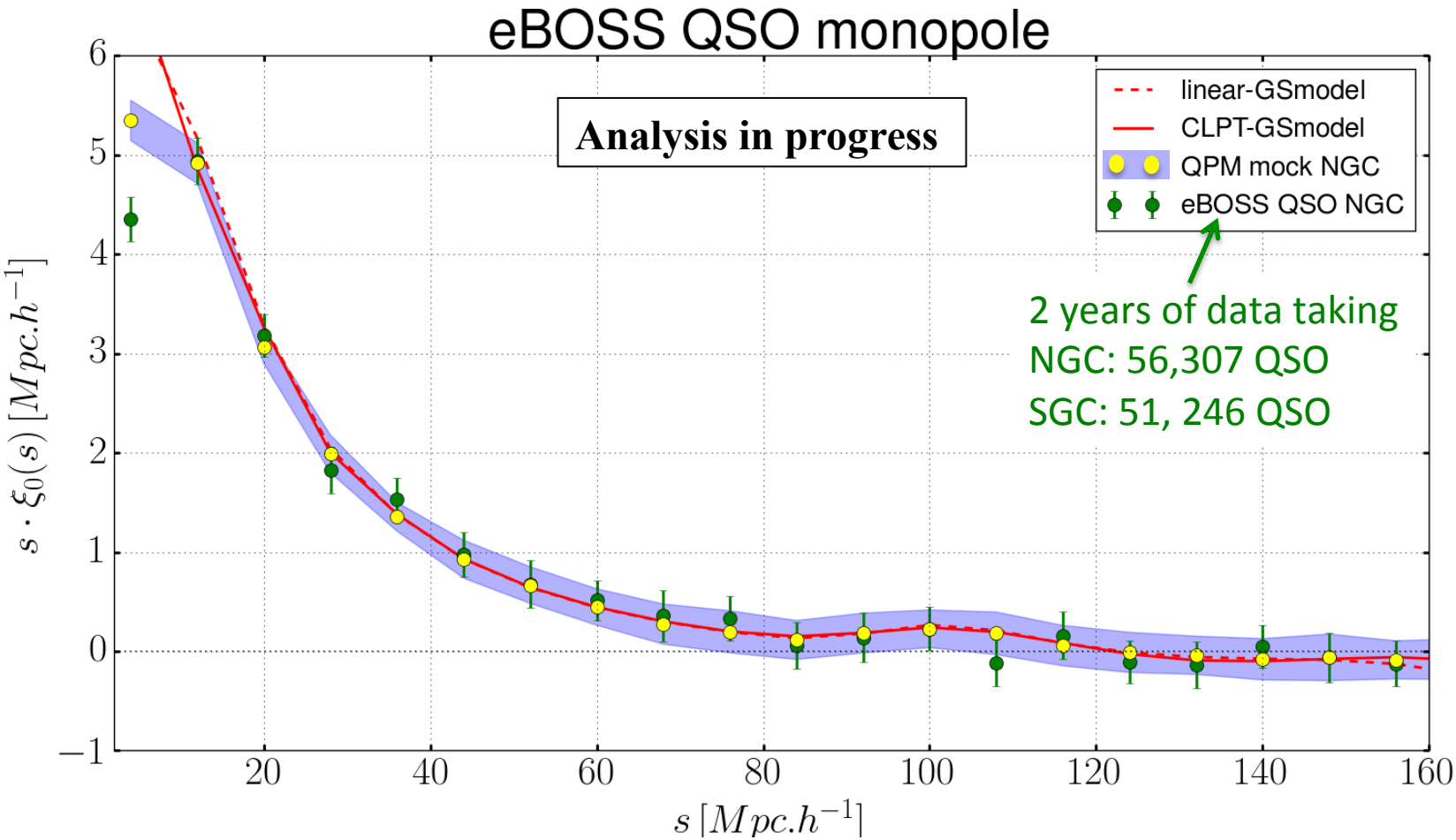
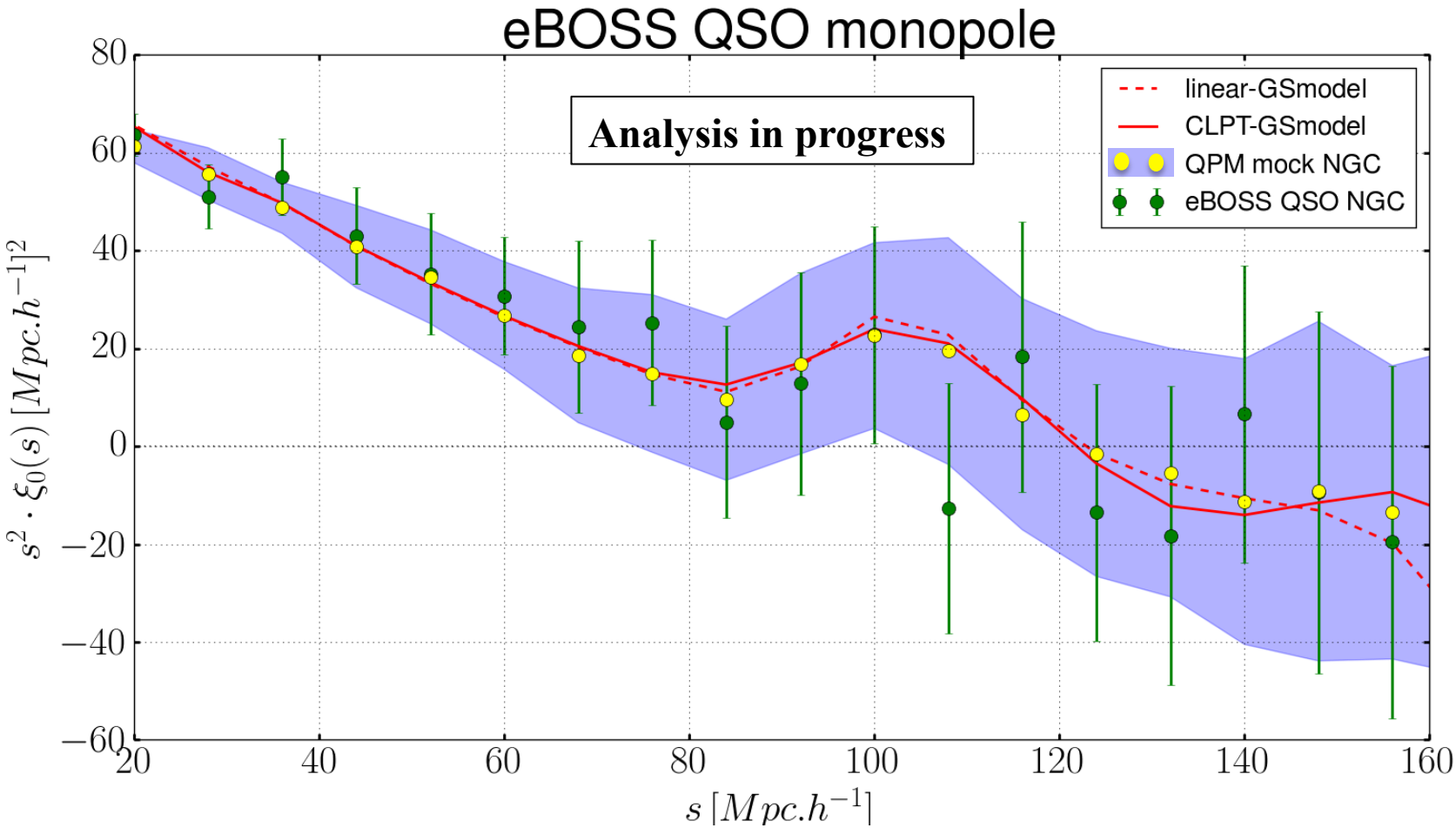


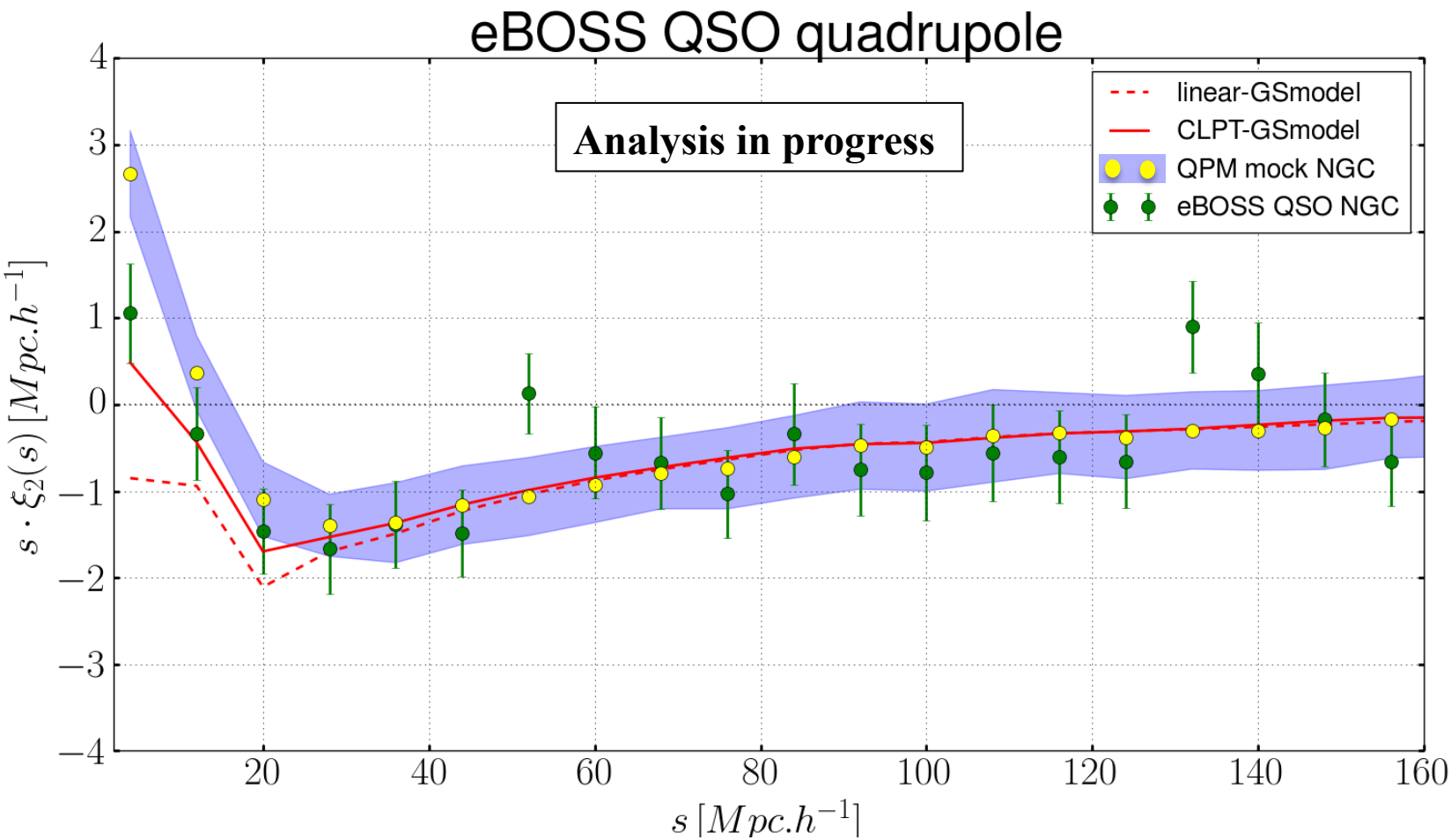
Monopole to determine H(z) and $b\sigma_8$



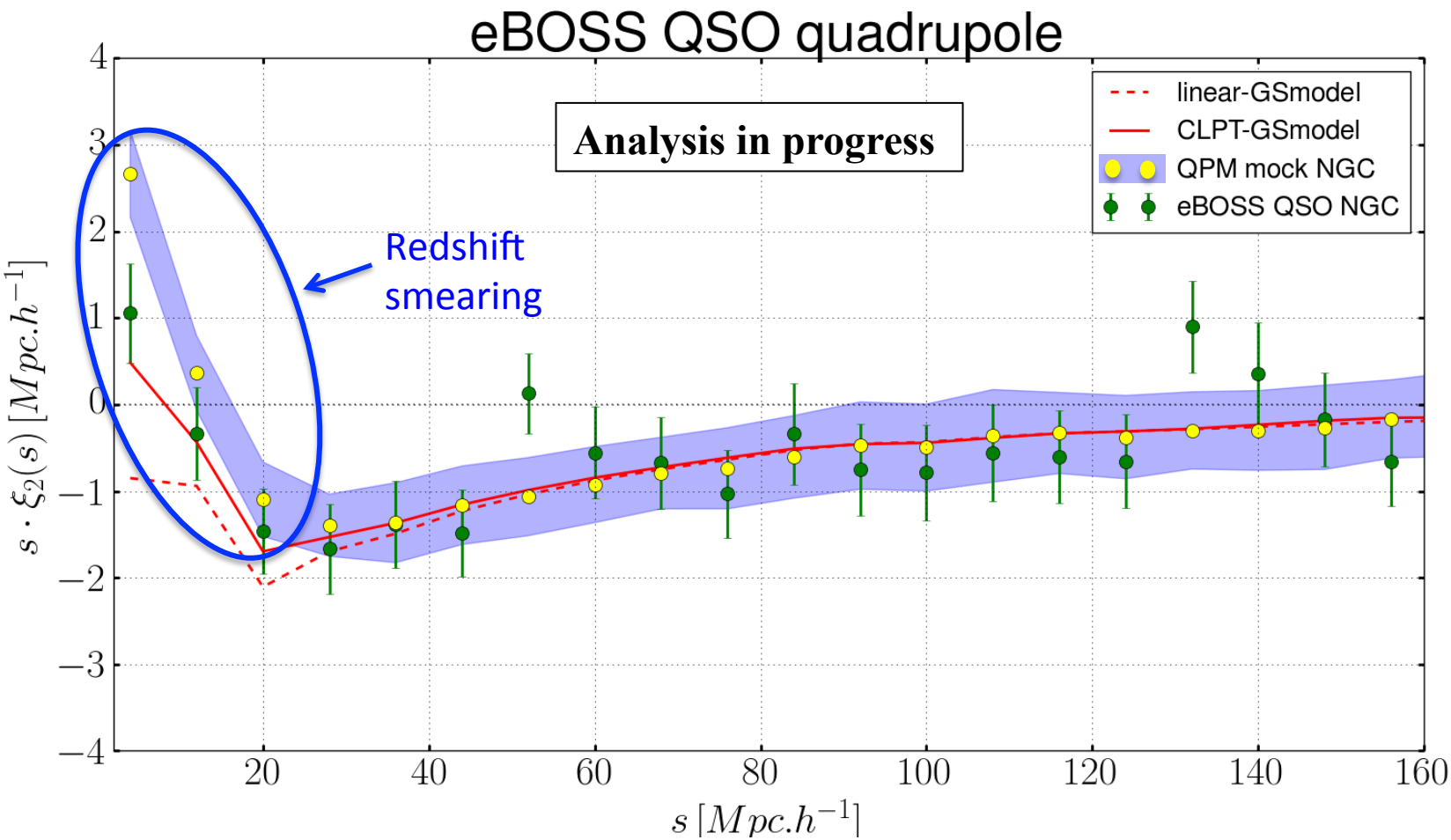
Hints for BAO



Non-zero quadrupole to determine $b\sigma_8$ and $f\sigma_8$



Non-zero quadrupole to determine $b\sigma_8$ and $f\sigma_8$



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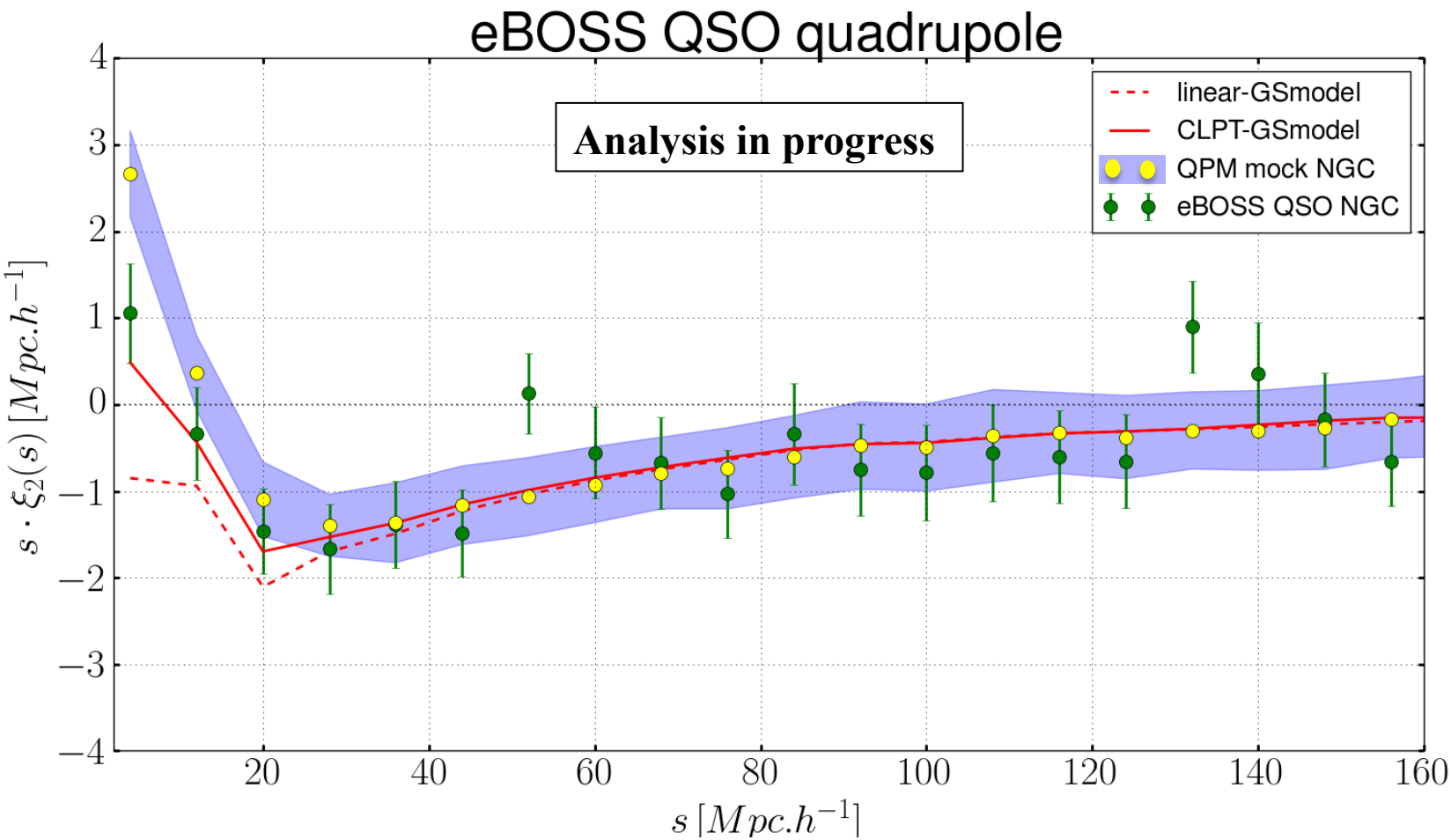
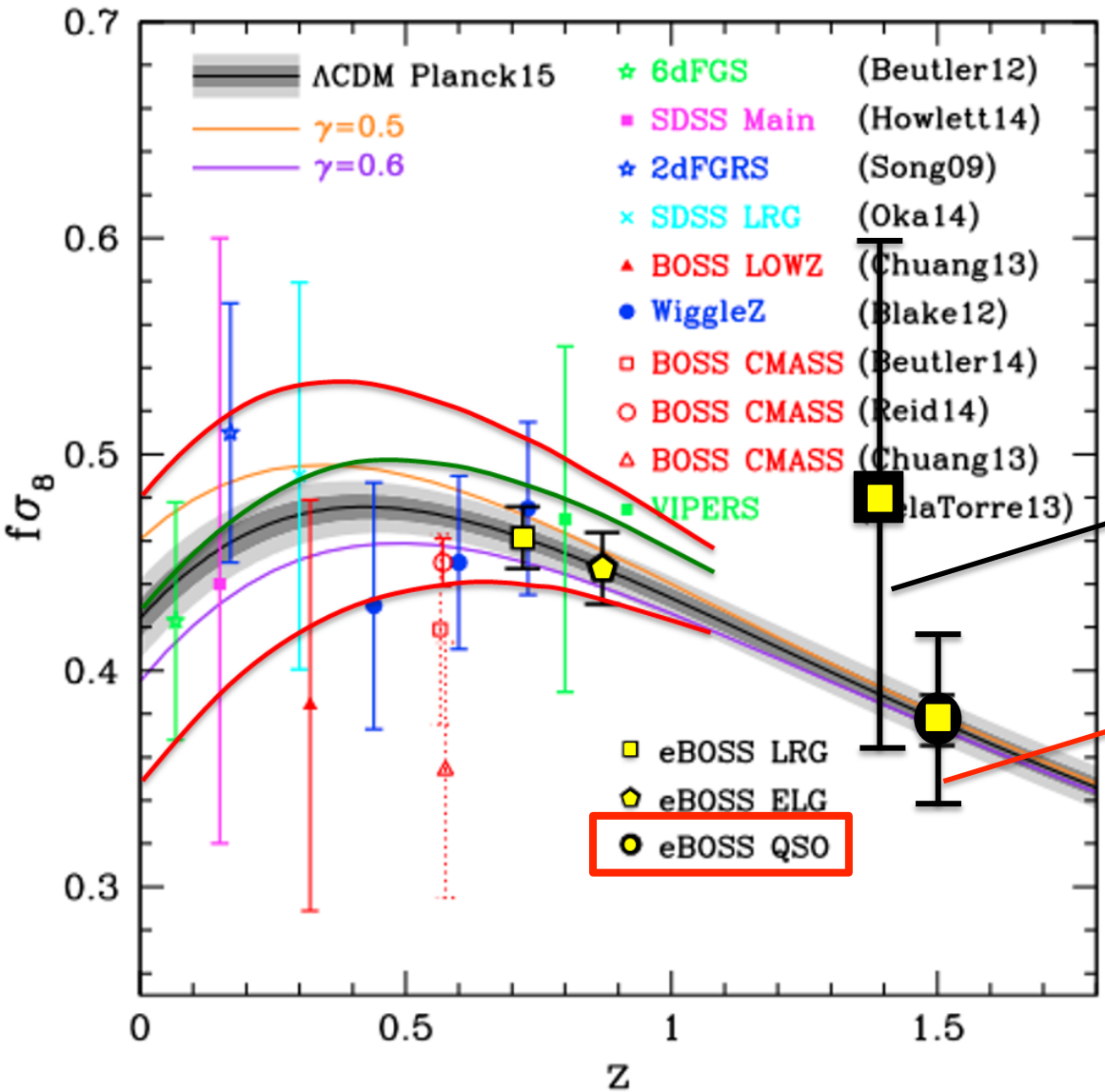


→ Current error on $f\sigma_8$ of the order of 11% at z~1.5

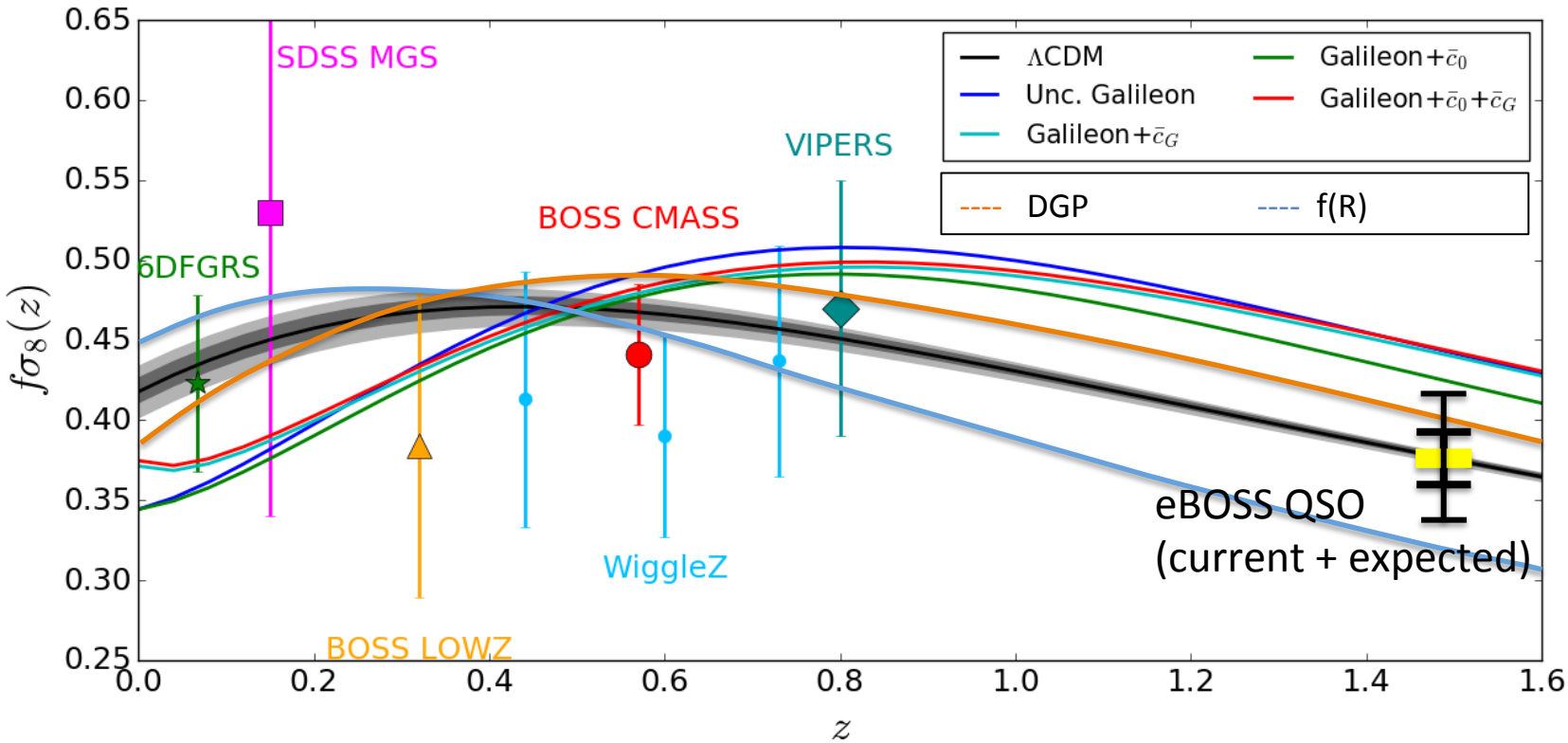
Current precision with eBOSS



Okumura et al. (2015) with Subaru FMOS

Current precision with eBOSS

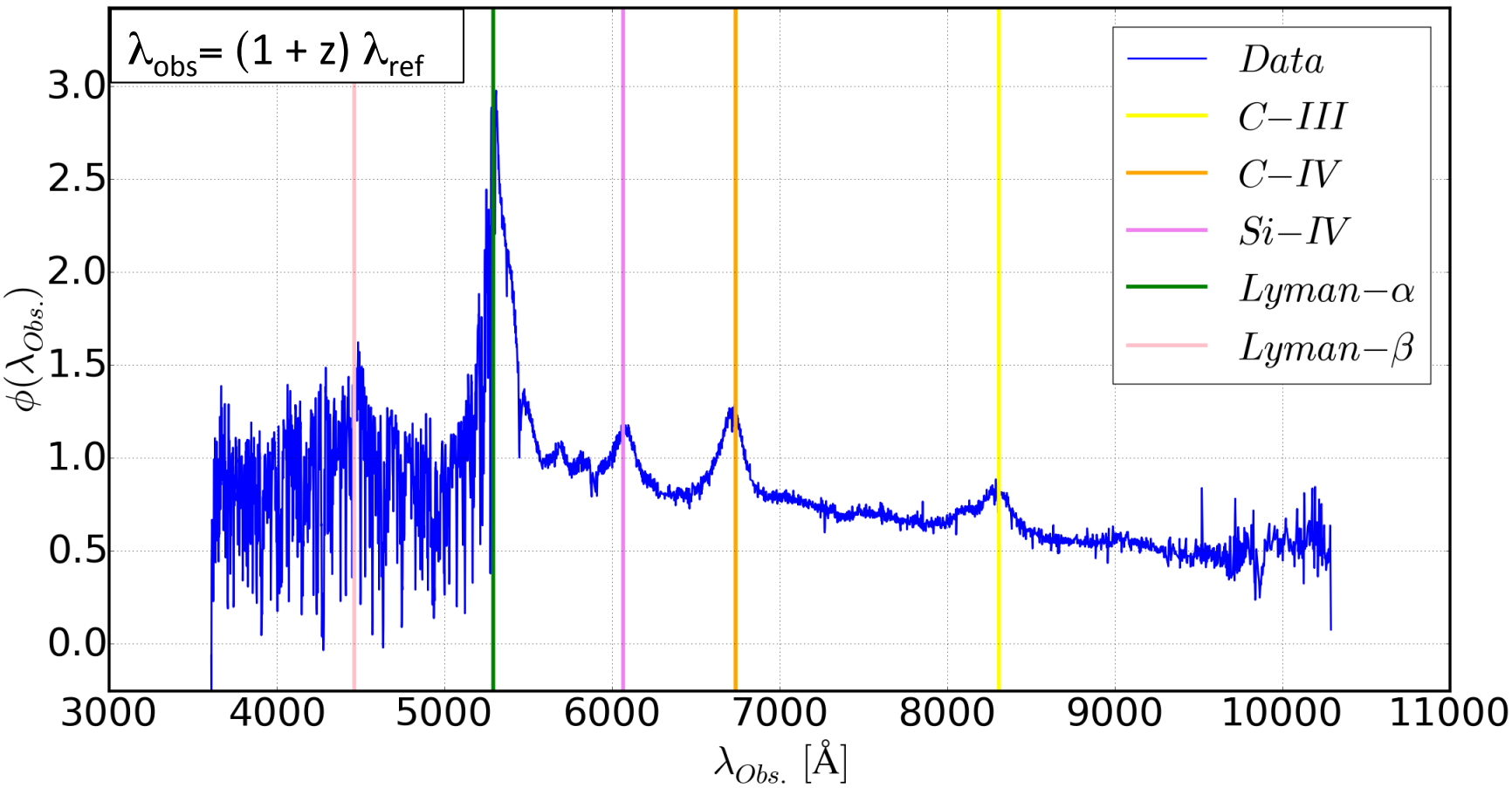
Powerful discriminant for modified gravity models



- DGP: extra-dimension theory
- f(R): scalar-field theory
- Galileon: add a scalar field in the Lagrangian that can couple with matter

Thank you for your attention!

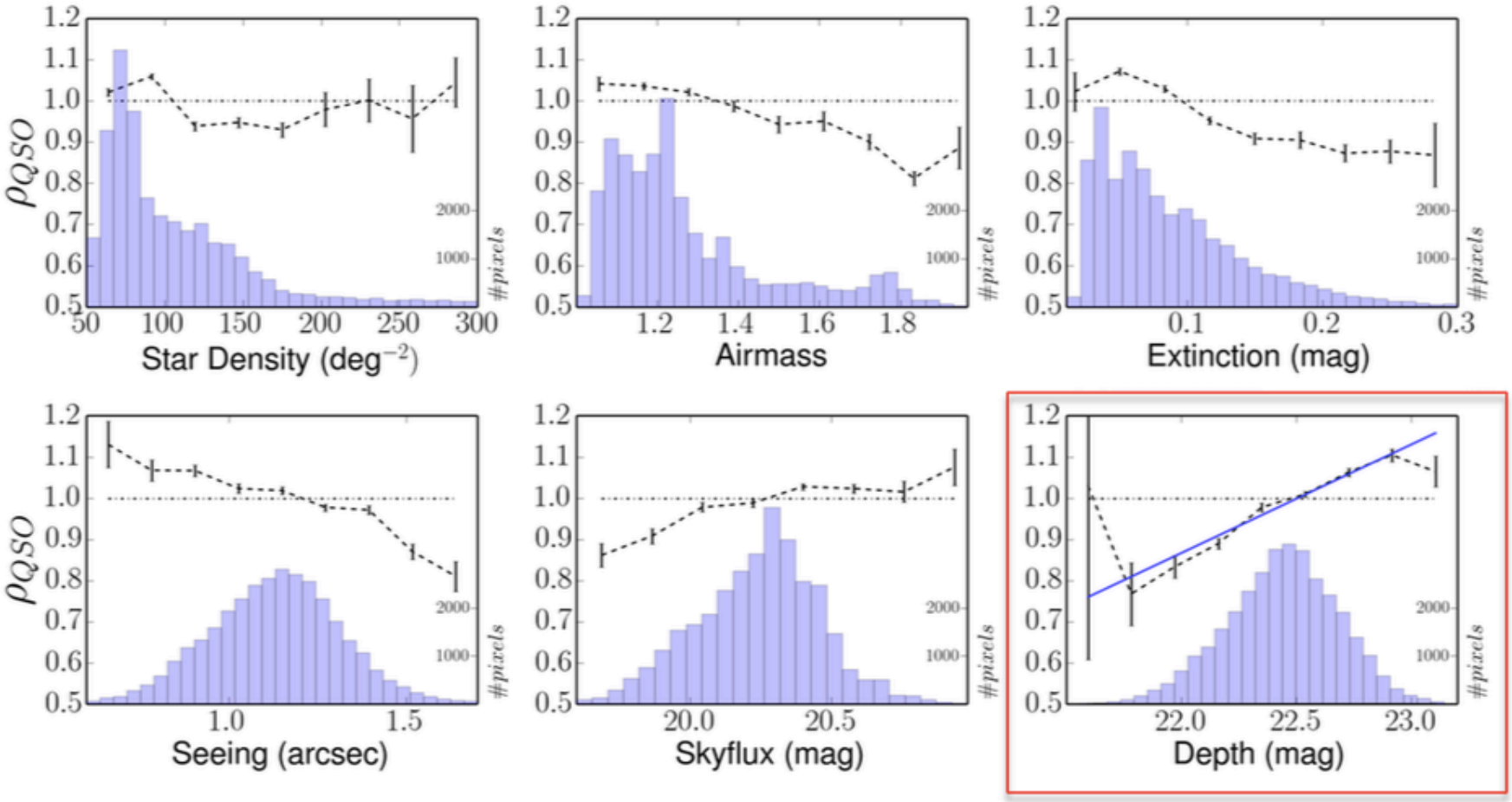
What is a quasar?



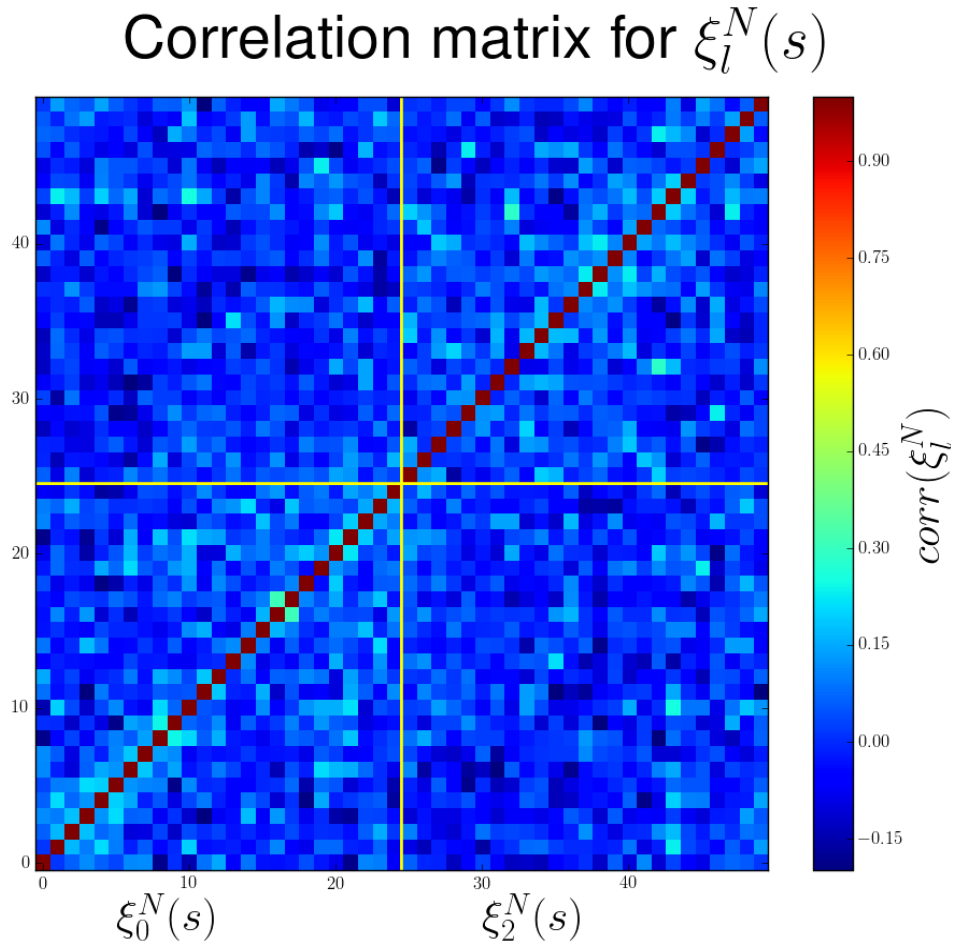
- Super luminous (~100 galaxies)
- Radio (sometimes nothing in optical)
- Point sources (but different from stars)
- Very massive (1 million times the Sun)

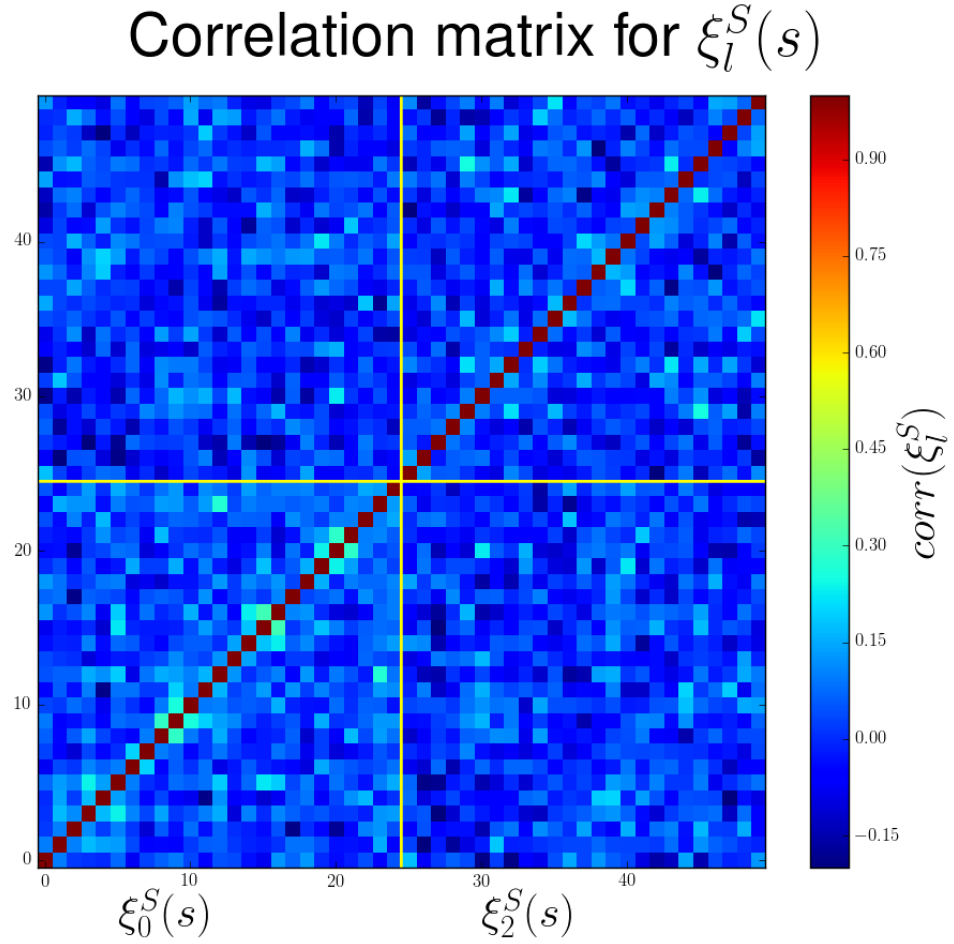
Systematic effects: apply depth weight

P. Laurent et al. (in prep.)

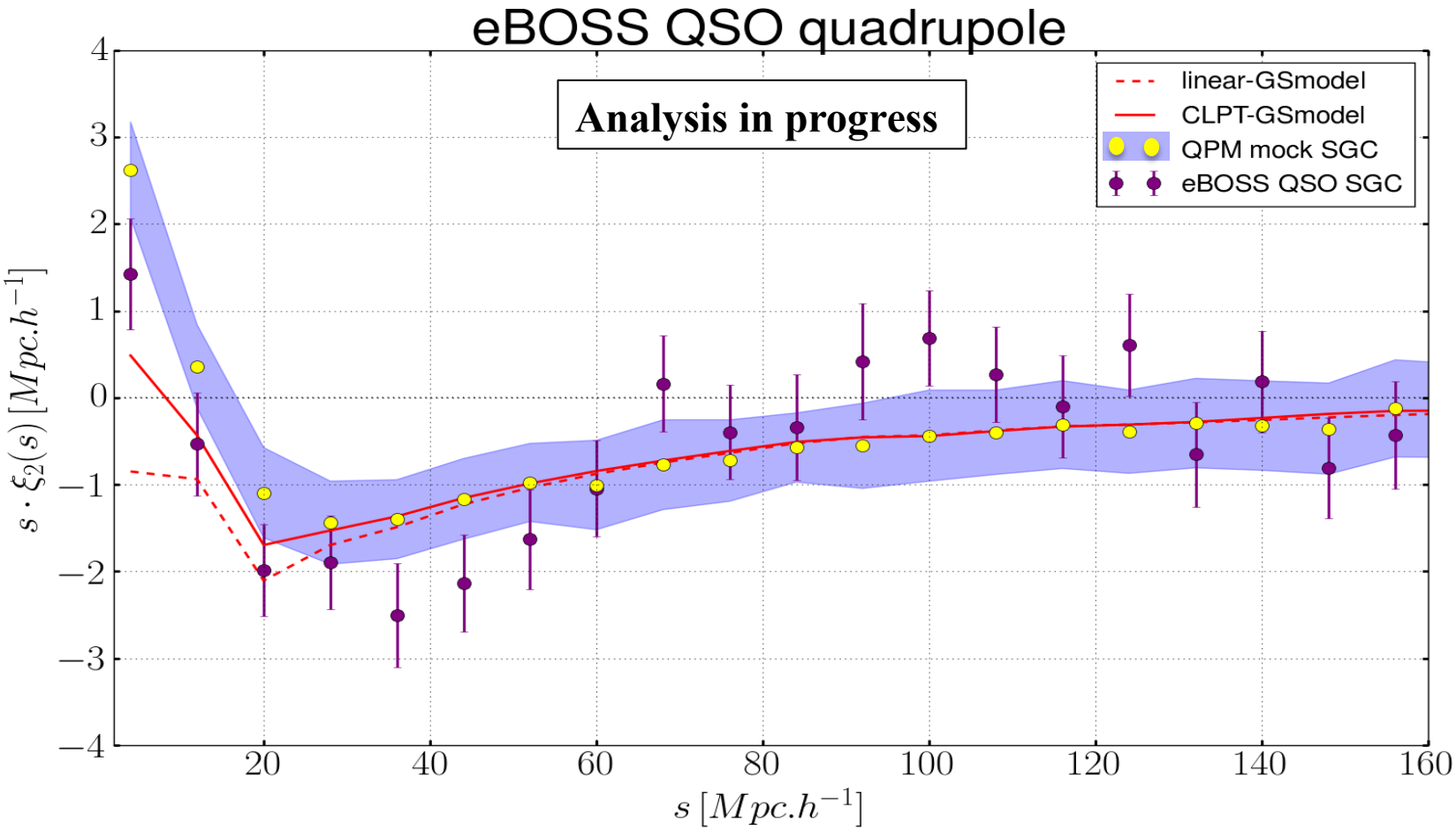


Correlation matrices





→ Computed from bootstrap realizations

→ This neglects cosmic variance, but survey shot-noise limited

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