Challenges of BAO peak measurement using photometric data

by

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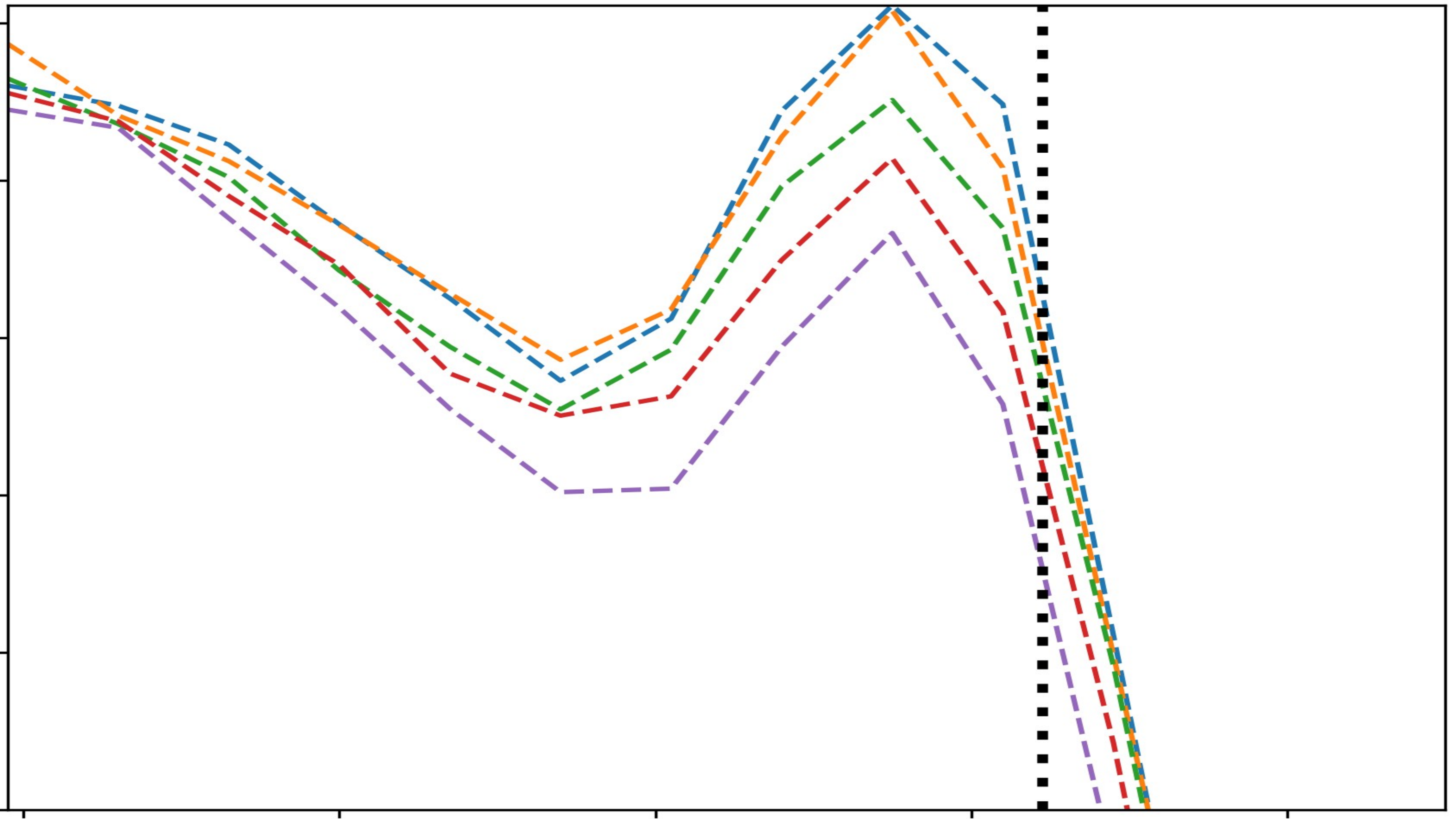
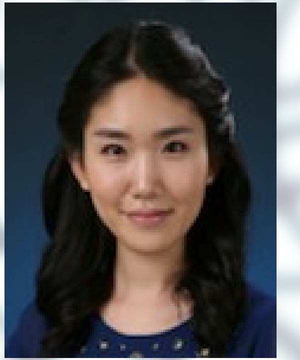
DARK ENERGY SPECTROSCOPIC INSTRUMENT

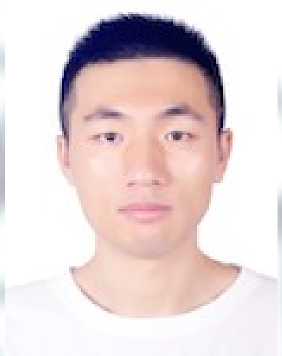


Collaborators

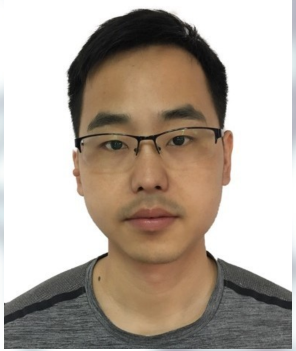
Yong-seon Song
(KASI)



Minji Oh
(Chosun University)



Yi Zheng
(SYSU)



Feng Shi
(Xidian University)

Srivatsan Sridhar
(formerly KASI)

Zhijie Ding
(SJTU)

Rongpu Zhou
(University of Pittsburgh)

Ashley Ross
(Ohio State University)

Jeffrey Newman
(University of Pittsburgh)

Chia-Hsun Chuang
(Stanford University)

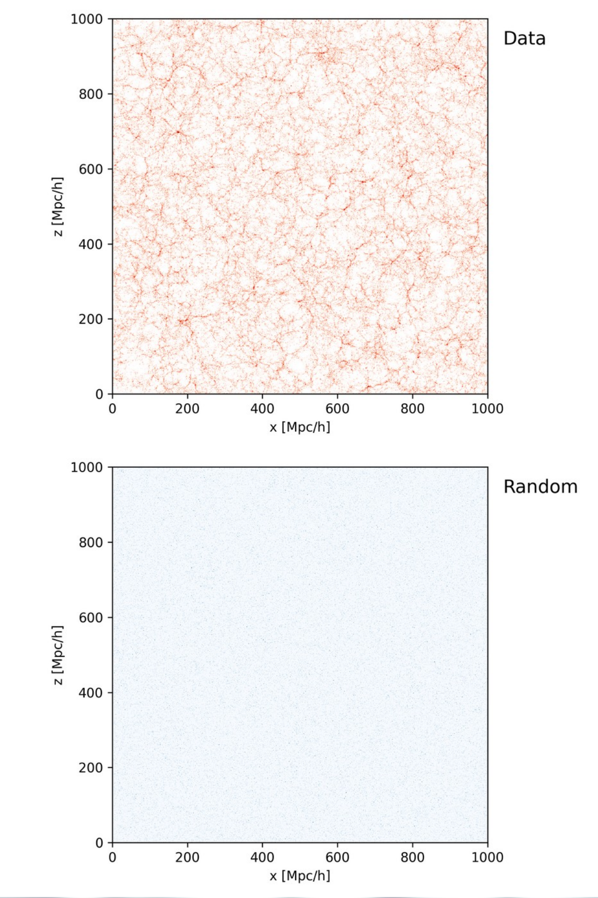
Measuring the BAO in configuration space

- Fast codes like corrfunc
- → number counts DD, DR, RR as a function of separation

- Estimator for correlation function:

ξ_{LS} = (DD - 2*DR + RR)/RR

(Landy-Szalay estimator)



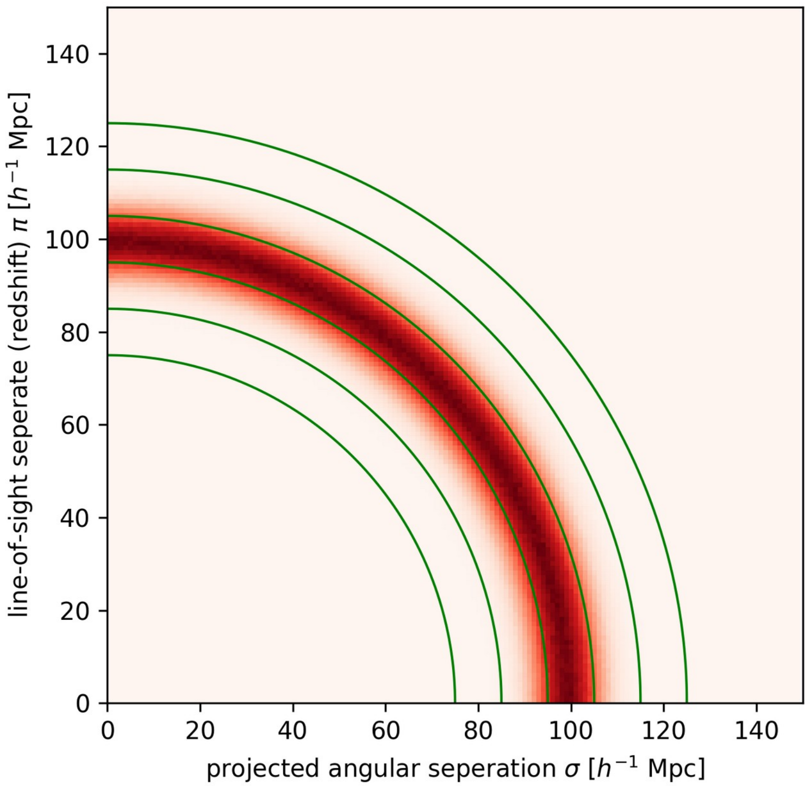
Anisotropic correlation function

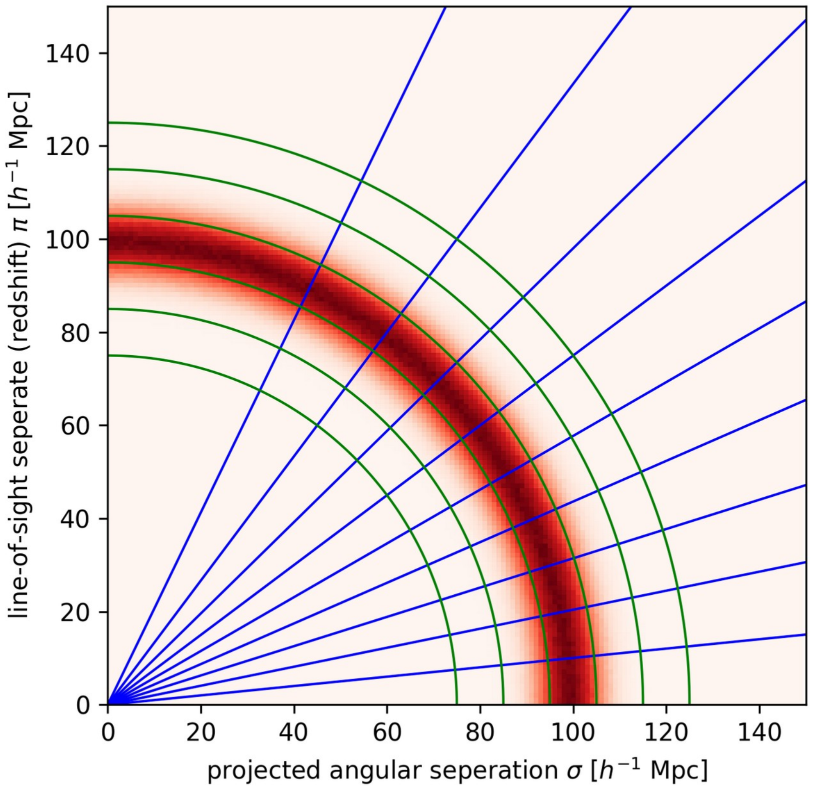
isotropic $\xi(s)$

$s^2 = \pi^2 + \sigma^2$

$\mu = \pi / s$

anisotropic $\xi(s,\mu)$

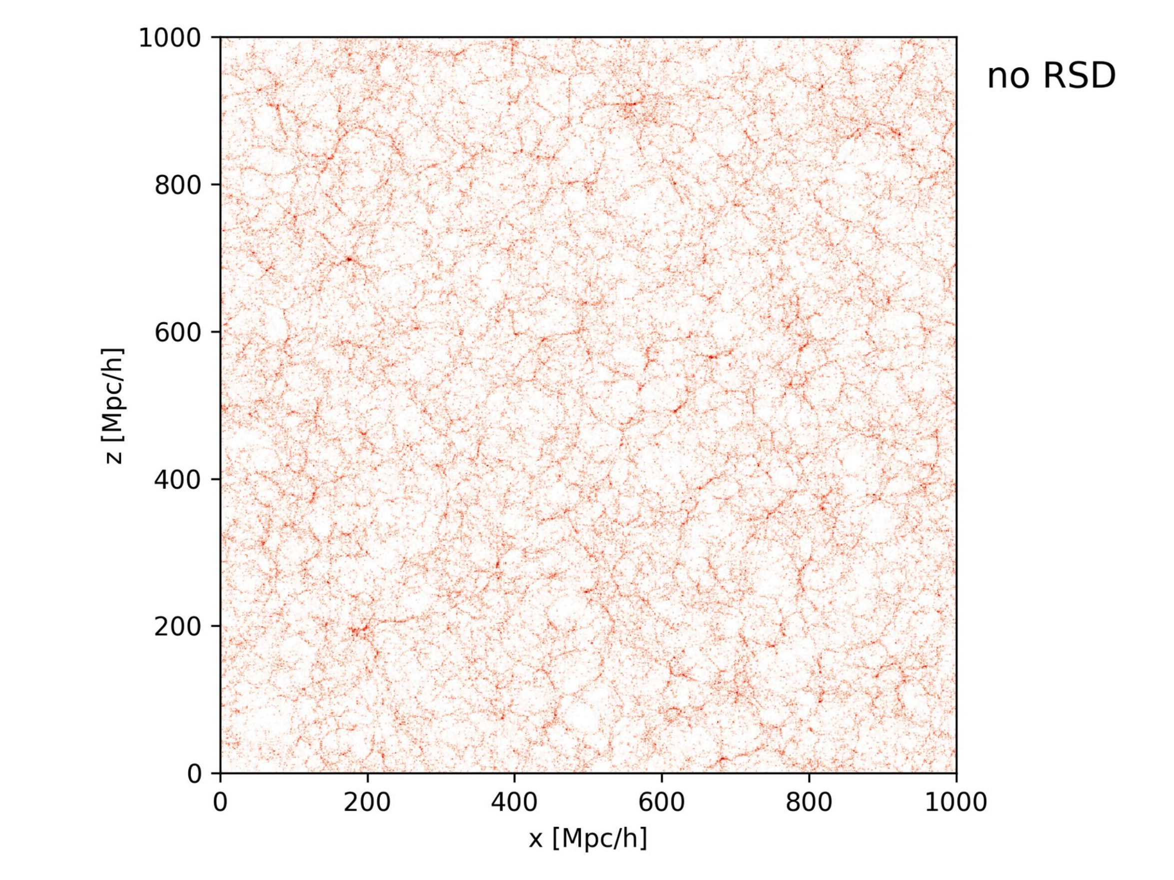




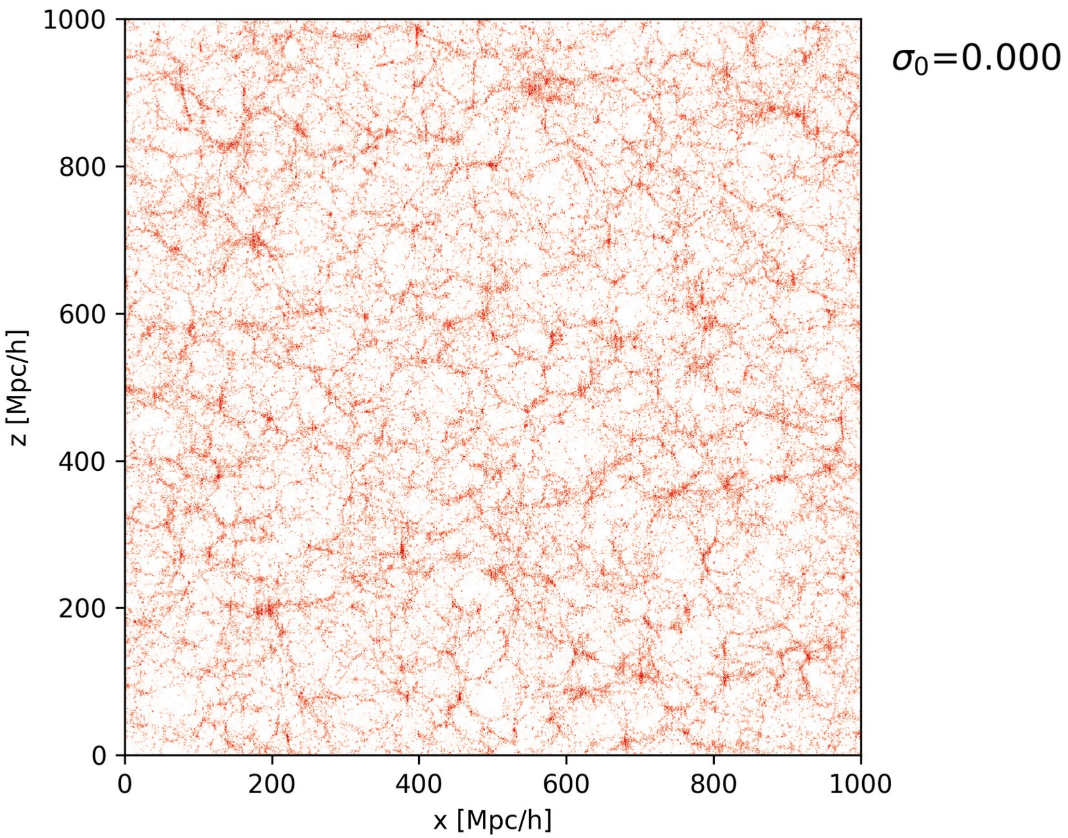
Redshift distance relation

- Ideally: perfect correlation between redshift and distance
- In practice:
  - Redshift space distortions due to peculiar motions
  - Uncertainty of redshift measurements
    - Relatively small for spectroscopic redshifts
    - **But huge for photometric redshifts (!)**

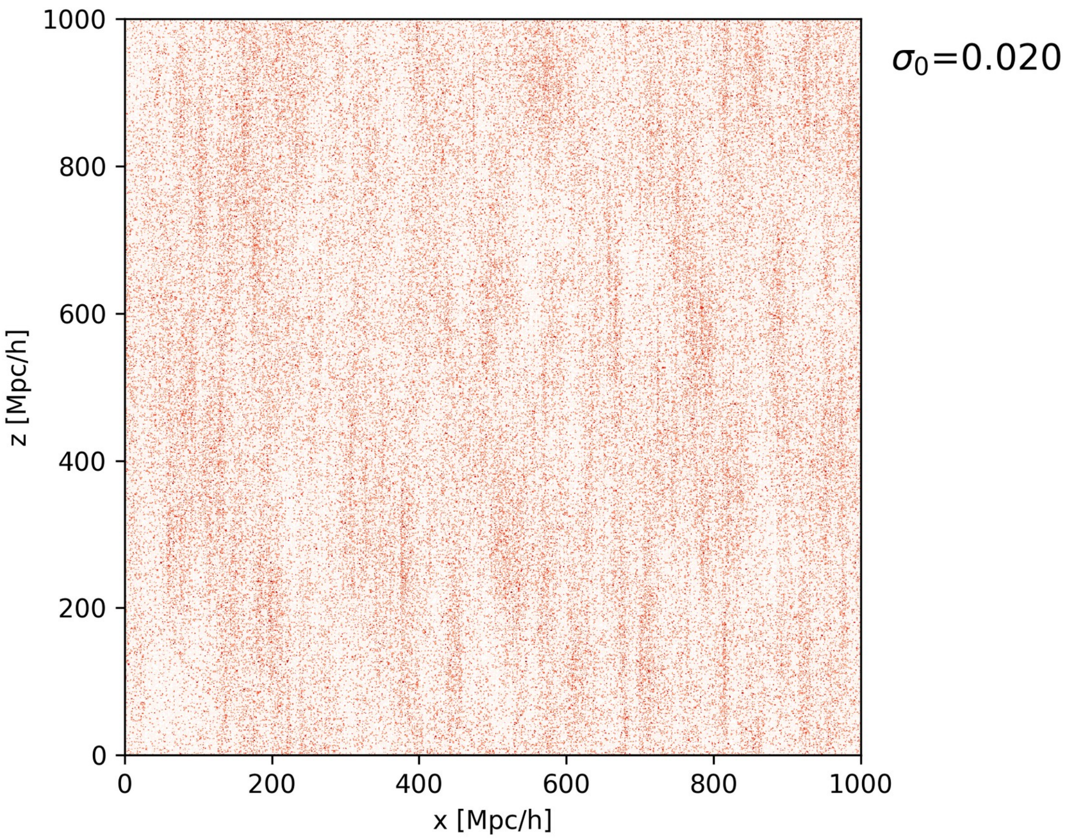
Photometric redshifts washes out clustering features



Photometric redshifts washes out clustering features



Photometric redshifts washes out clustering features



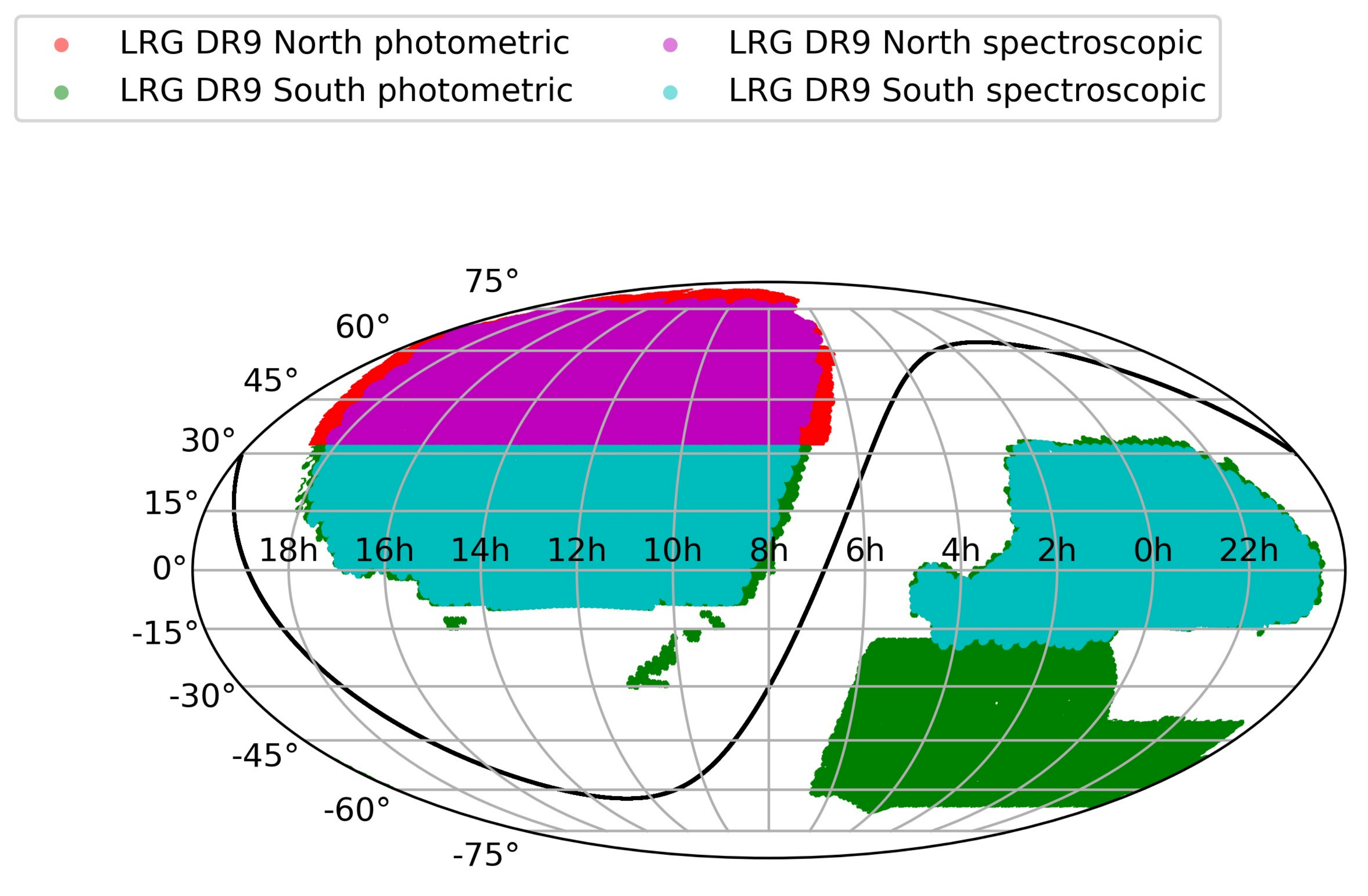
Simulations

- 100 Cubic box dark matter only simulation with 1890 Mpc/h and a mass resolution of 5.5 10^{11} $M_\odot$
- Populated using an HOD model corresponding to the DESI LRG at z=0.7
- Used for basic tests of our methods

DESI

- Dark Energy Spectroscopic Instrument survey
- Ongoing spectroscopic survey
- Running 5 years (1 done, 4 more to go)
- Photometric survey for target selection: DESI Legacy survey DR9 … already available!

Footprint

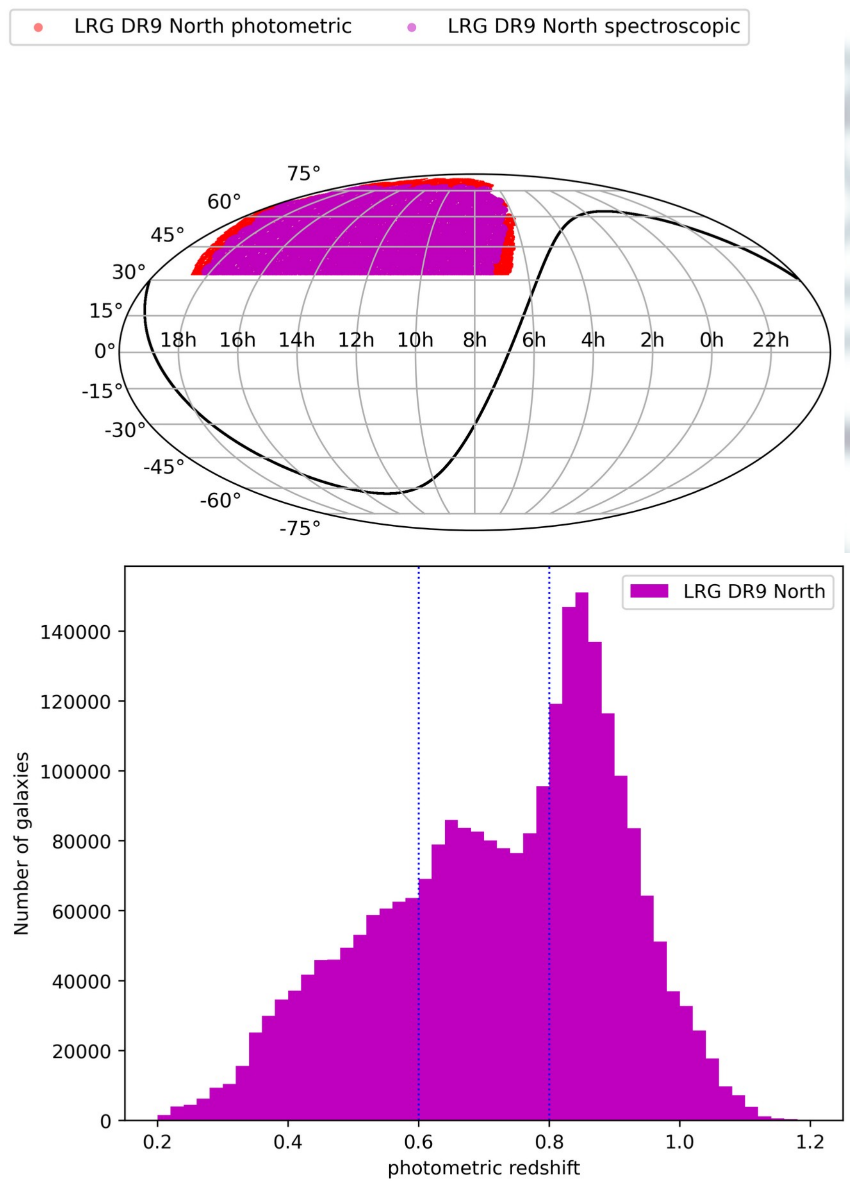


LRG DR9 North photometric
LRG DR9 North spectroscopic
LRG DR9 South photometric
LRG DR9 South spectroscopic
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
18h
16h
14h
12h
10h
8h
6h
4h
2h
0h
22h

Target classes

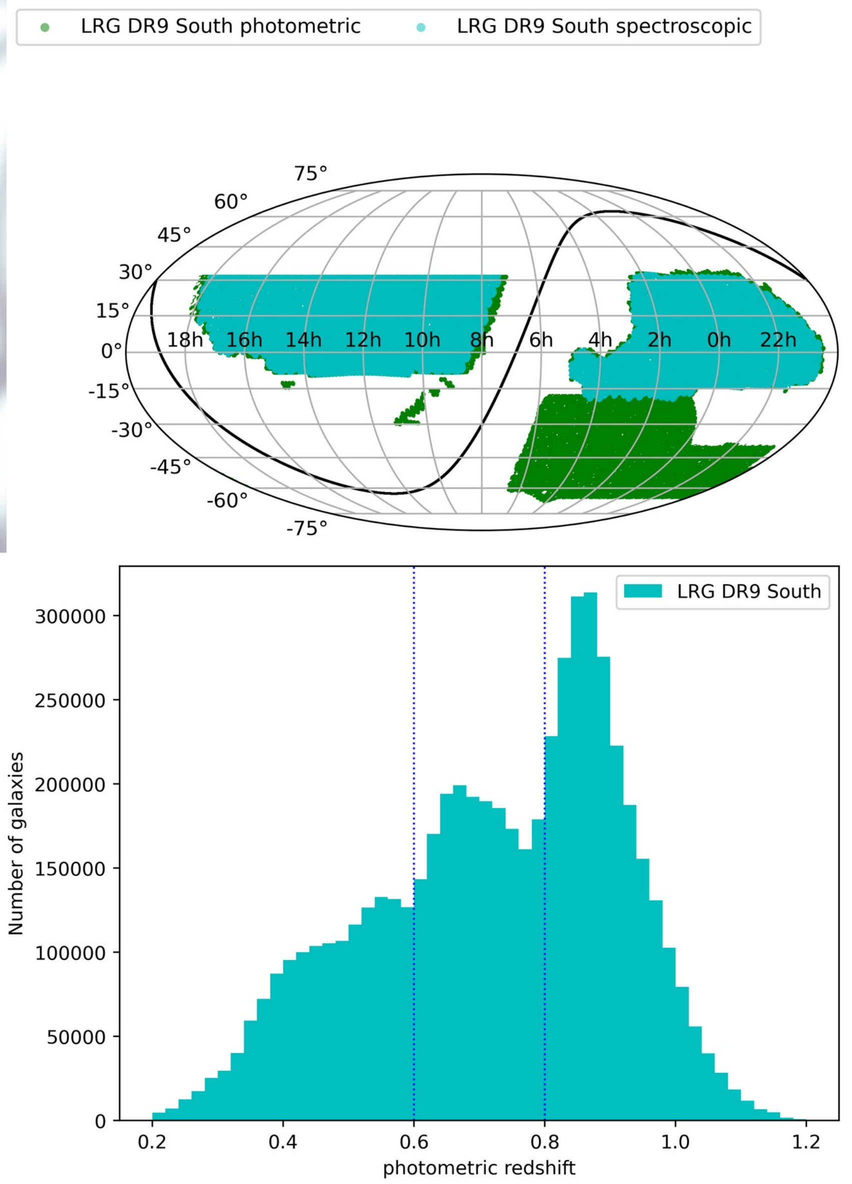
- MWS: not for cosmology
- BGS: $z < 0.5$
- **LRG: $0.4 < z < 1.1$**
- ELG: $0.6 < z < 1.5$
- QSO: $0.8 < z\ 3.5$

- Focus on LRG: balance between photometric redshift uncertainty and sample size


LRG DR9 North photometric
LRG DR9 North spectroscopic
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
18h 16h 14h 12h 10h 8h 6h 4h 2h 0h 22h
LRG DR9 North
Number of galaxies
0 20000 40000 60000 80000 100000 120000 140000
0.2 0.4 0.6 0.8 1.0 1.2
photometric redshift

LRGs

0.6<z<0.8

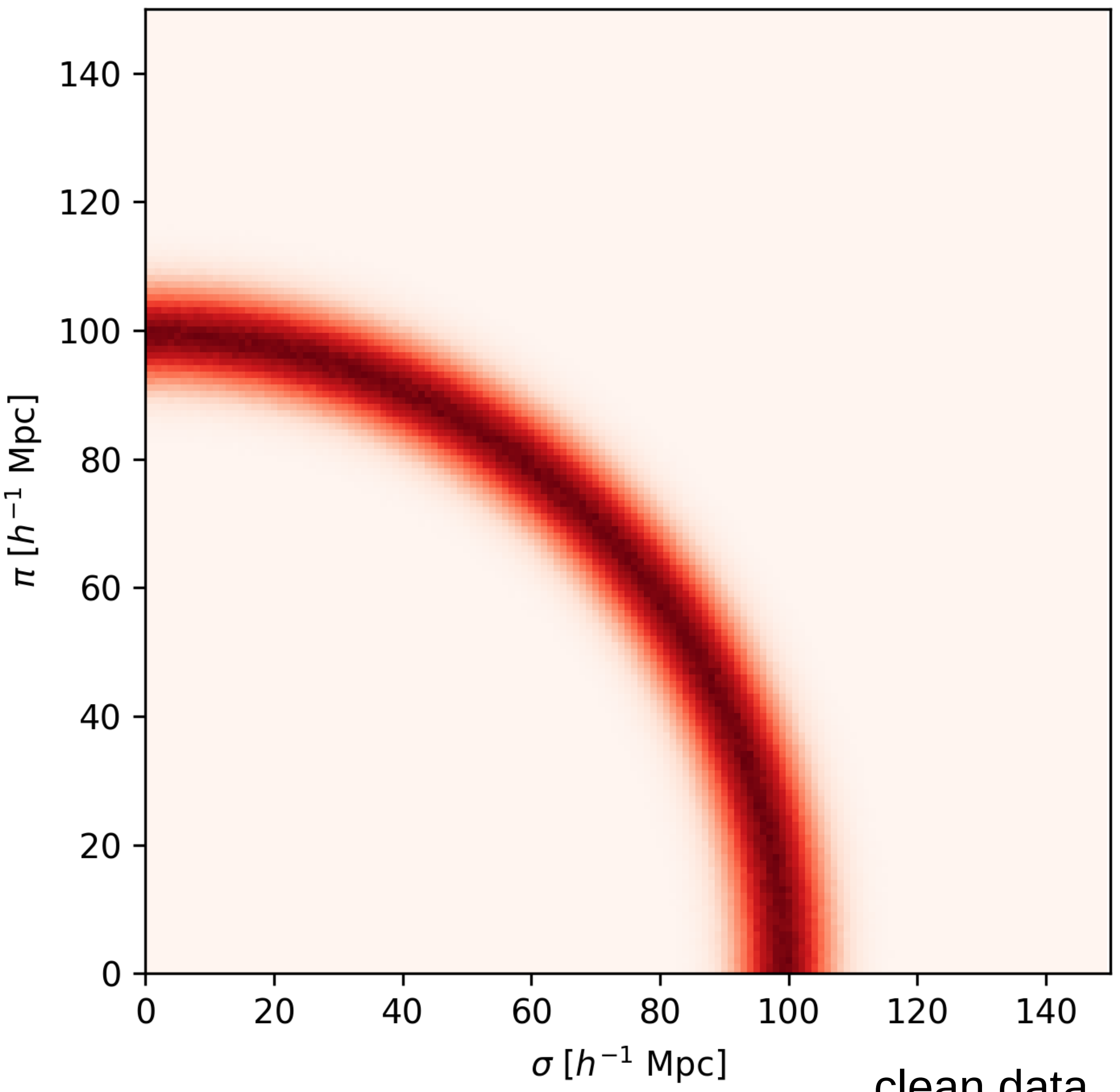

LRG DR9 South photometric
LRG DR9 South spectroscopic
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
18h 16h 14h 12h 10h 8h 6h 4h 2h 0h 22h
LRG DR9 South
Number of galaxies
0 50000 100000 150000 200000 250000 300000
0.2 0.4 0.6 0.8 1.0 1.2
photometric redshift

Photometric data from DESI

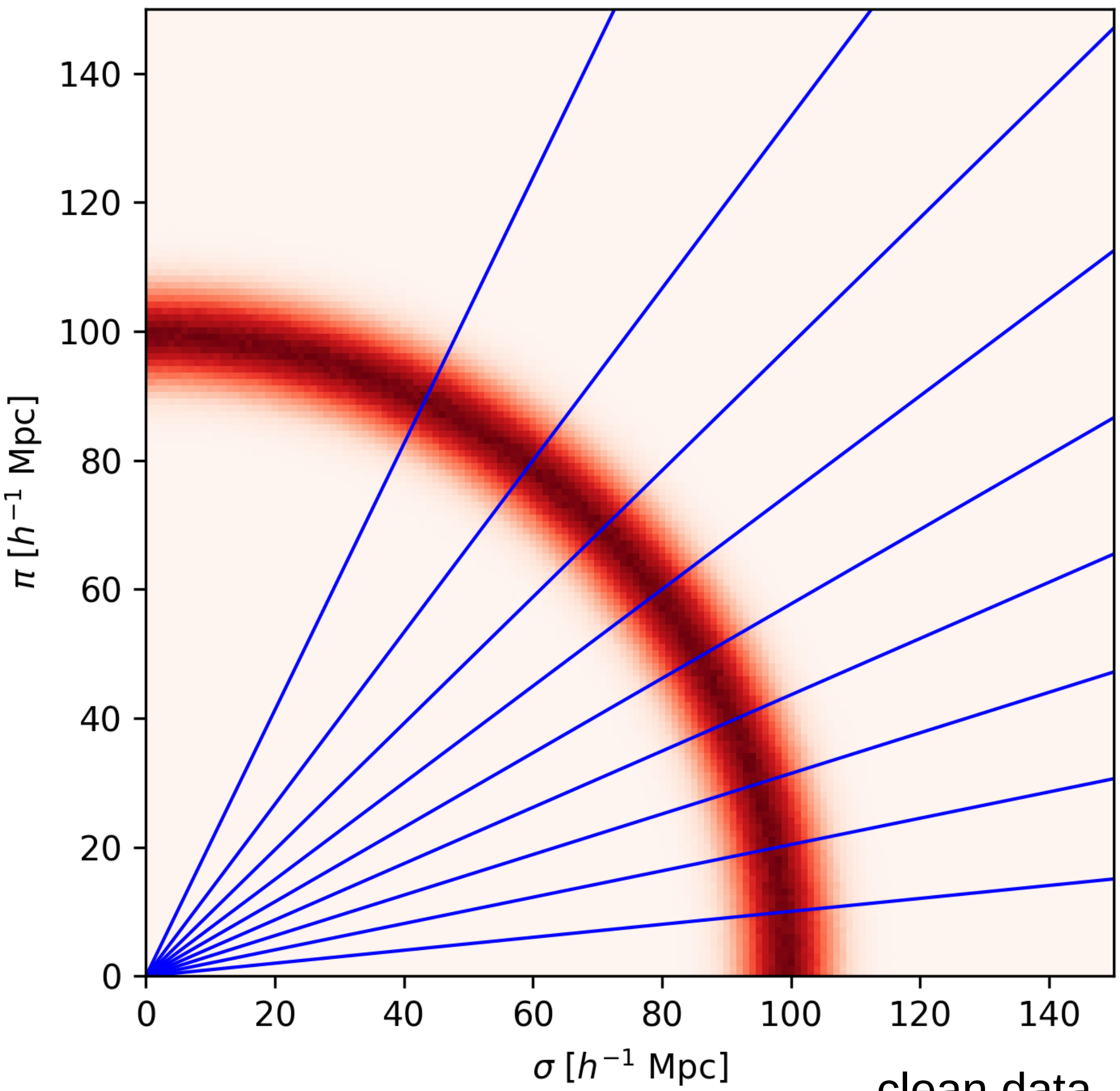
- Observational data from the DESI Legacy Imaging survey DR9
- Sridhar+ 2020 already did the Southern photometric footprint with DR8
- Original plan: update with DR9 and also include the Northern photometric footprint
- Improved LRG target selection

Why is it challenging?

- We can only use the lower μ-bins, signal gets washed out in the others.
- Systematic shift of the photometric BAO as a function of μ.
- Chan+2021 found a similar effect and also a possible solution, but there is more to it.
- Systematic shift of the BAO peak location when comparing spectroscopic and photometric data!

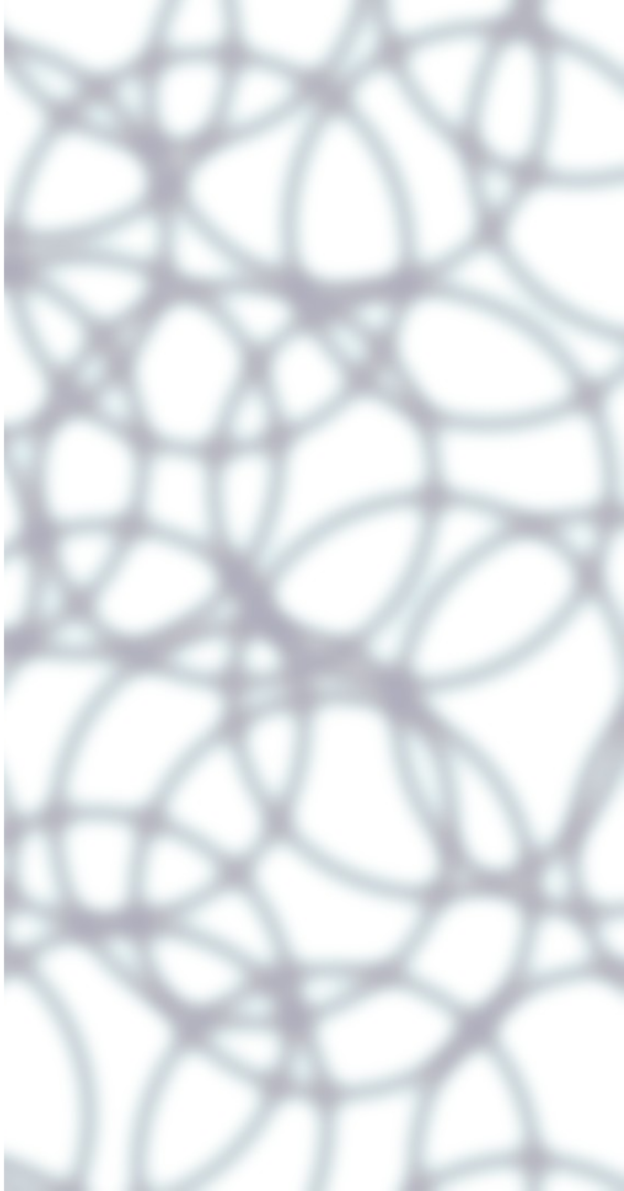


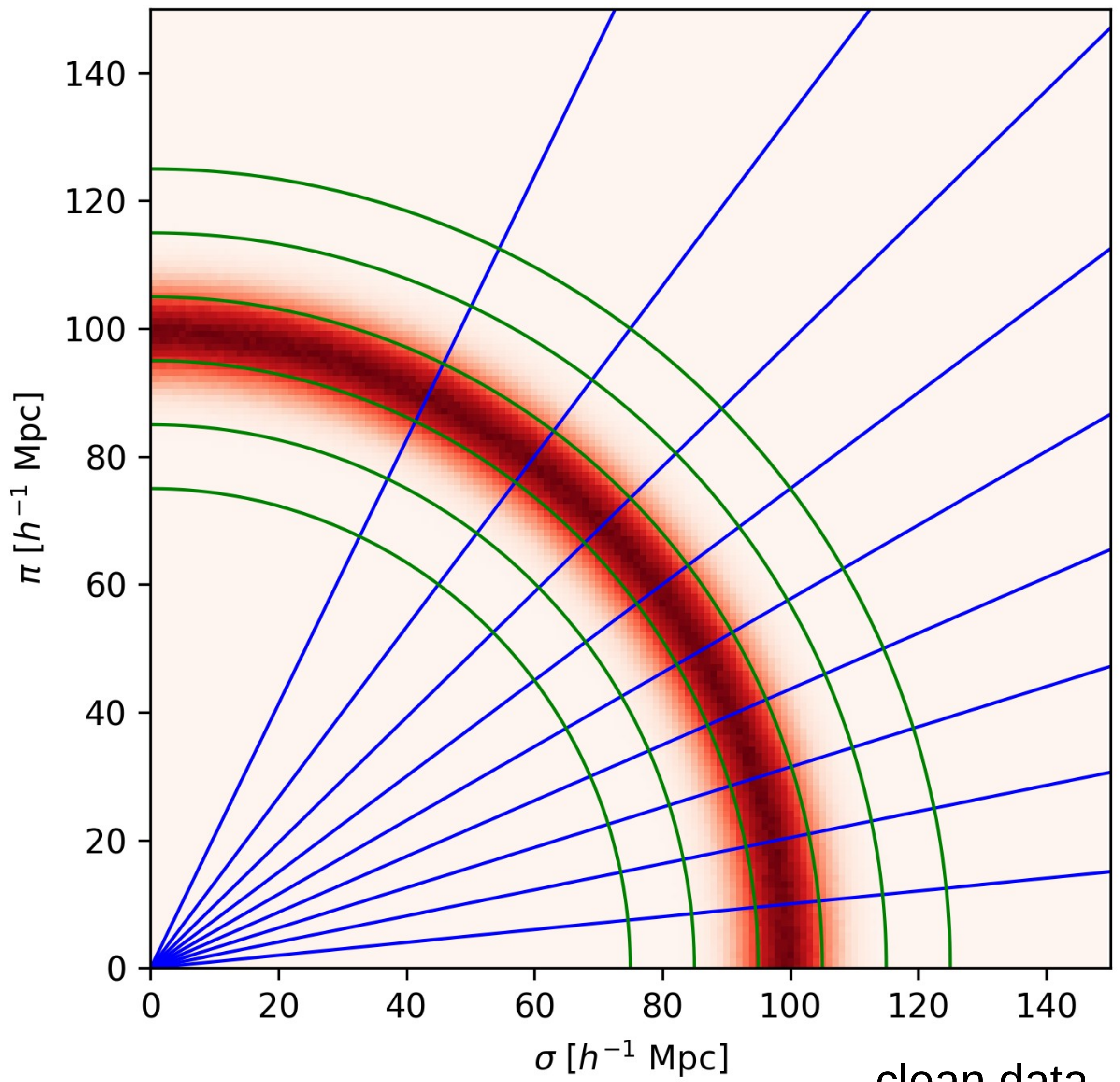
clean data



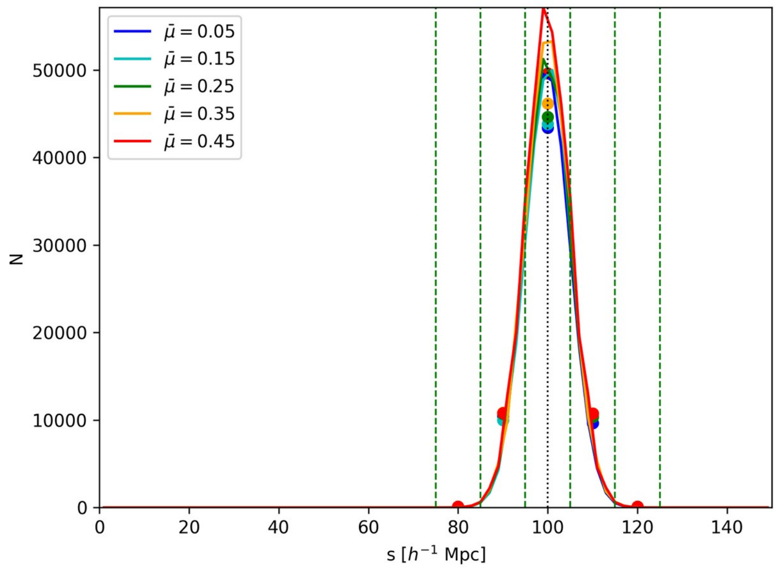
140
120
100
80
60
40
20
0
π [h^{-1} Mpc]
0 20 40 60 80 100 120 140
σ [h^{-1} Mpc]

clean data



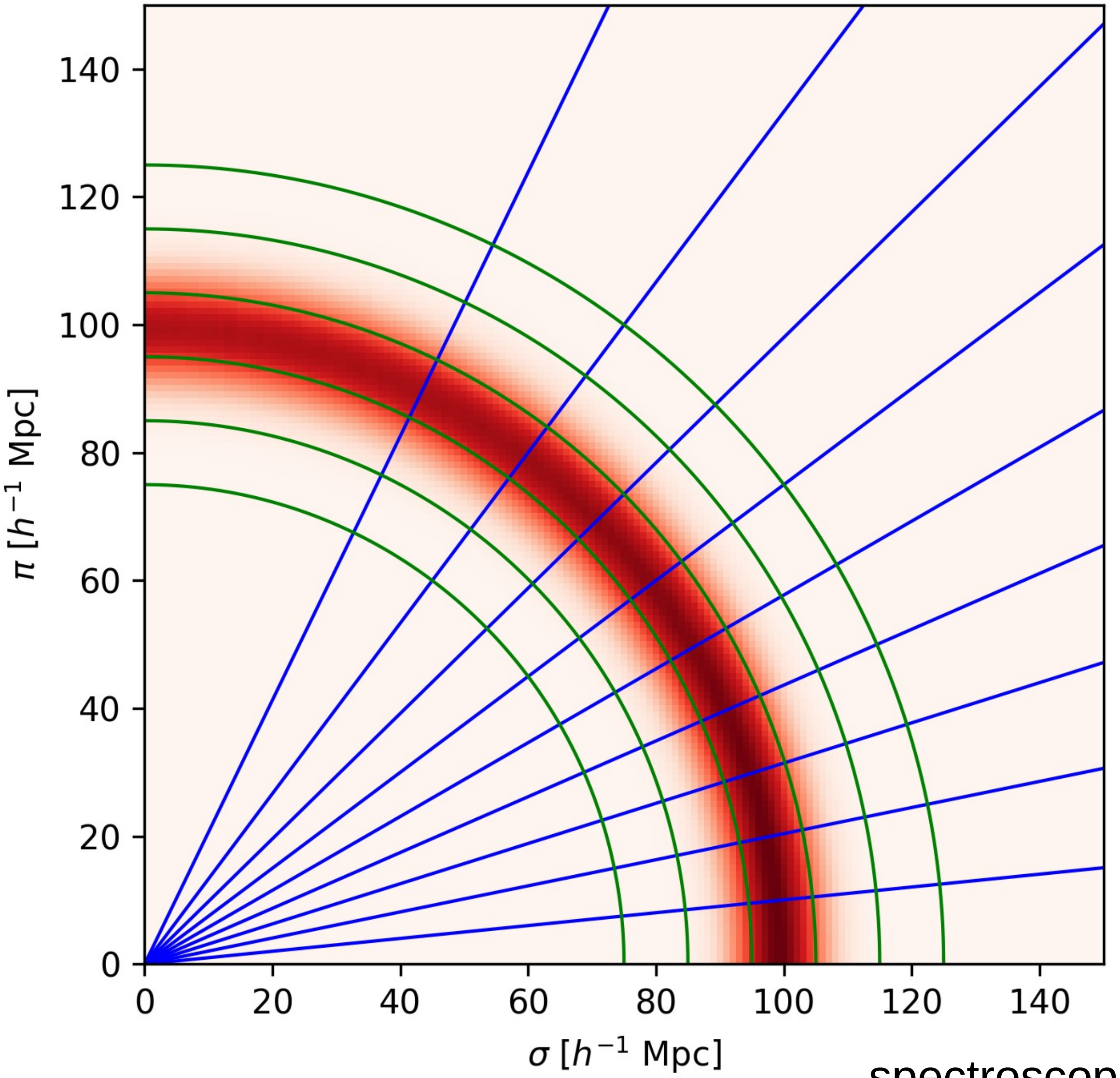


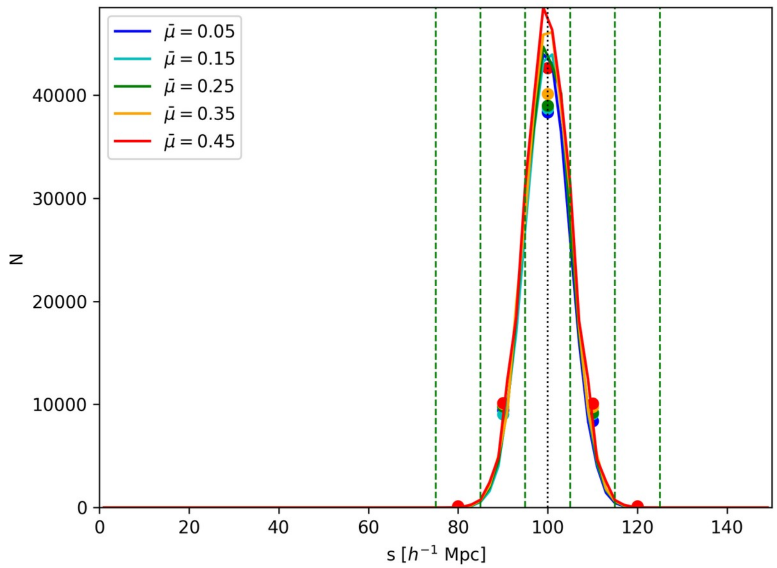
$\pi\ [h^{-1}\ \mathrm{Mpc}]$
$\sigma\ [h^{-1}\ \mathrm{Mpc}]$
0
20
40
60
80
100
120
140



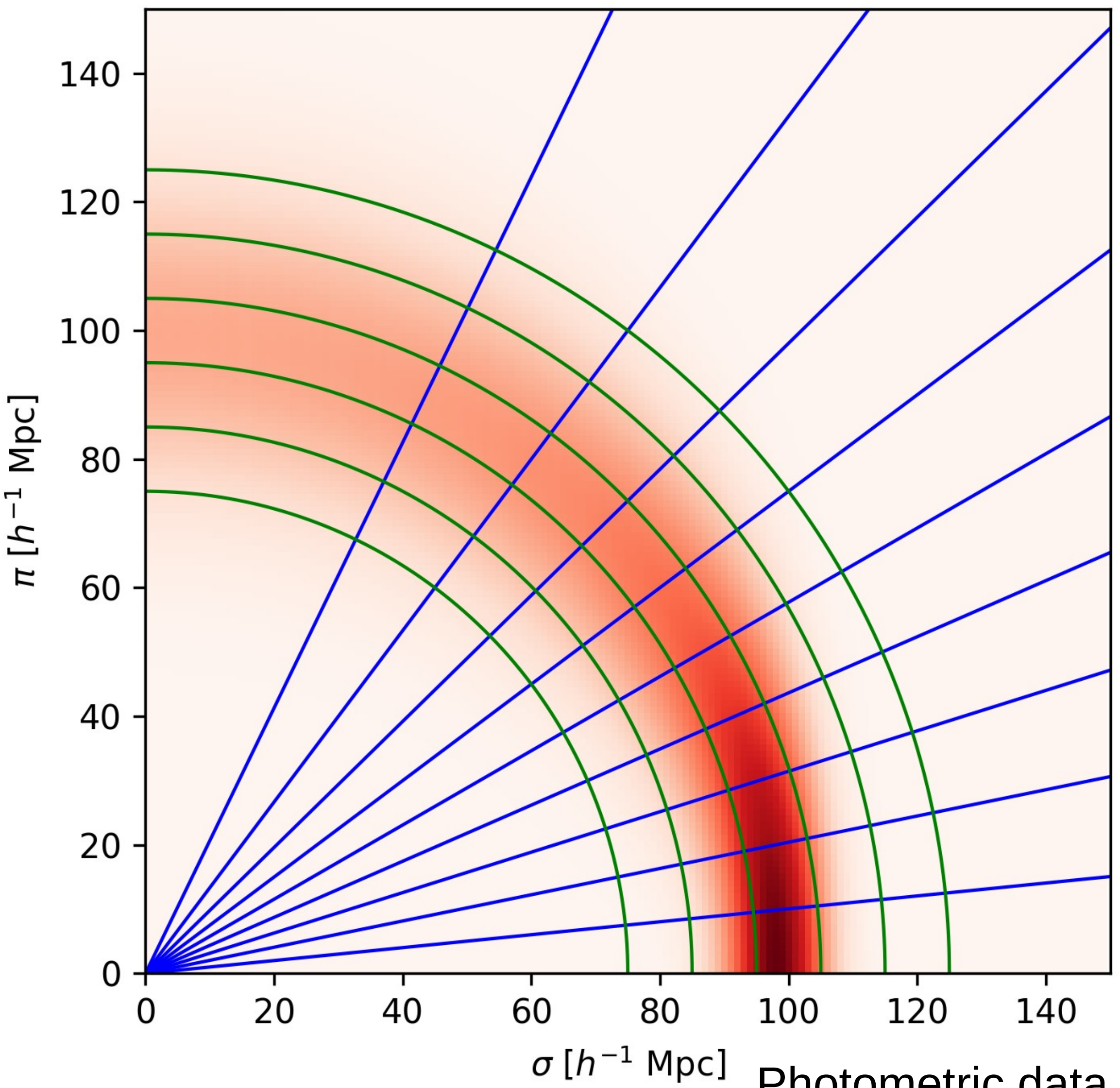
$\bar{\mu} = 0.05$
$\bar{\mu} = 0.15$
$\bar{\mu} = 0.25$
$\bar{\mu} = 0.35$
$\bar{\mu} = 0.45$
N
s $[h^{-1}$ Mpc]
0
10000
20000
30000
40000
50000
0
20
40
60
80
100
120
140

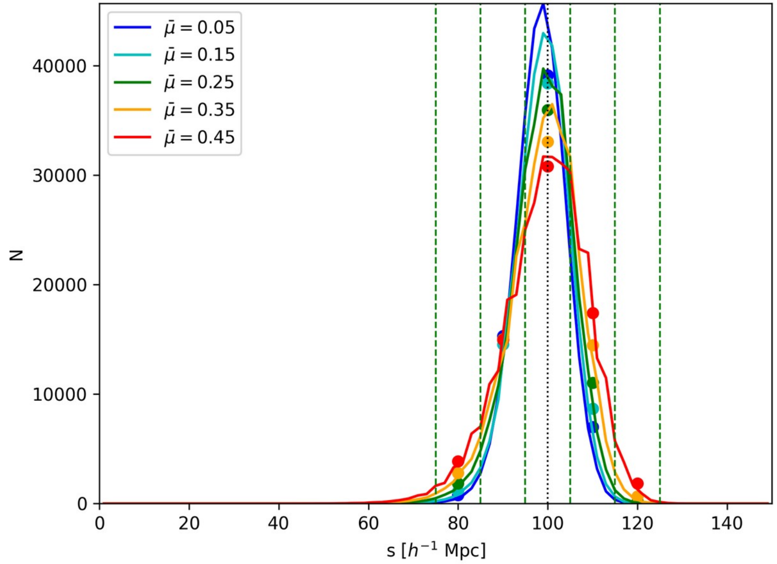
clean data



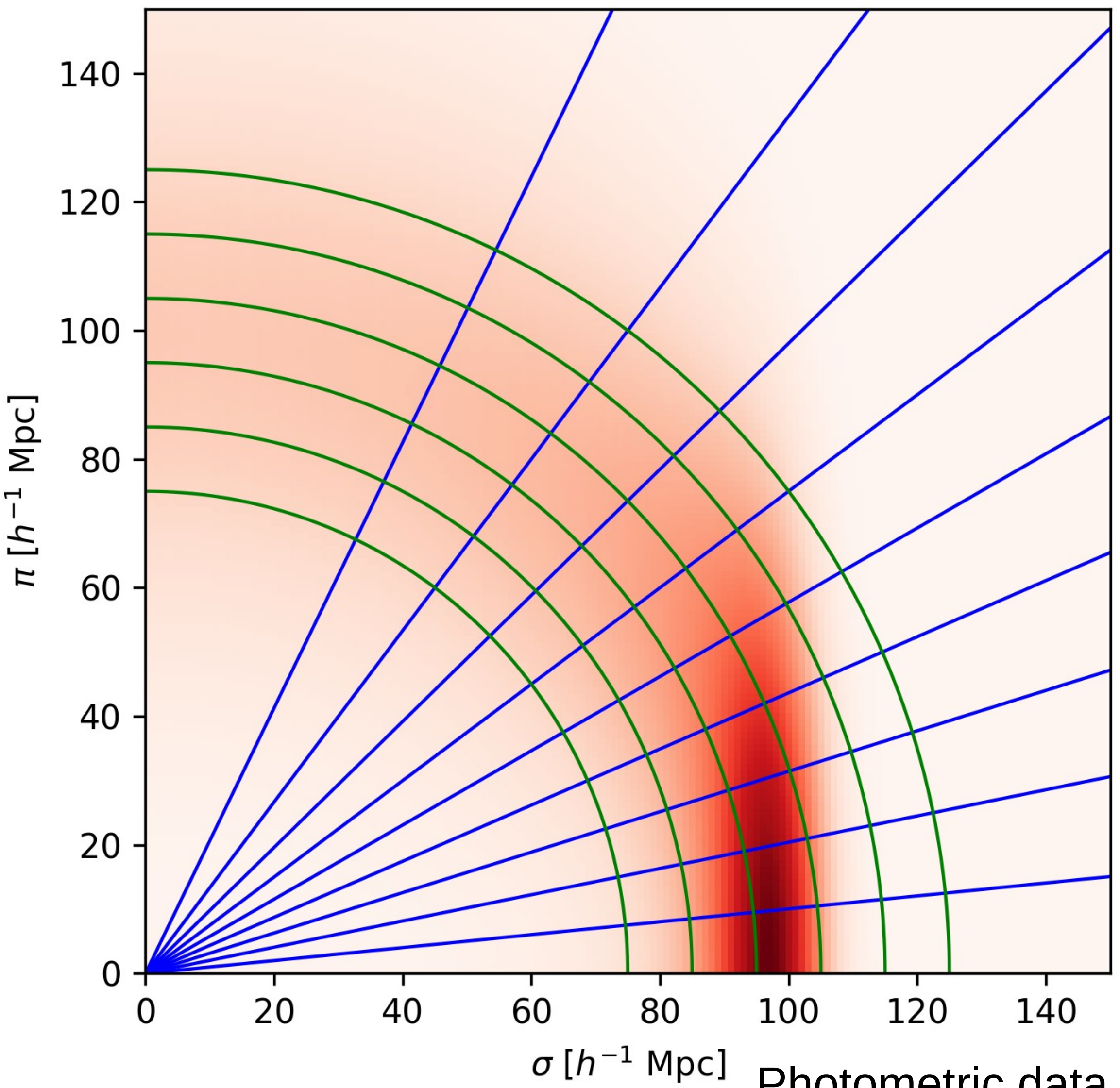


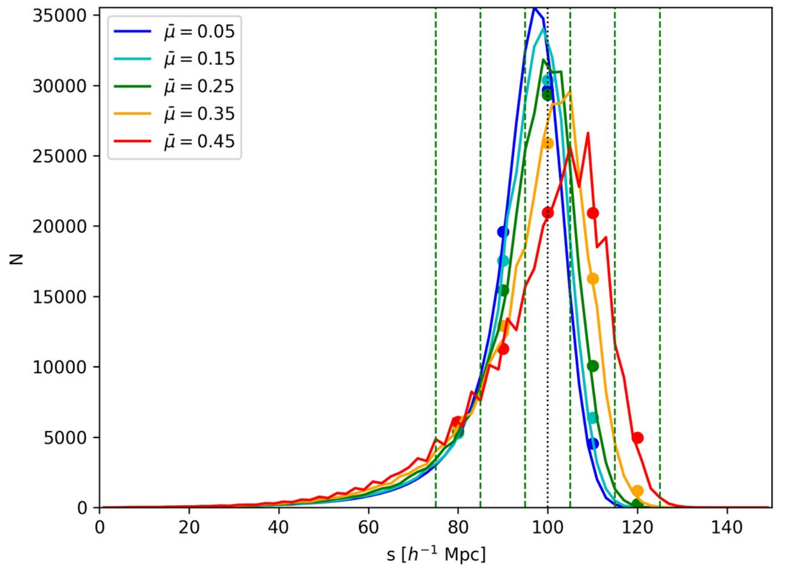
spectroscopic data



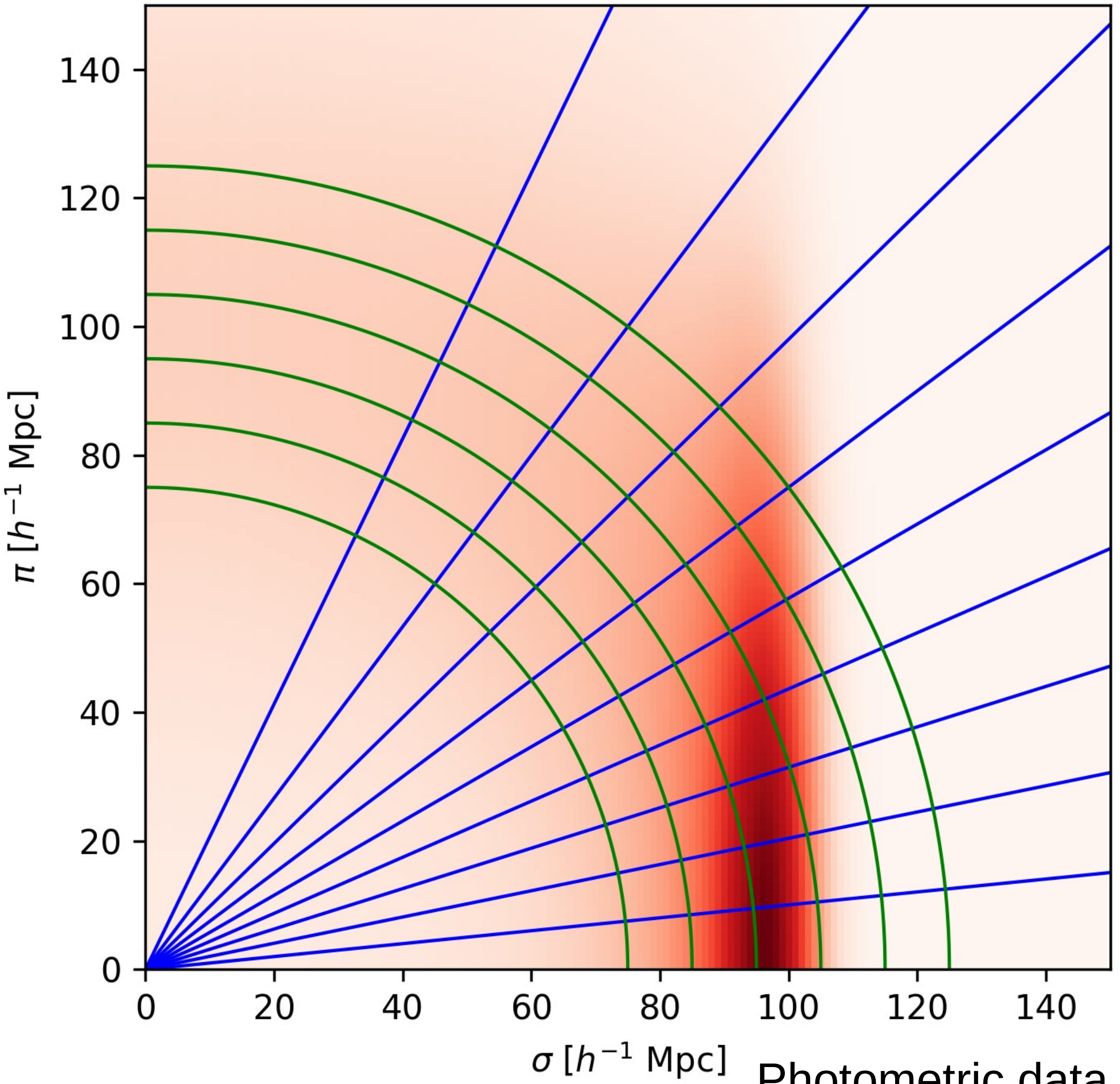


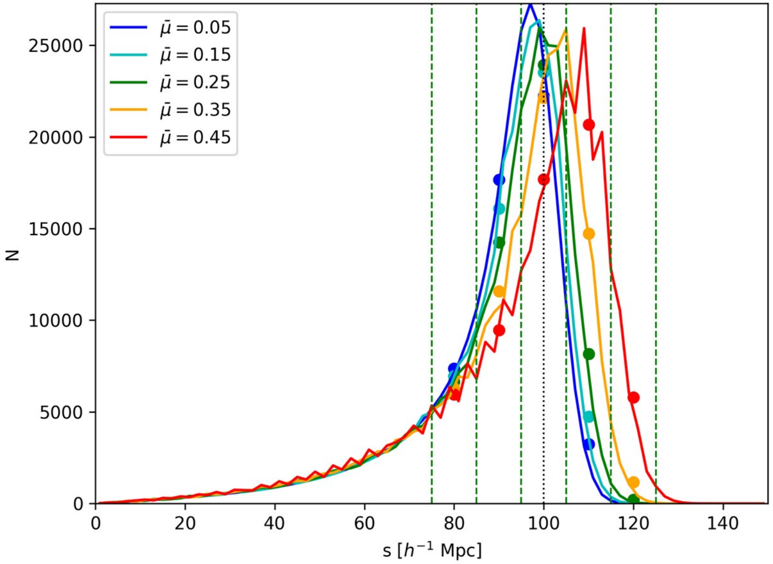
Photometric data σ_0=0.005



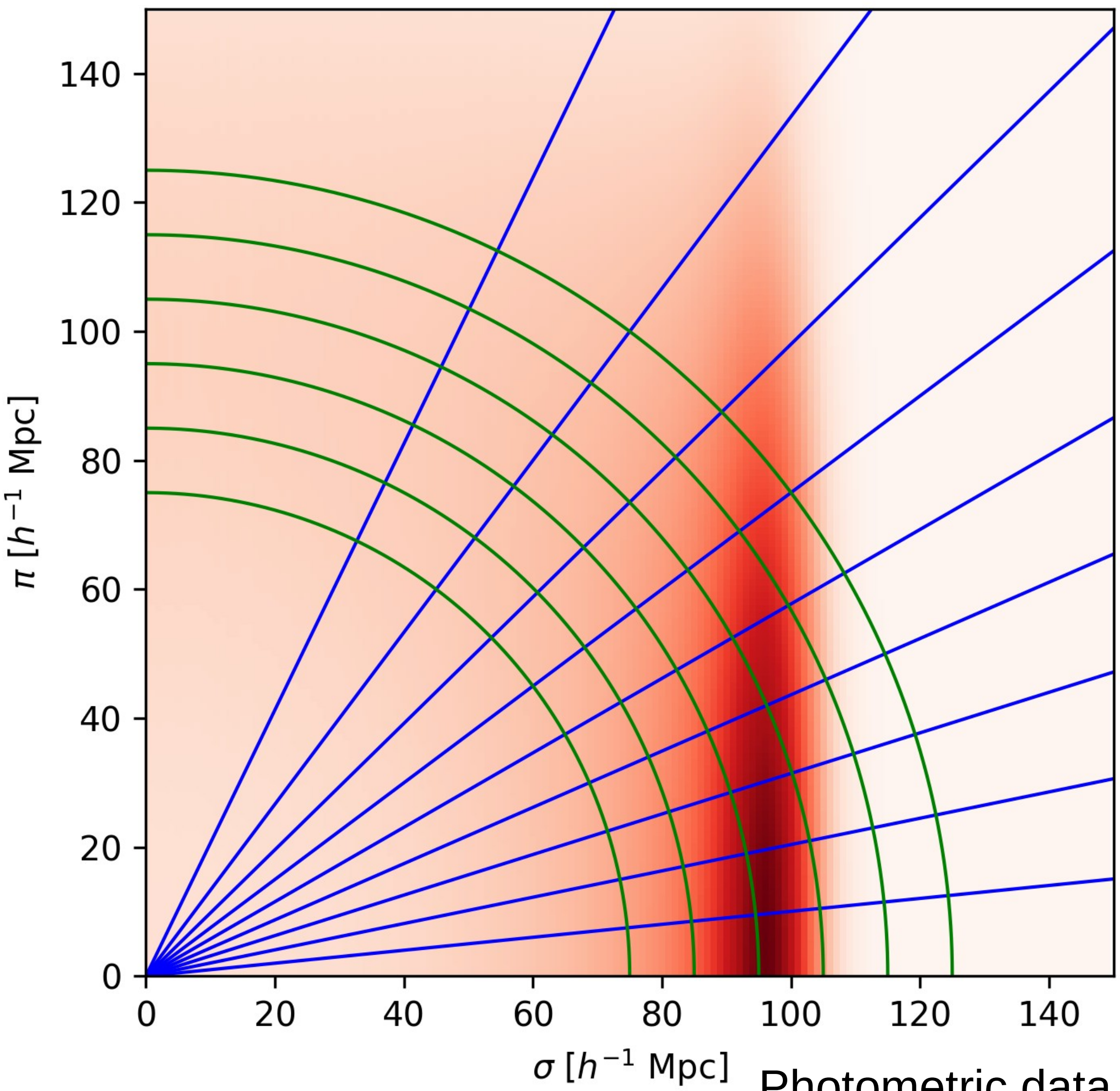


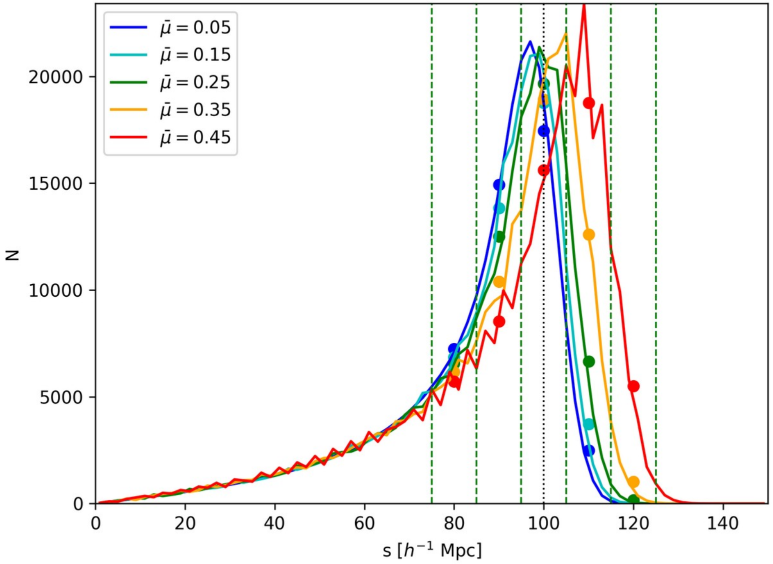
Photometric data σ_0=0.010



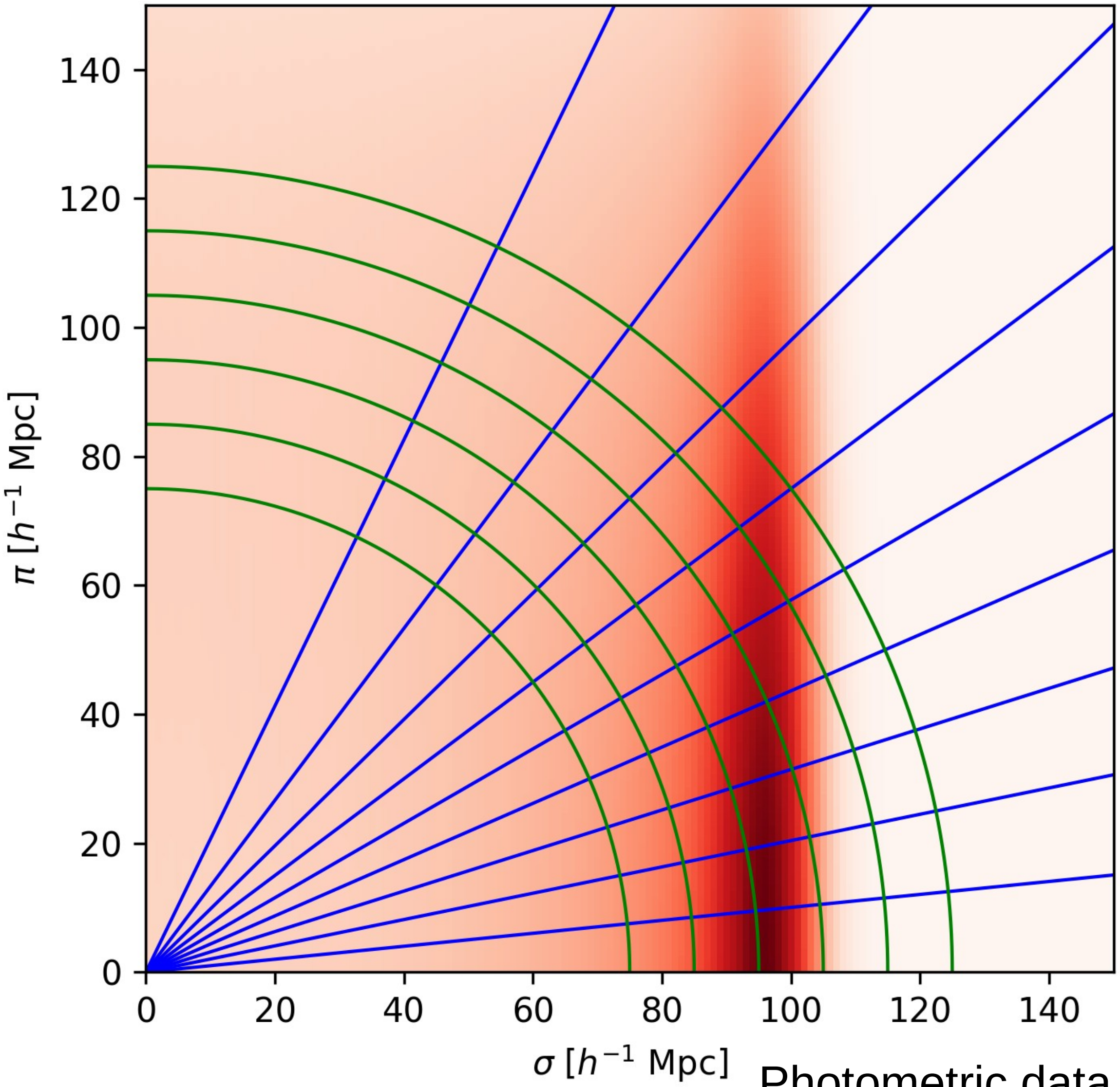


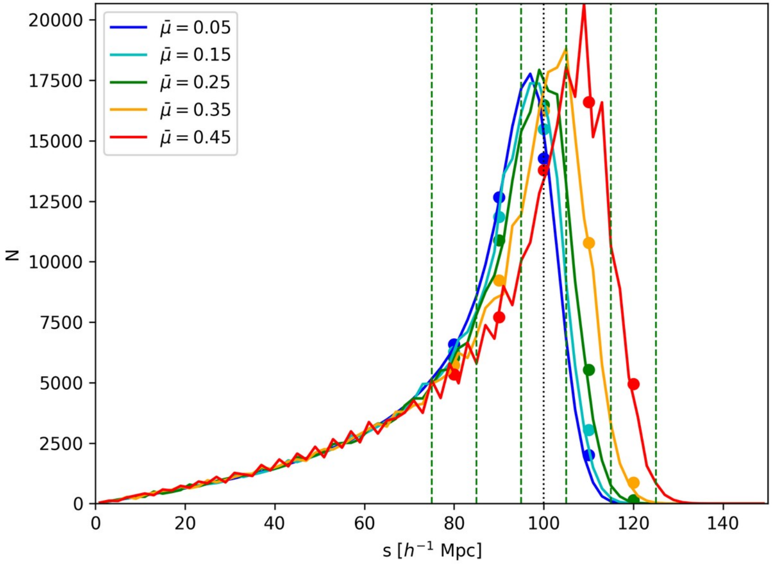
Photometric data σ_0=0.015



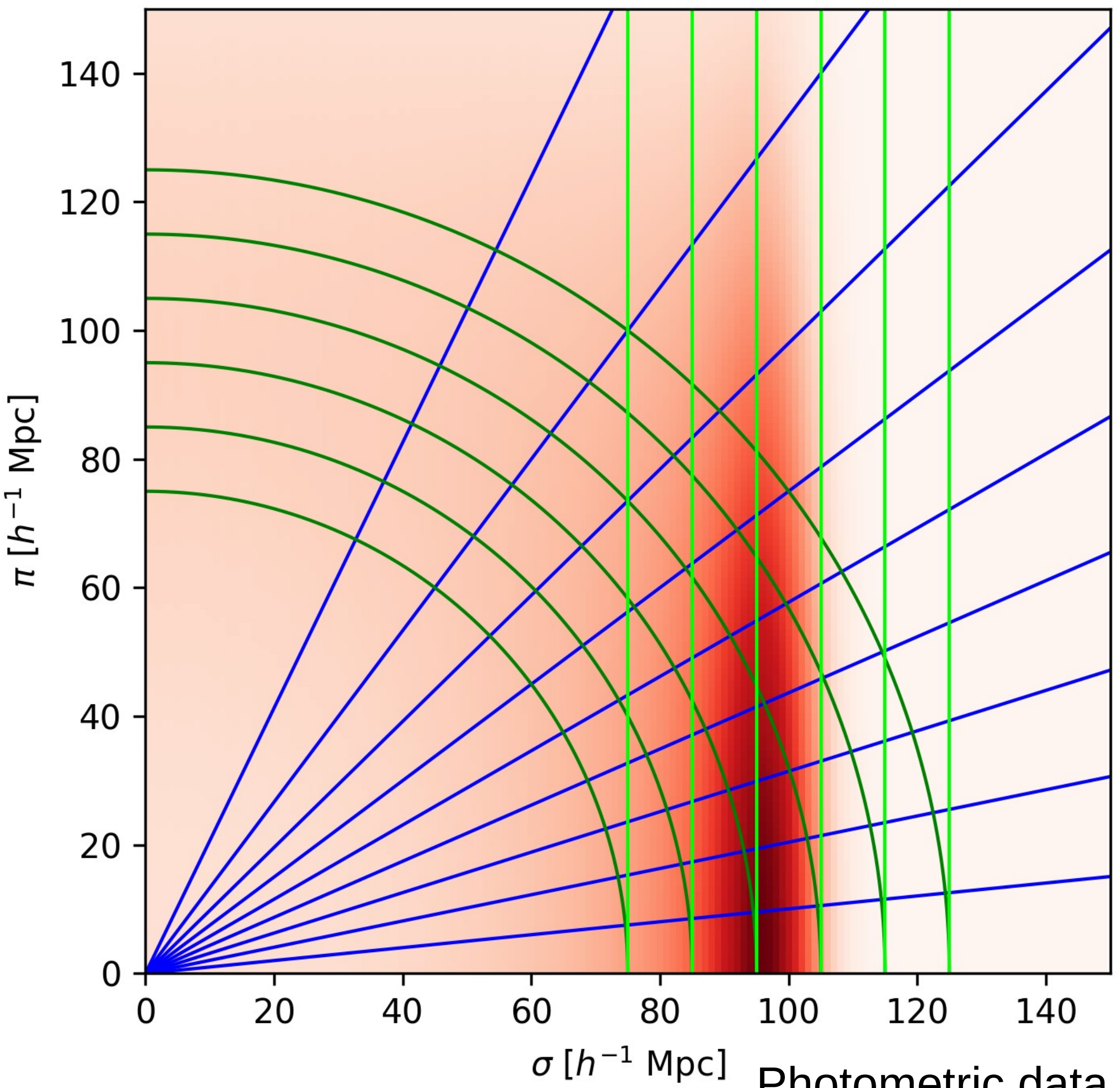


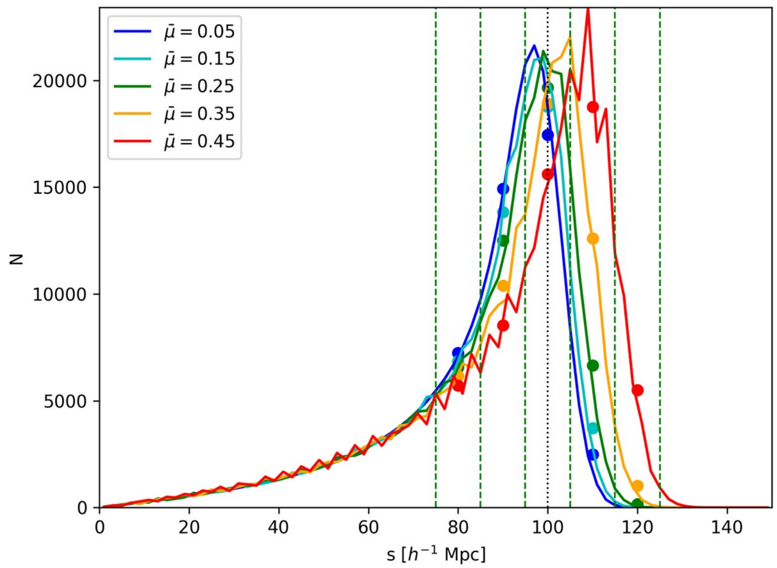
Photometric data σ_0=0.020

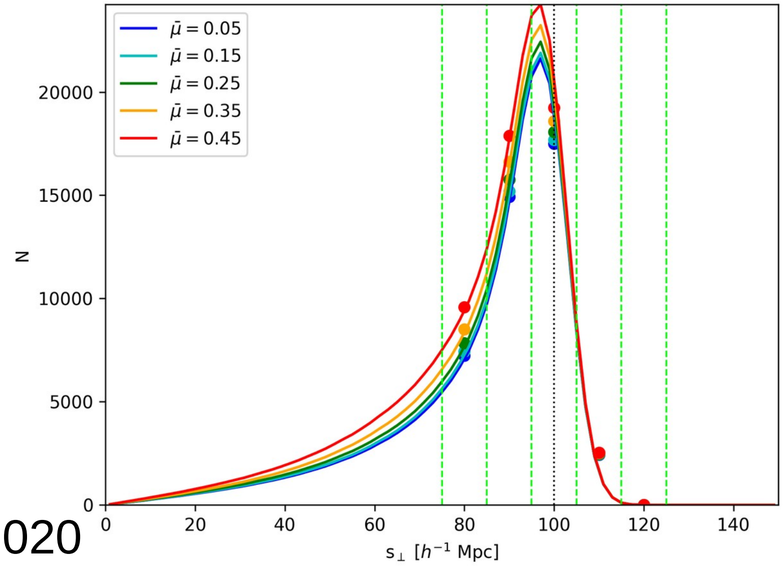




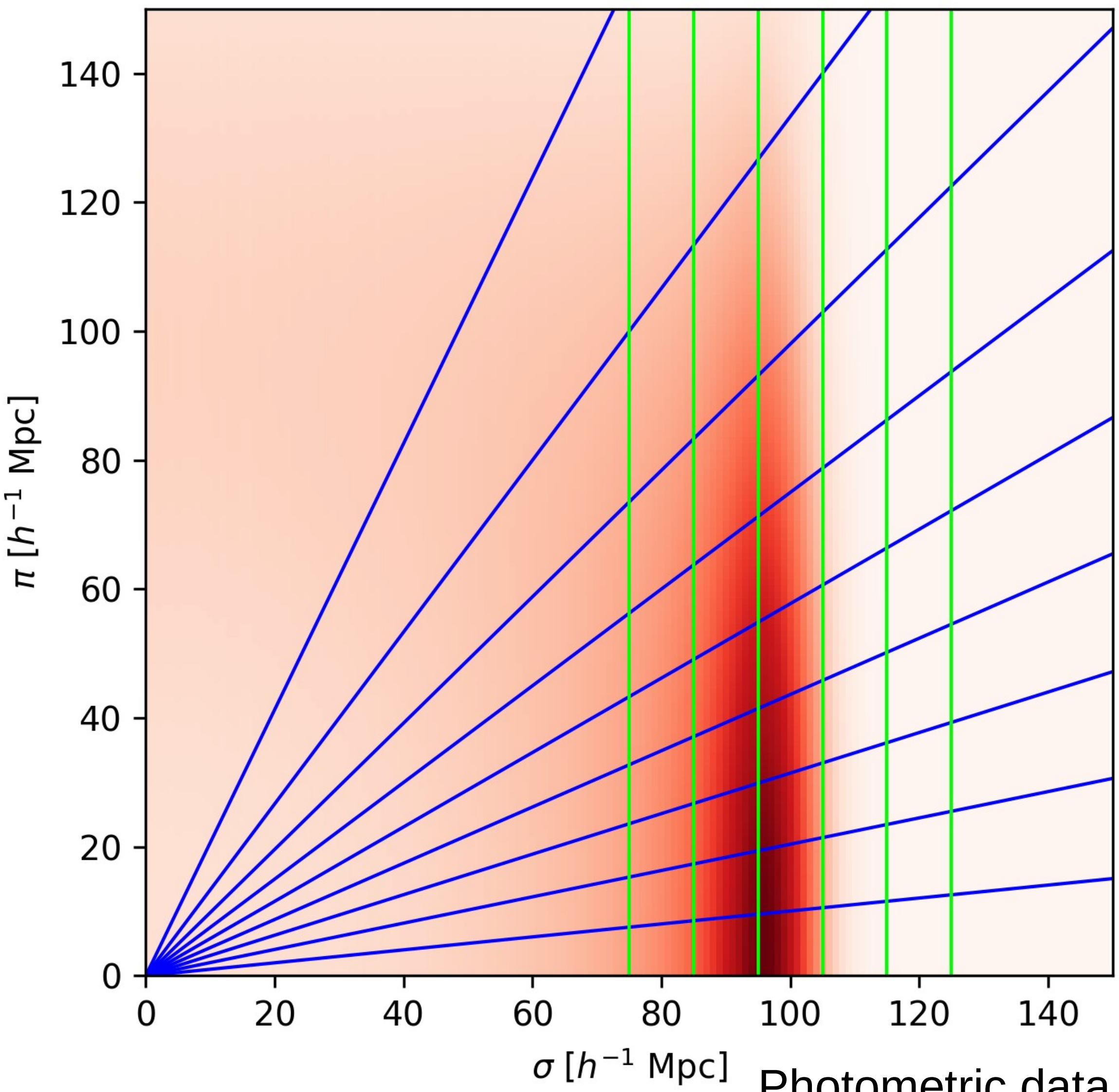
Photometric data σ_0=0.025

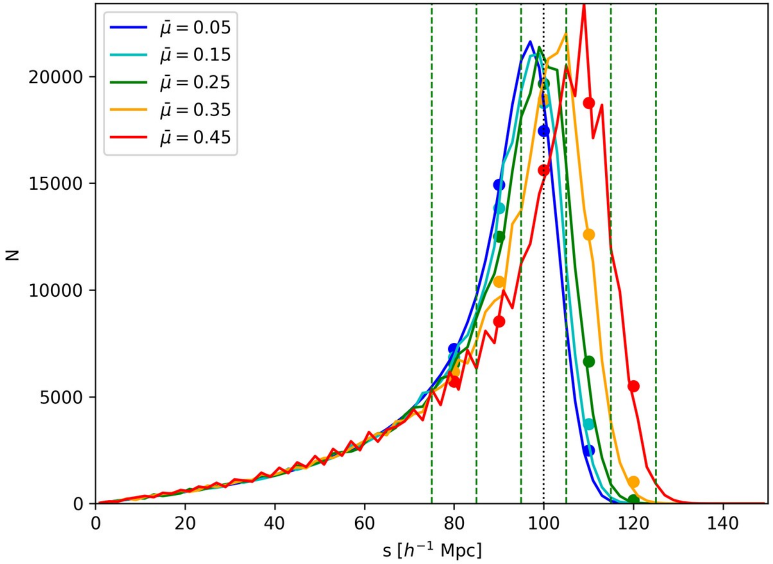


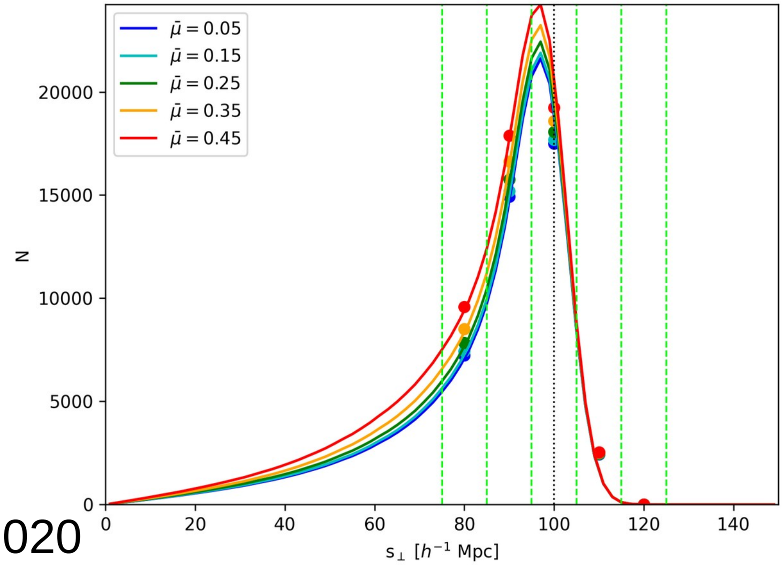




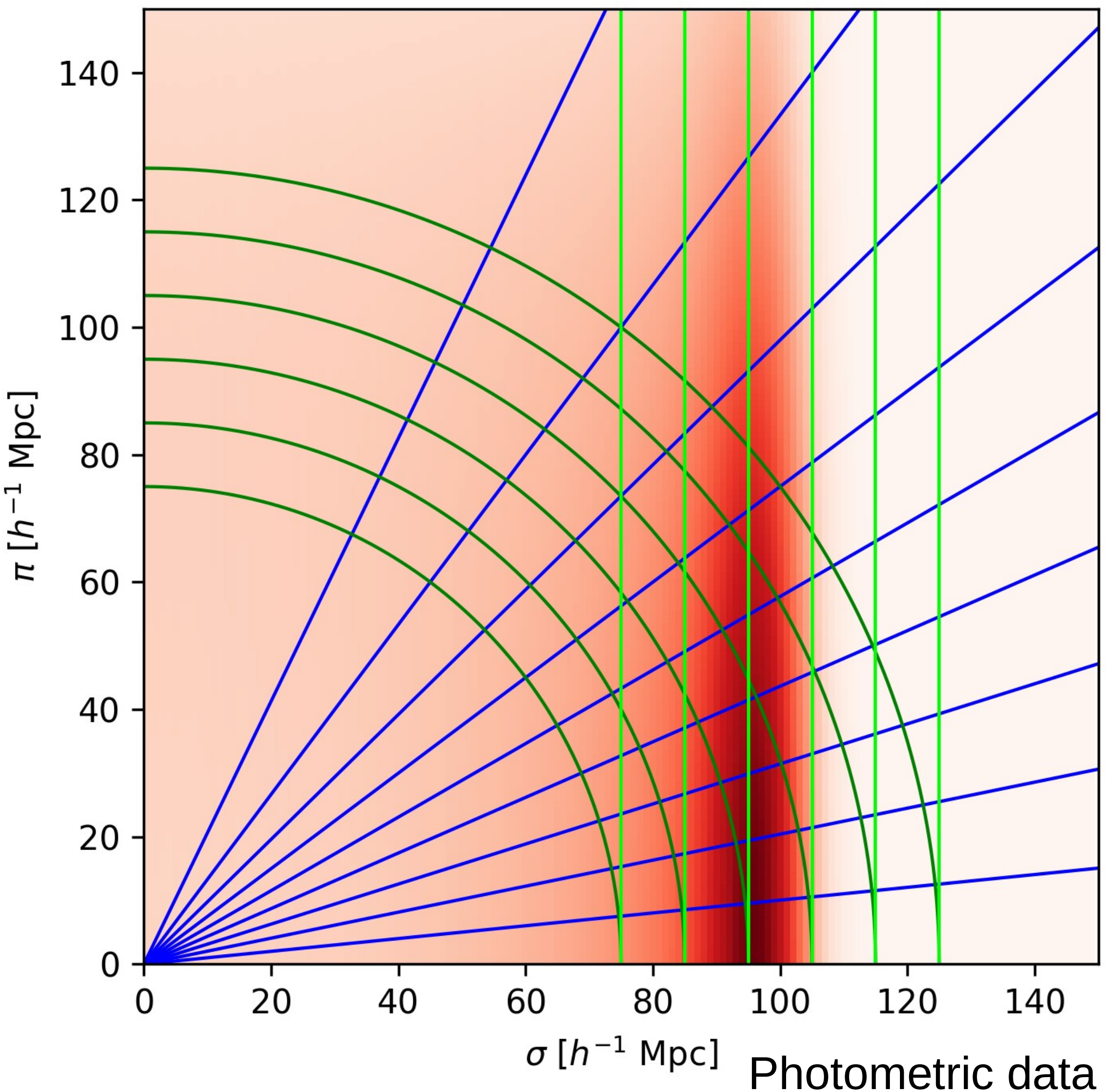
Photometric data σ_0=0.020

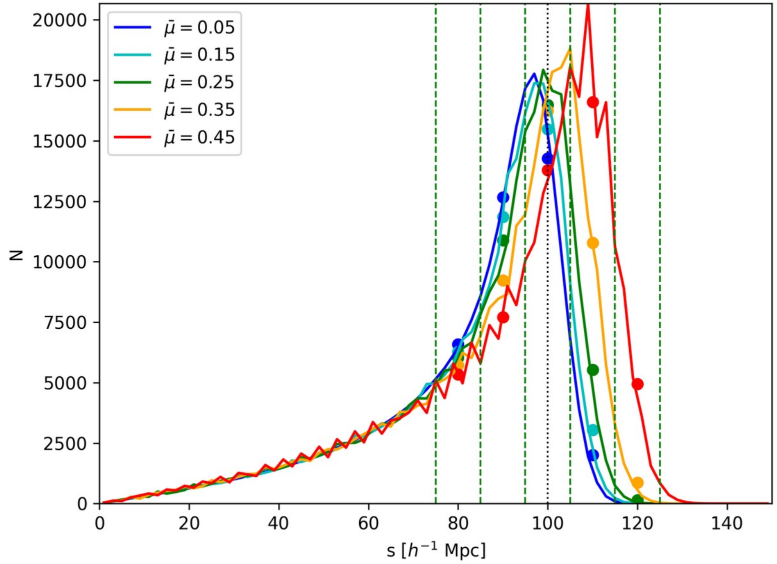


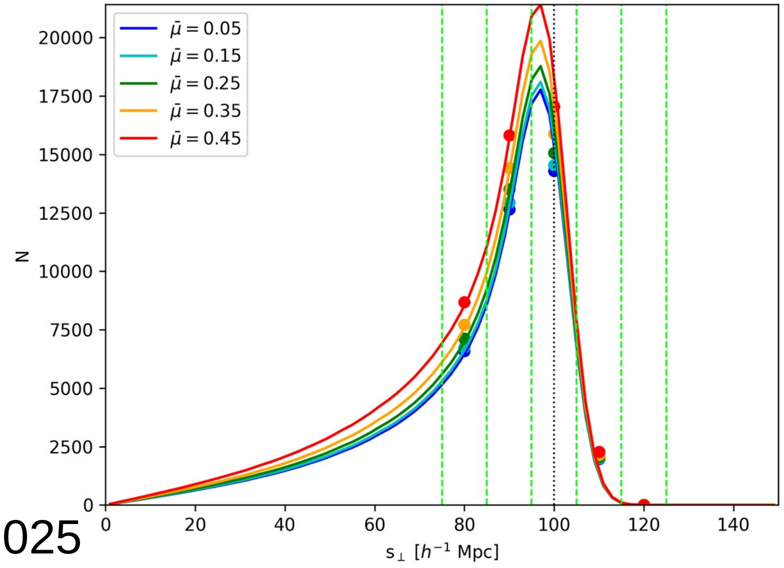




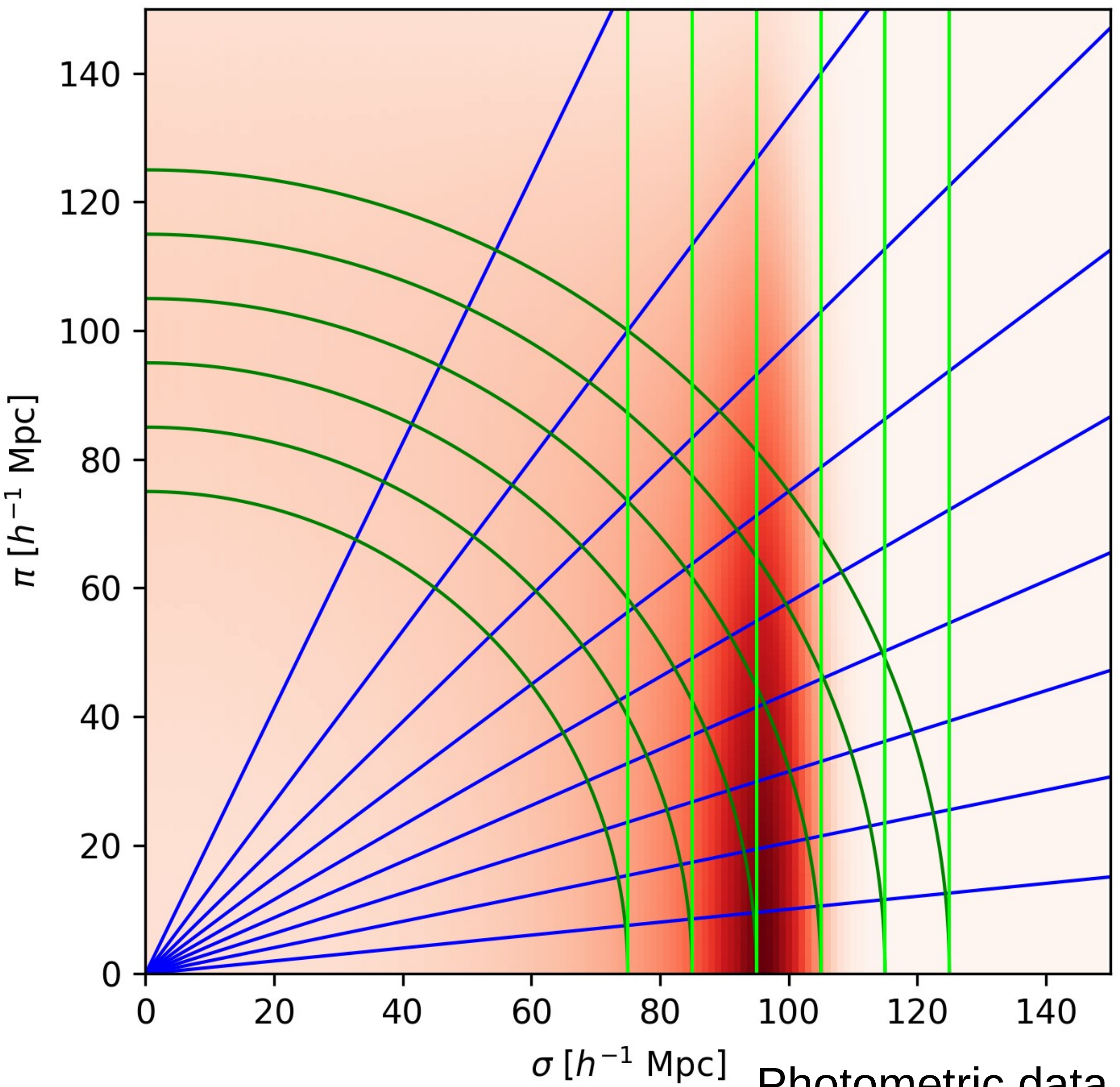
Photometric data σ_0=0.020

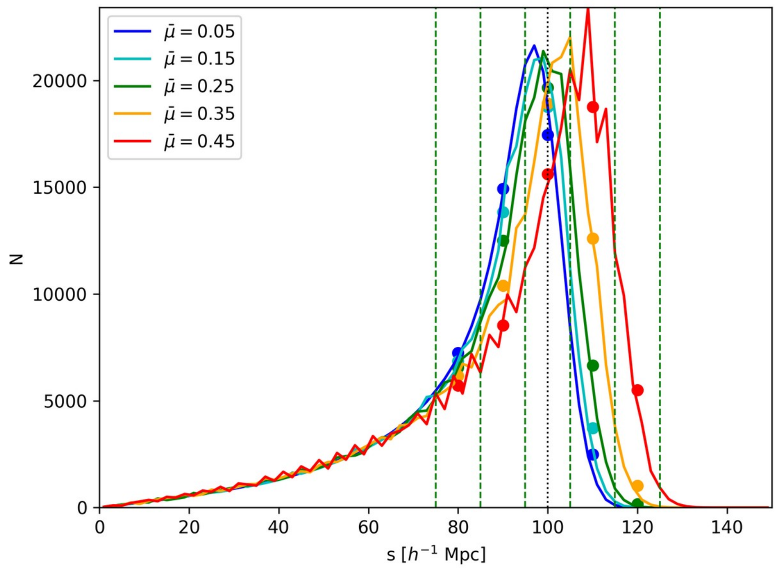


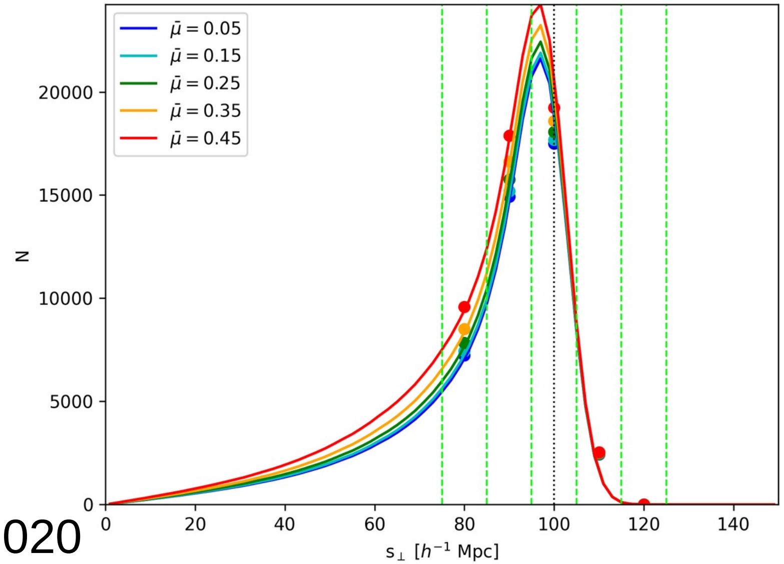




Photometric data σ_0=0.025







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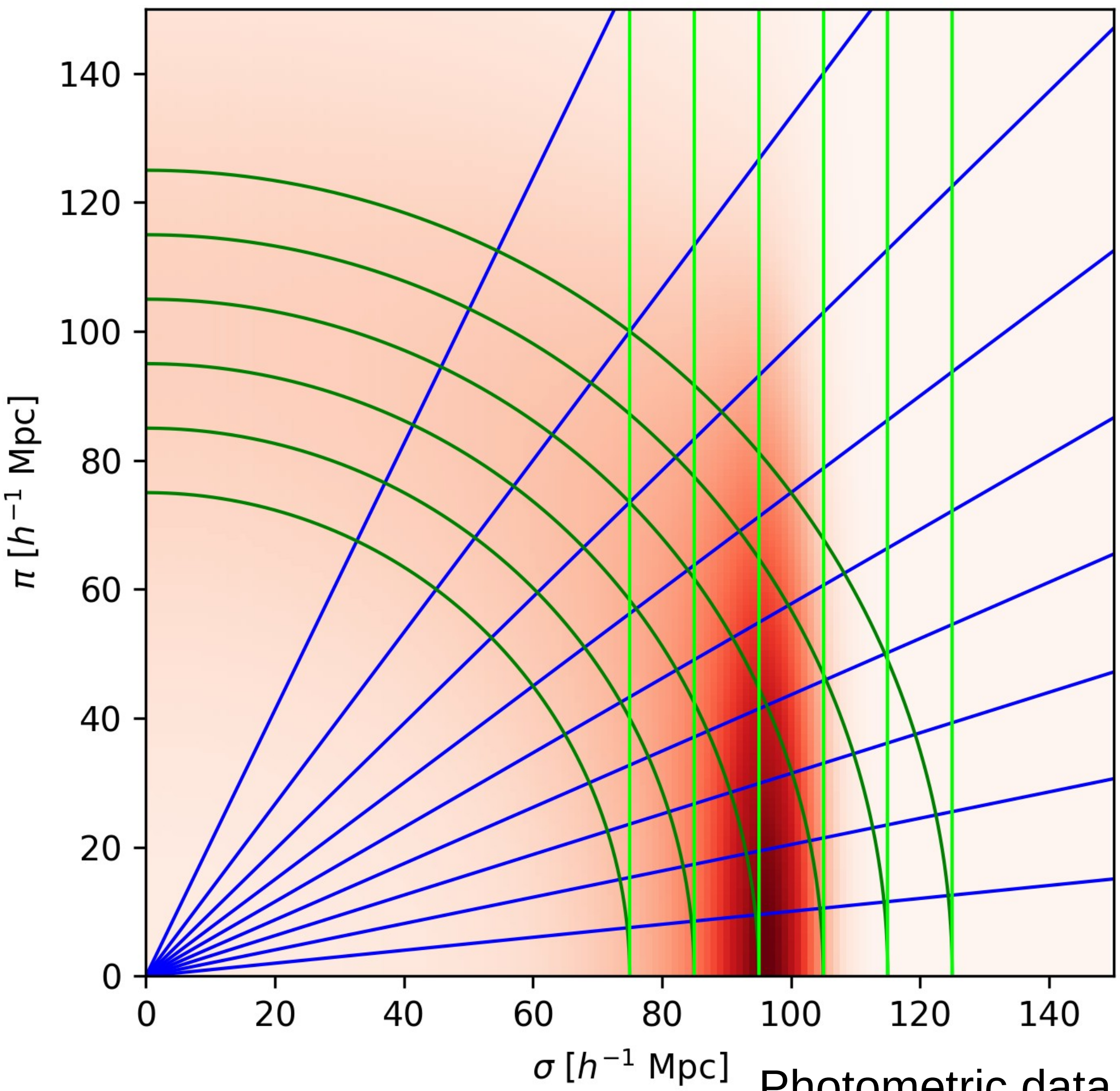
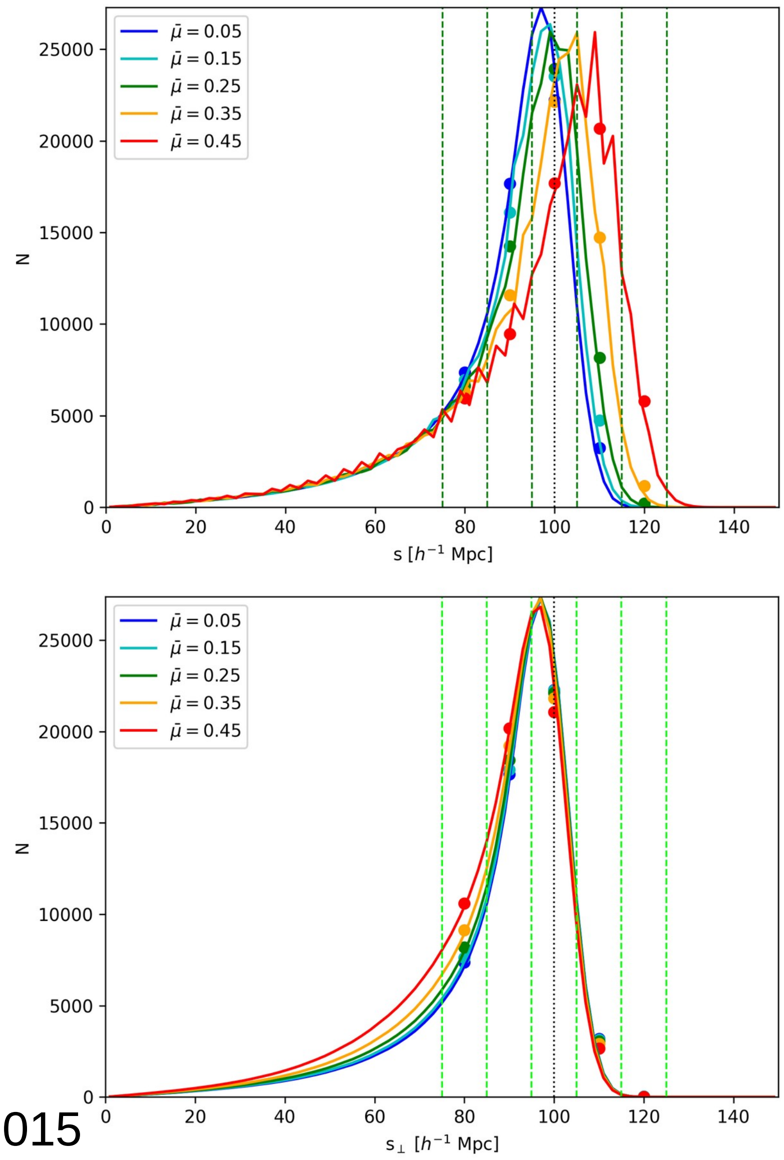
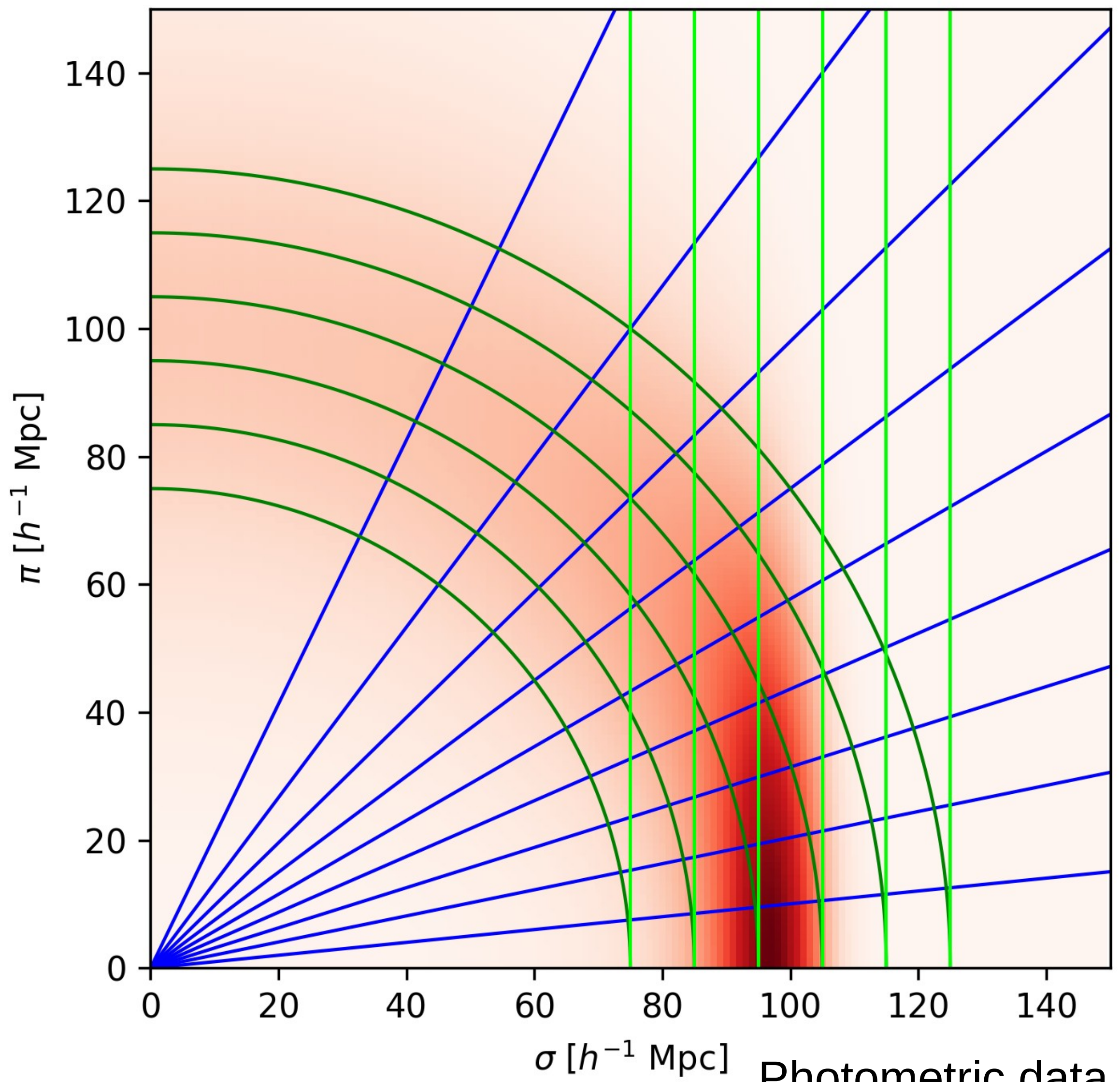
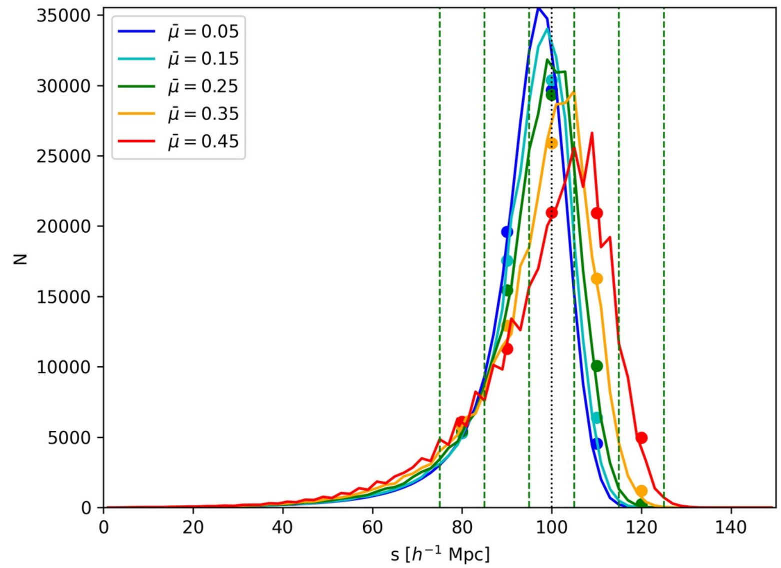
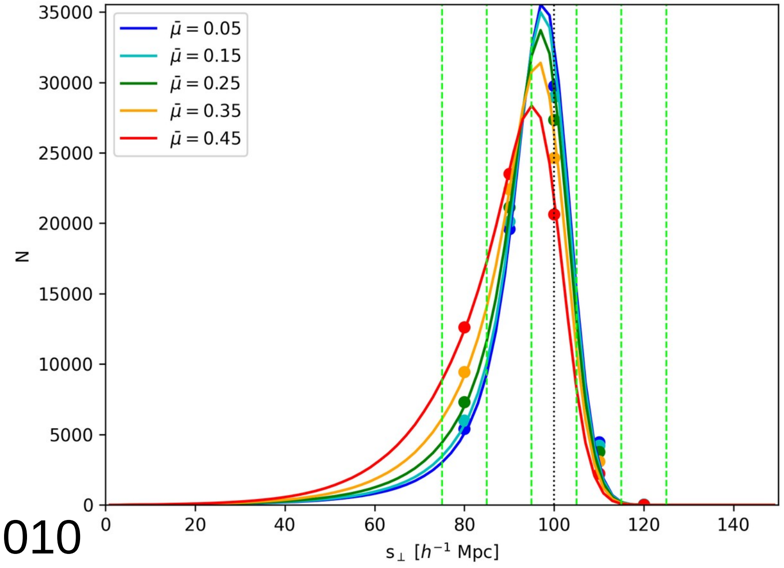




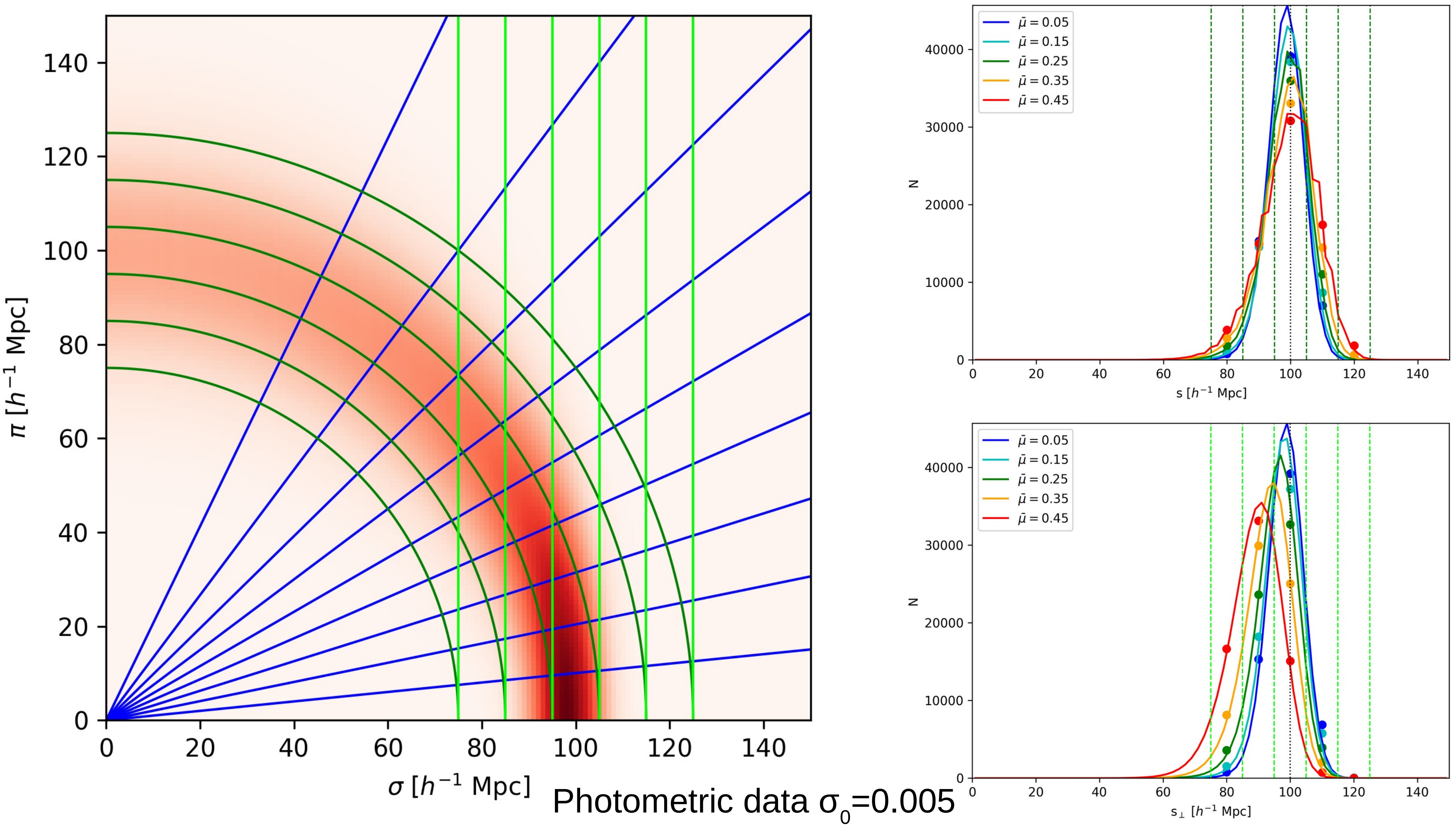
Photometric data σ_0=0.015



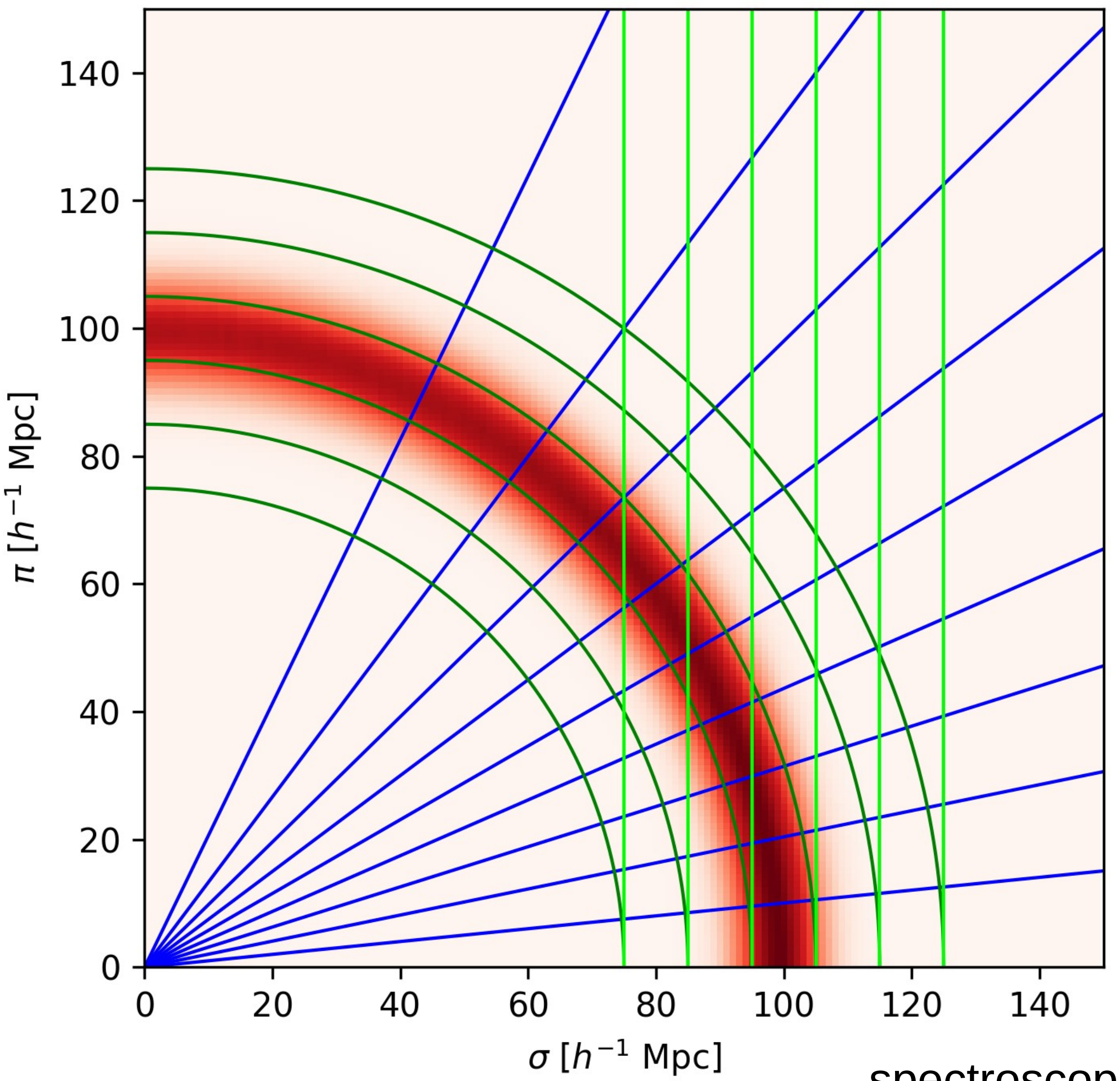




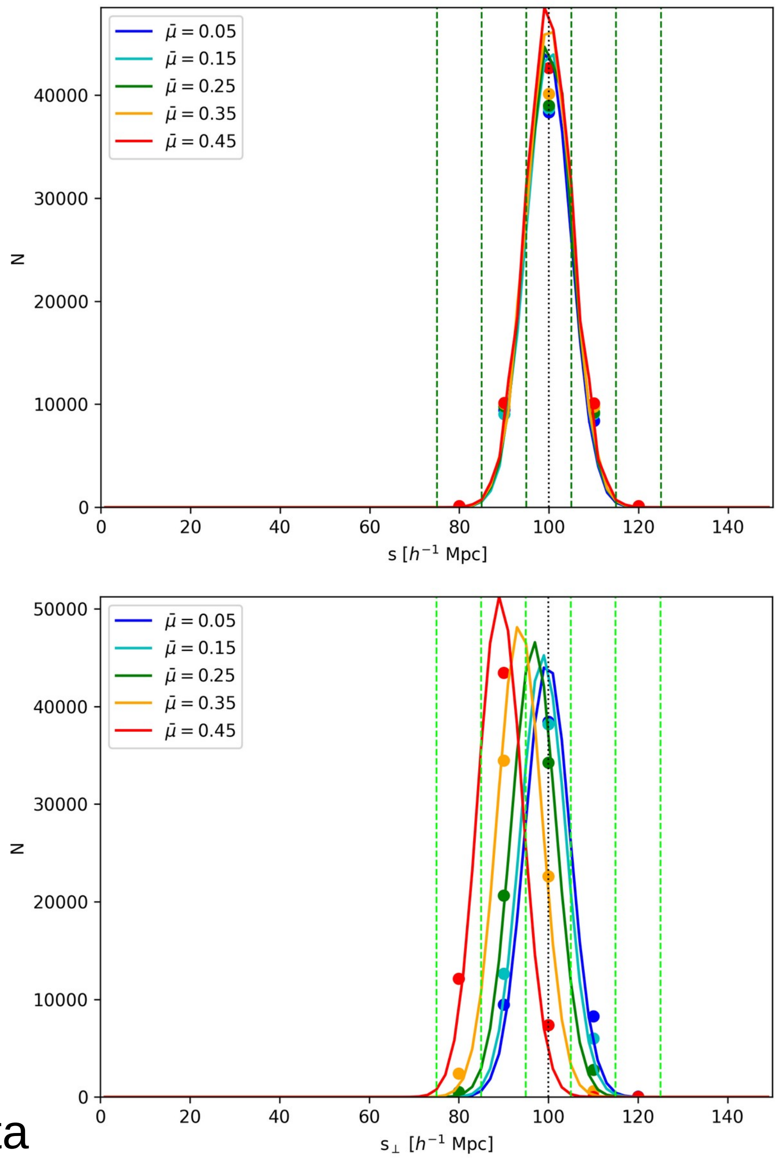
Photometric data σ_0=0.010

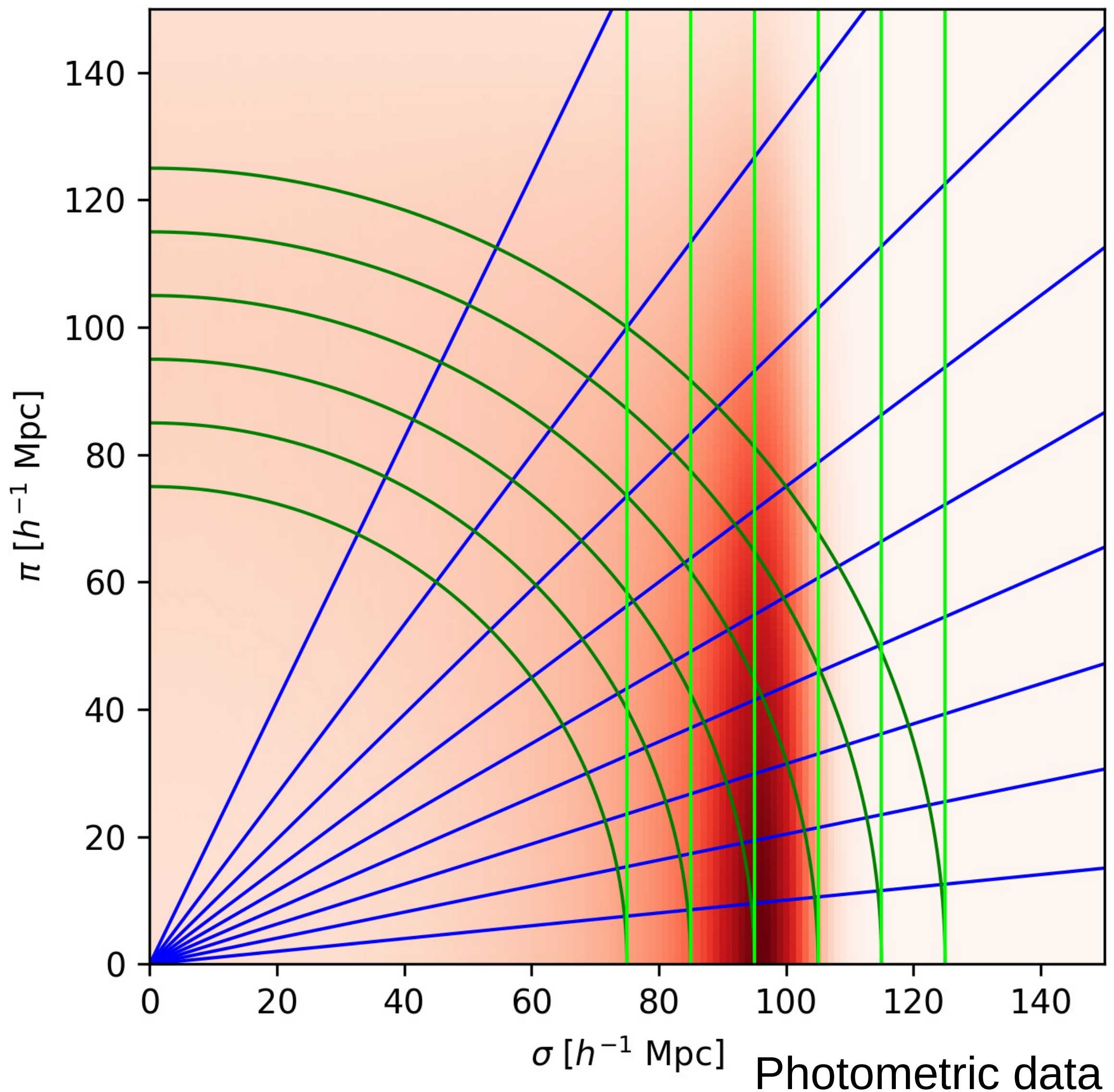


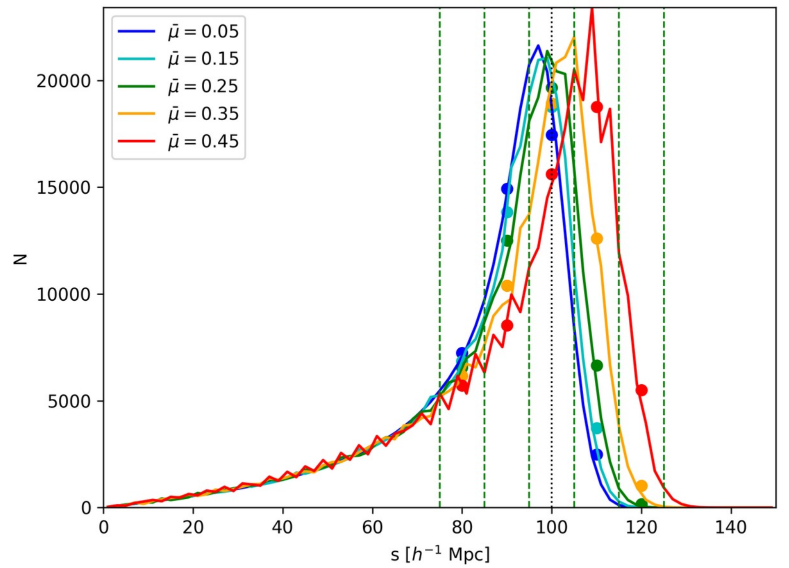
Photometric data σ_0=0.005

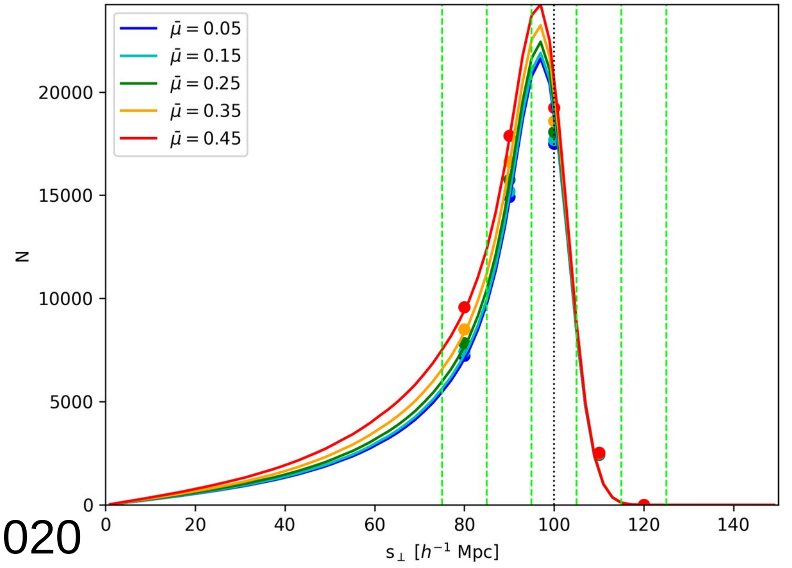


spectroscopic data

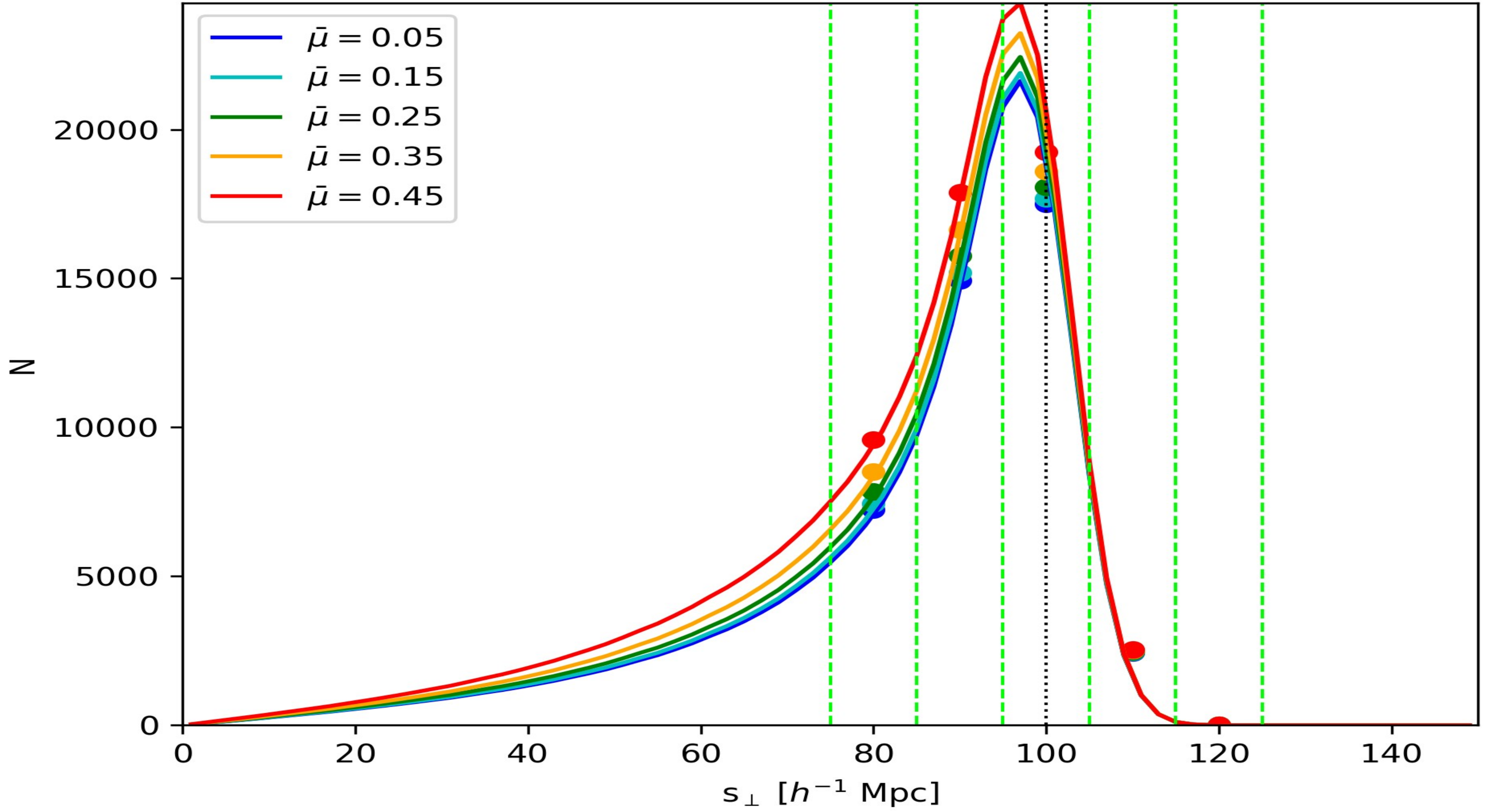




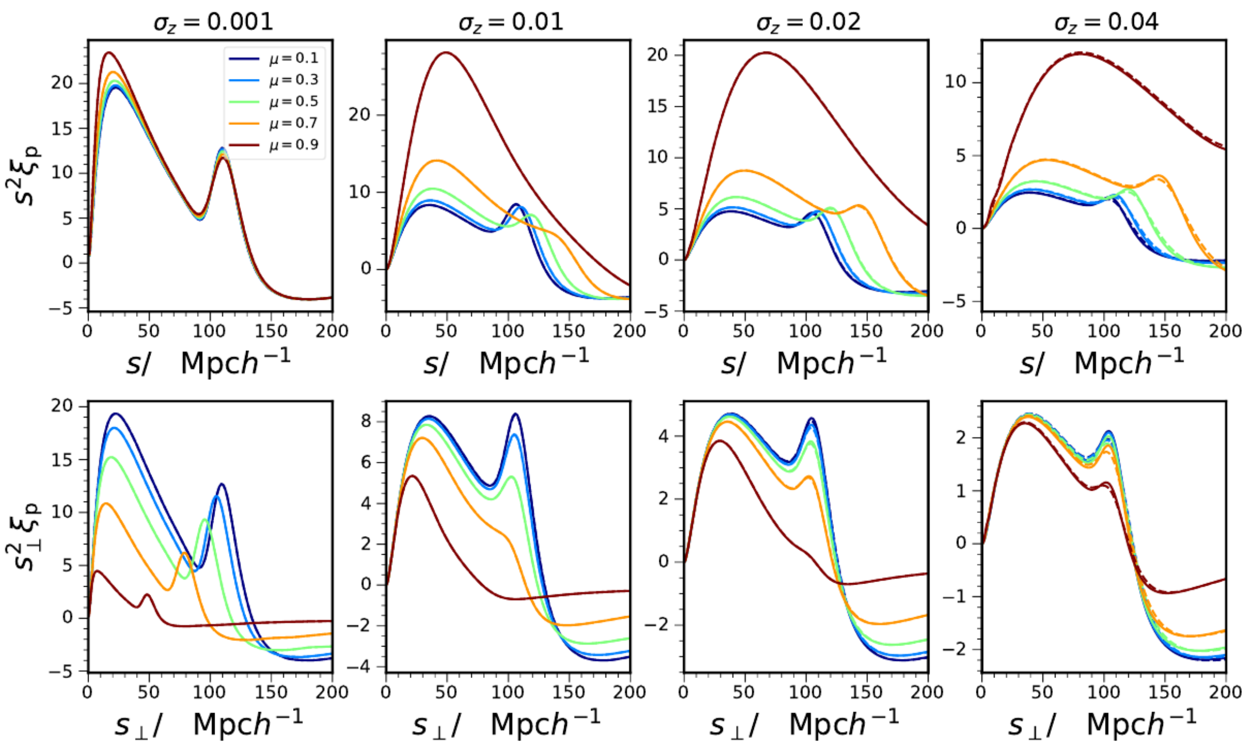


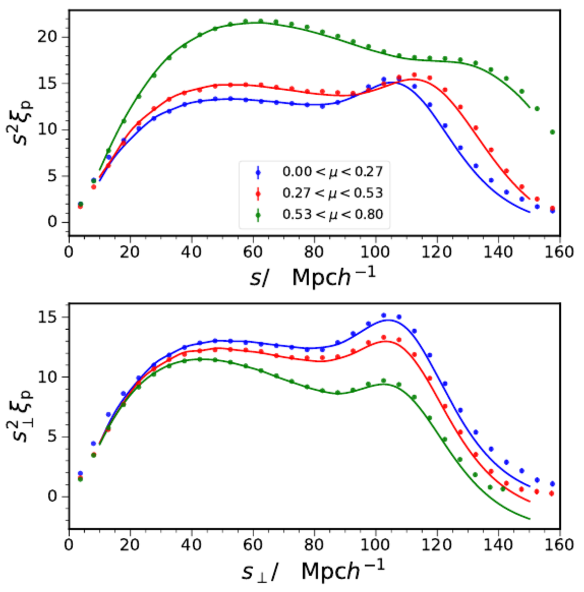


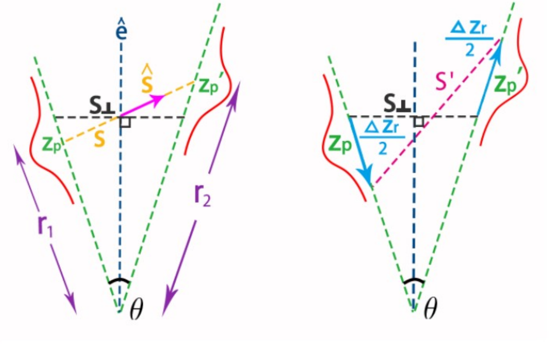
Photometric data σ_0=0.020


$\bar{\mu} = 0.05$
$\bar{\mu} = 0.15$
$\bar{\mu} = 0.25$
$\bar{\mu} = 0.35$
$\bar{\mu} = 0.45$
N
0
5000
10000
15000
20000
0
20
40
60
80
100
120
140
$s_\perp$ [h^{-1} Mpc]

Old news: shifting BAO peak

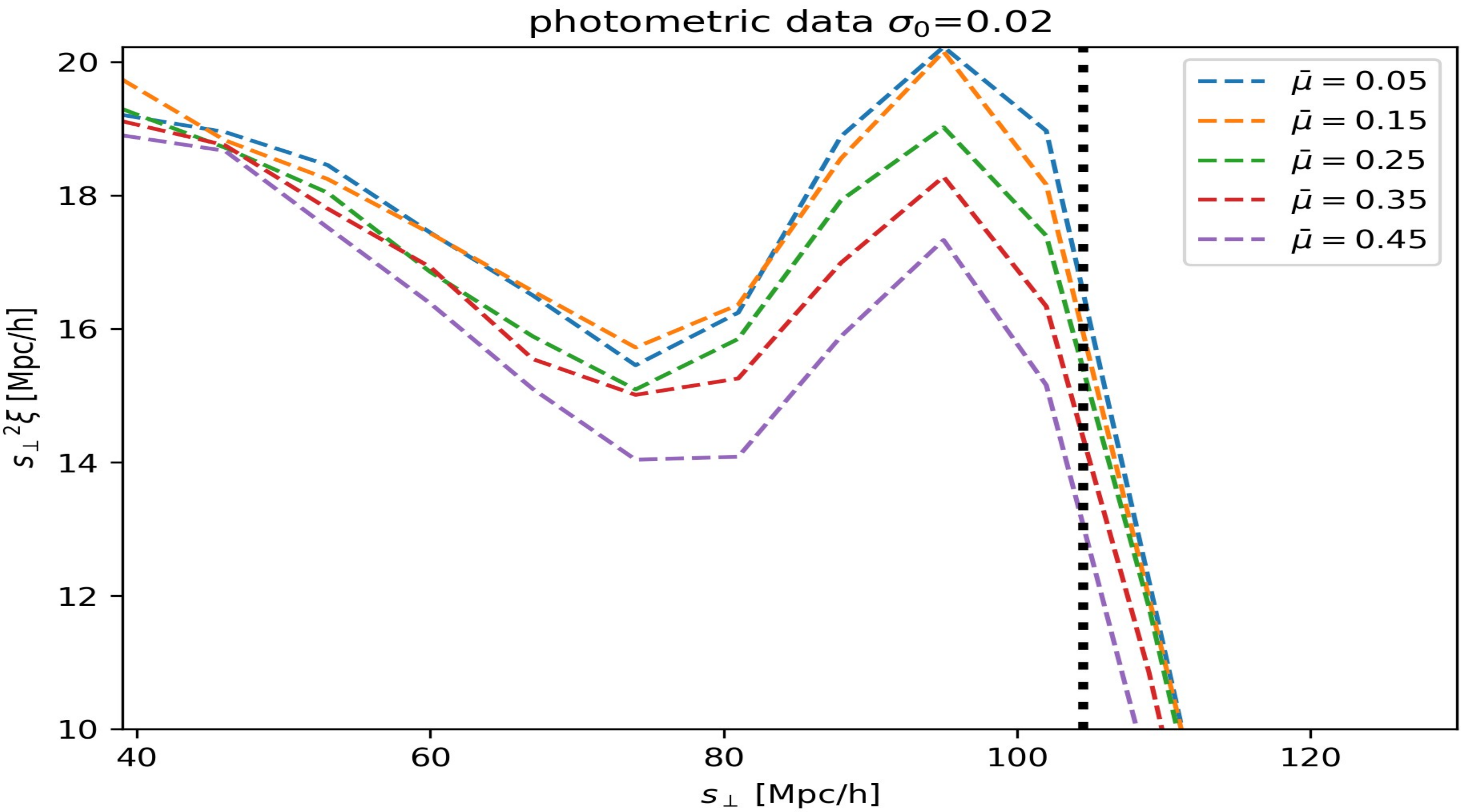






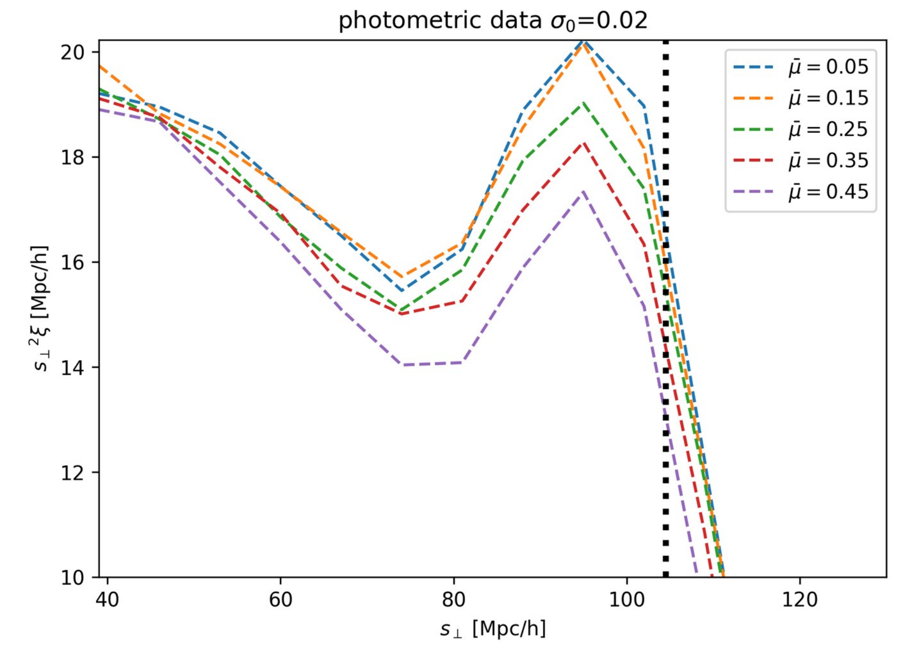
All figures on this slide are from Chan+2021 (arXiv:2110.13332)

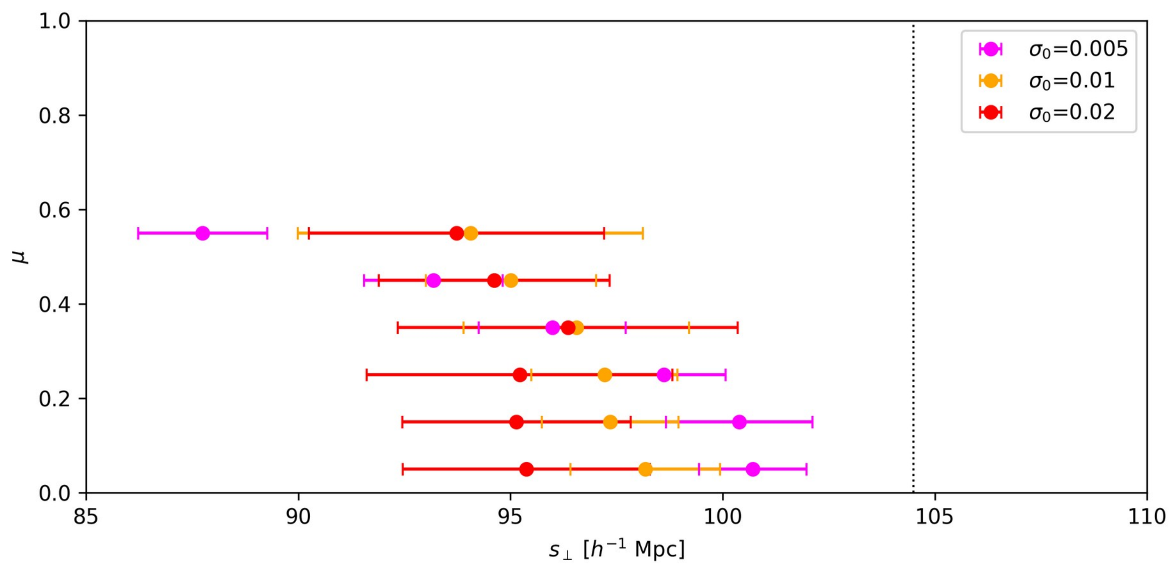
Solution: S → $S_\perp$


photometric data σ_0=0.02
$\bar{\mu} = 0.05$
$\bar{\mu} = 0.15$
$\bar{\mu} = 0.25$
$\bar{\mu} = 0.35$
$\bar{\mu} = 0.45$
$s_\perp{}^2\xi$ [Mpc/h]
$s_\perp$ [Mpc/h]
10
12
14
16
18
20
40
60
80
100
120

Fresh news: BAO peak offset

- One detail missed: the location of the **photometric BAO is systematically offset** from the spectroscopic BAO peak





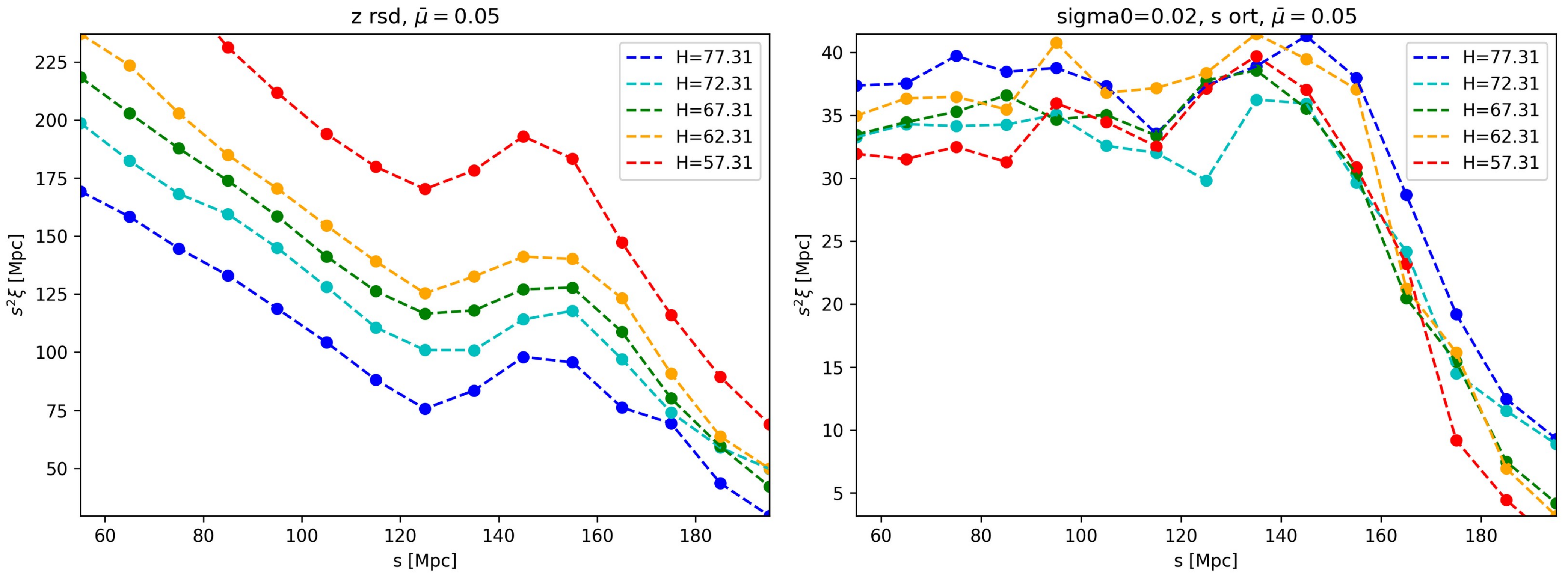
New findings, new problems

- Quantifying the offset

- Re-evaluating older papers (eg. Sridhar+ 2020)

- Cosmology dependence of the offset? →
  What can we still learn from the BAO peak?

Testing for cosmological dependency of the offset

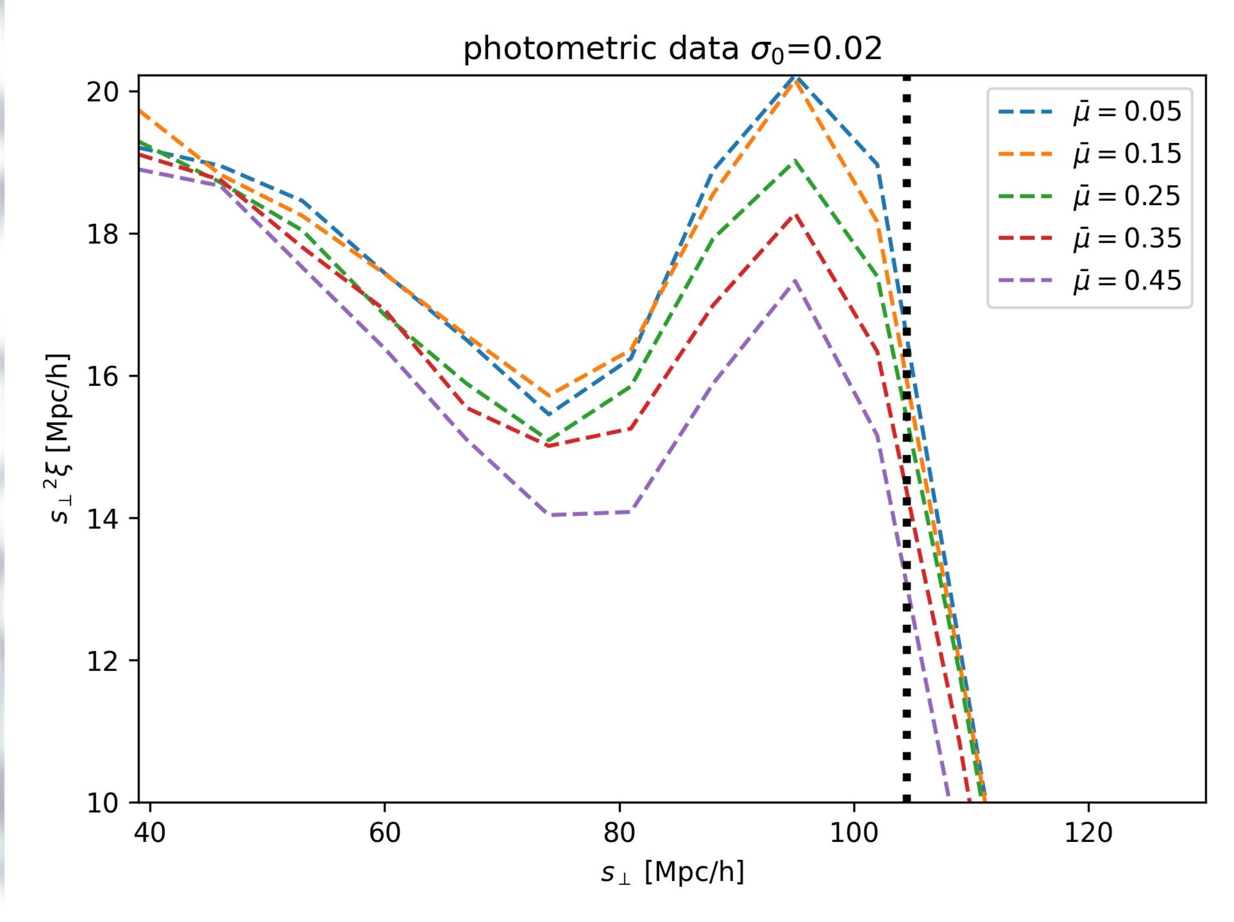


Challenge: cosmic variance and HOD effects

Summary and Conclusion

- Photometric BAO peak is shifting between different μ-bins as a function of s
- Location of the photometric BAO peak is stable between different μ-bins as a function of $s_{\perp}$
- Location of the photometric BAO peak is systematically offset from the spectroscopic (true) location
- A challenge for all future BAO peak studies using photometric data

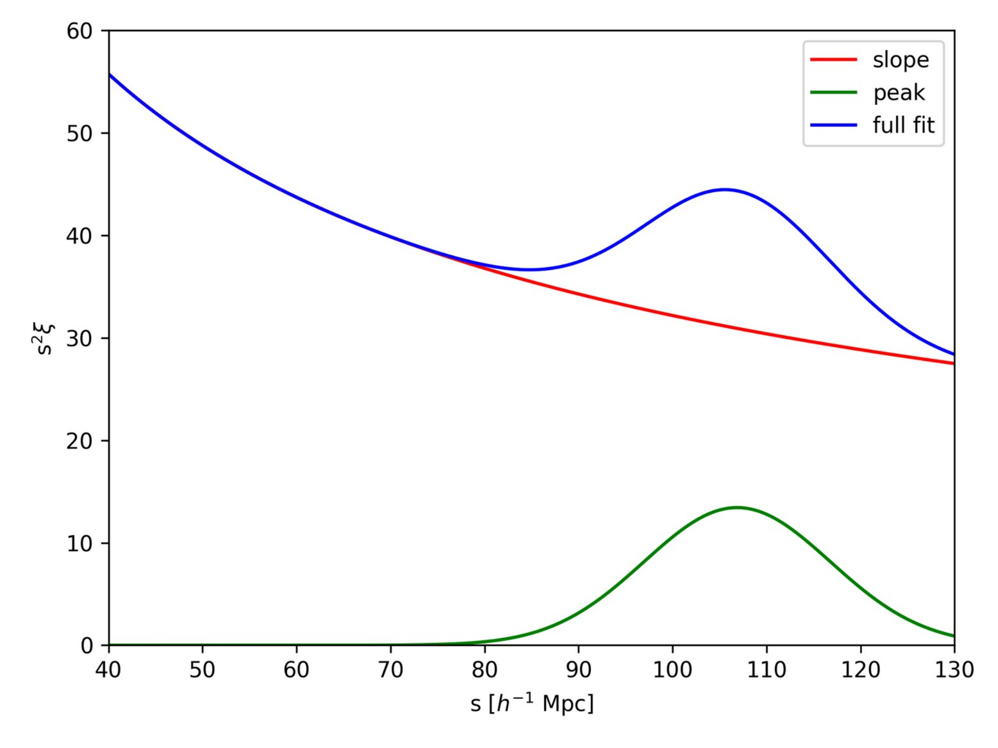
ANY QUESTIONS?



Backup Slides

The fitting function

$$\xi_{\mathrm{mod}}(s) = B + \left(\frac{s}{s_0}\right)^{-\gamma} + \frac{N}{\sqrt{2\pi\sigma^2}}\exp\left(-\frac{(s-s_m)^2}{2\sigma^2}\right)$$



Other BAO peak measurements