Cosmology with the Redshift Desert Survey on the Korea Large Survey Telescope (KLST)

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On behalf of the cosmology working group

Introduction: New eyes on cosmology with a dedicated spectroscopic telescope

The 2030's will be the beginning of the main era of spectroscopy in astronomy

The proposals like MSE, MegaMapper, DESI-2, Spec-S5, and upcoming/on-going surveys like PFS, HETDEX, etc all give us more justification for the bright future of large spectroscopic surveys of galaxies in the 2030's and beyond.

Expecting major competitions in the future, we need to seek for a unique & productive path that will result in the maximal science return.

Resolving cosmological challenges through expansion history of the universe

$$D_c(z) = \frac{c}{H_0}\int_o^z dz' \frac{H_0}{H(z')} \quad \& \quad \frac{H^2(z)}{H_0^2} = \Omega_r(1+z)^4 + \boxed{\Omega_m}(1+z)^3 + \boxed{\Omega_\Lambda} + \Omega_k(1+z)^2$$

⬇

- D and H at different z's sensitive to different ratios of matter density & DE density
- The expansion will also change if DE density varies with z.

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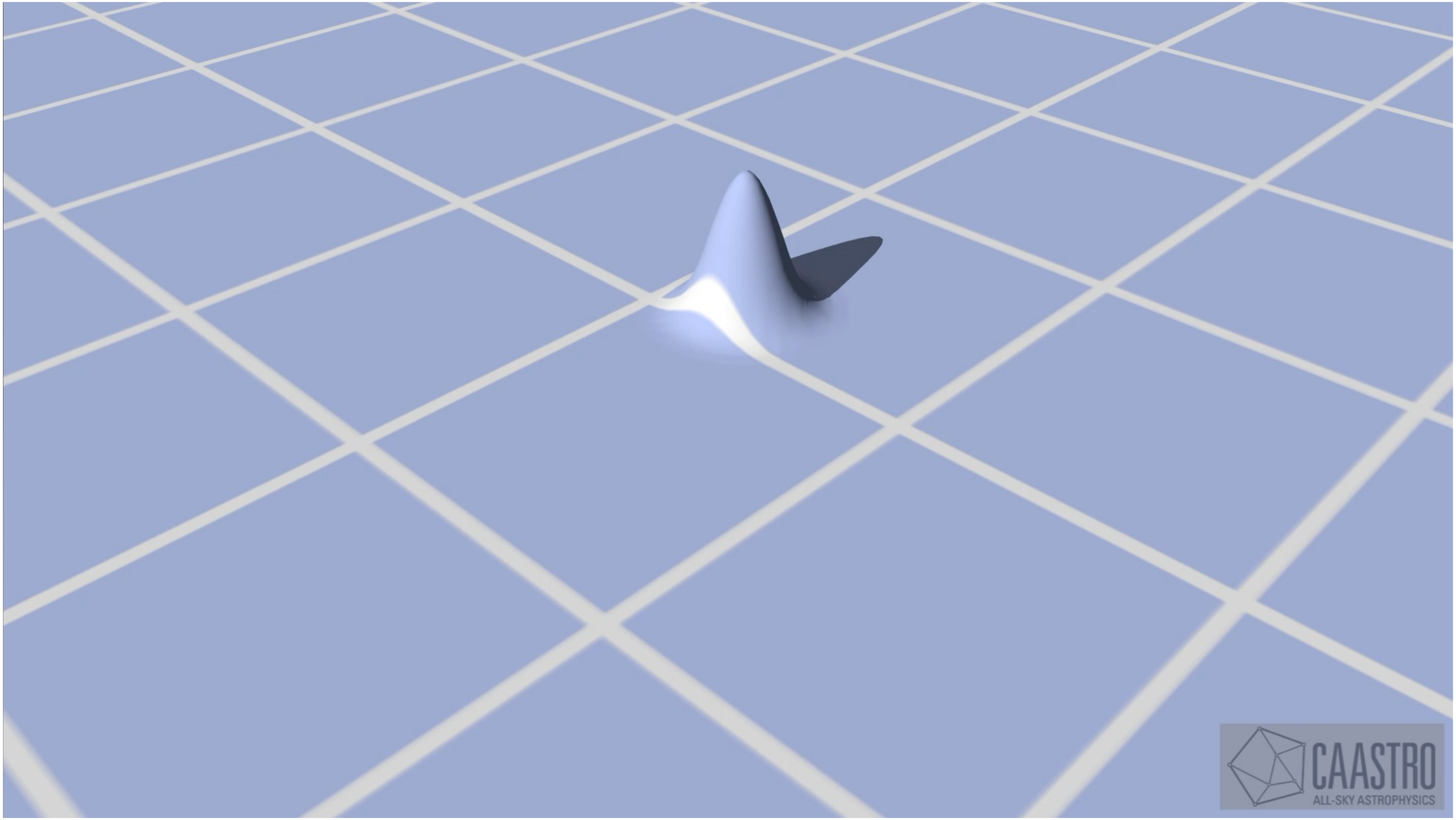
Cosmological tensions

Though ΛCDM has successfully provided predictions consistent with the data, there are a number of tensions/challenges that have emerged.

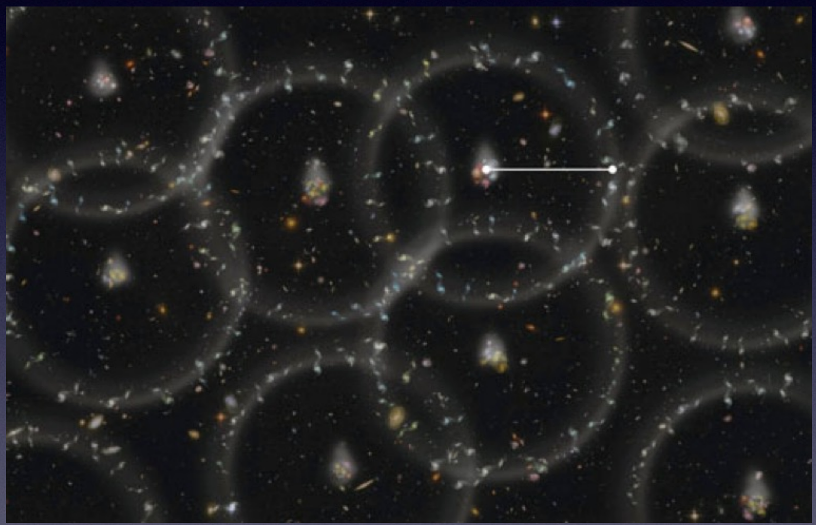
- Hubble tension: H_0 measurement from local Cepheids/SN not consistent with CMB inference
- Dark energy dynamics: recent results suggest deviations from Λ

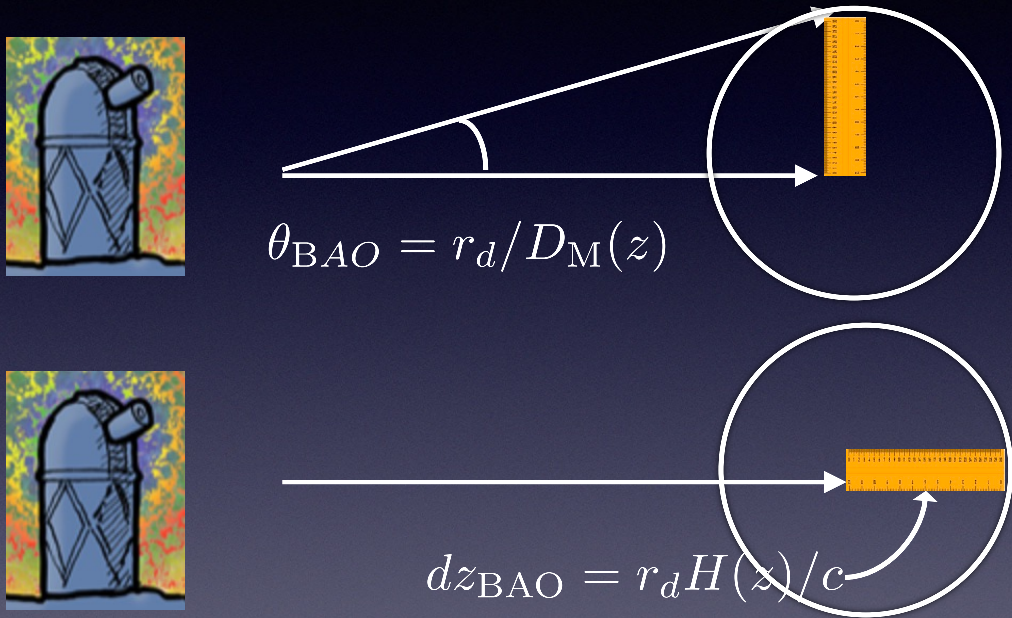
Distance Measures

- The distance-redshift relation can tell us about the nature of Dark Energy


CAASTRO
ALL-SKY ASTROPHYSICS

Baryon Acoustic Oscillations





$$\theta_{\mathrm{BAO}} = r_d / D_{\mathrm{M}}(z)$$

$$dz_{\mathrm{BAO}} = r_d H(z)/c$$

- DM(z) and H(z) encode the expansion history of the Universe

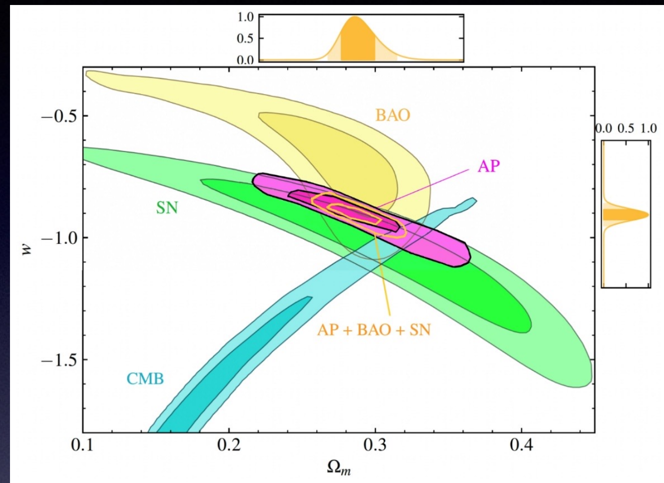
Non-Λ dynamics - AP & BAO

Alcock-Paczynski test on SDSS [Dong et al. 2023]

- SDSS AP + SDSS BAO + SN (without CMB combined!)

  $w_{eff}(z=0\sim0.7) = -0.903 \pm 0.023$

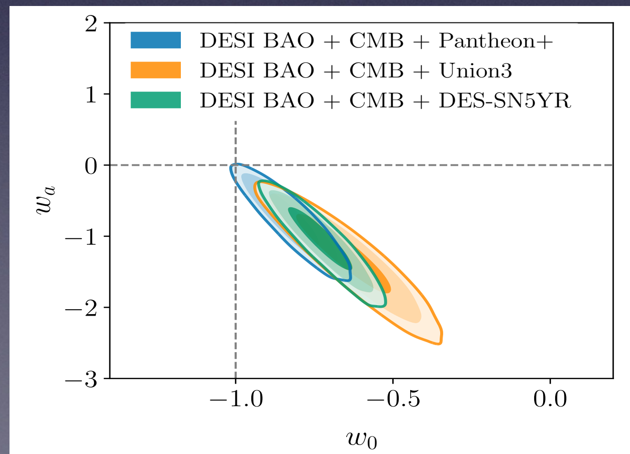
  4.2σ away from ΛCDM w=-1!



BAO on DESI [et al. 2024]

- DESI + CMB + DES-SN5YR ⟹ 3.9σ

$$w_0 = -0.727 \pm 0.067 \quad w_a = -1.05^{+0.31}_{-0.27}$$

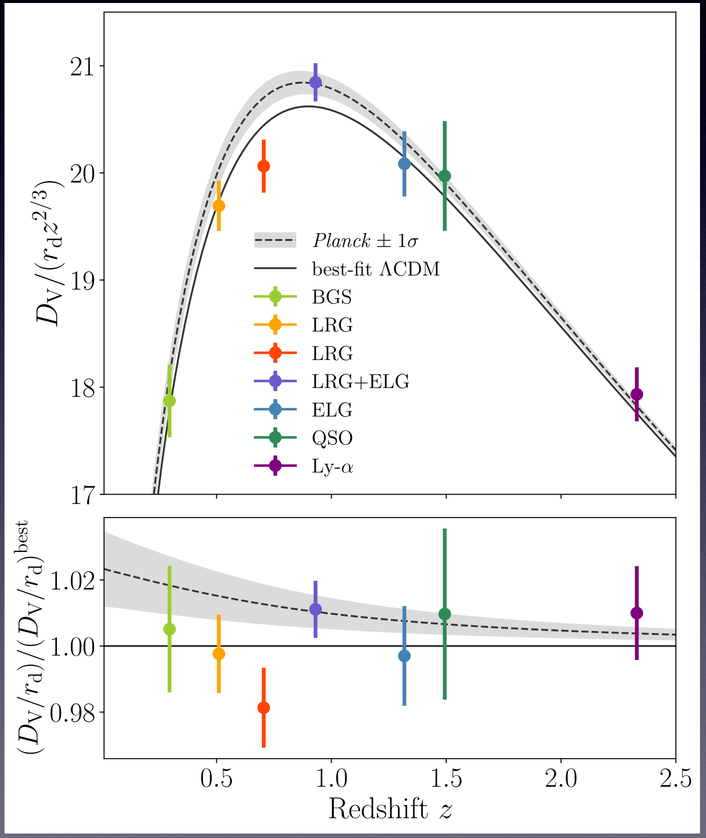


Current Landscape

- Upcoming data from DESI will provide more precise measurement of BAO in late-time Universe ($z<1$)
- In this case, what would be a new, unique survey look like?

Redshift Desert Survey

- BAO measurements trace optical galaxies with easy to detect lines: most below z<1.5 (LRG and ELG) or above z>2.3 (QSO and Ly-**α**)
- Missing measurements in redshift desert, where dark energy density transitions to zero
- RDS survey z_{max} = 1.7, trying to push further into the regime where we would expect the dark energy density to be ~0
    - Provides calibration for redshift standard rulers at lower redshifts
- Target [OII] doublet (3726-3729 Å), [OIII] (5007 Å) and H**α** (6564 Å) of star-forming galaxies



BAO Accuracy

- BAO precision scales with volume (sample variance) and number density of tracers (shot noise)
- As number density increases, shot noise contribution to the error will decrease, but reach a plateau, when sample variance takes over
- DESI already has a 2.5% d_A, 3% H(z) measurement in a similar range
- What is the minimum volume and number needed to improve on this?

tracer	redshift	$N_{\rm tracer}$	$z_{\rm eff}$	$D_{\rm M}/r_{\rm d}$	$D_{\rm H}/r_{\rm d}$	r or $D_{\rm V}/r_{\rm d}$	$V_{\rm eff}$ (Gpc^3)
BGS	$0.1-0.4$	300,017	0.295	—	—	7.93 ± 0.15	1.7
LRG1	$0.4-0.6$	506,905	0.510	13.62 ± 0.25	20.98 ± 0.61	-0.445	2.6
LRG2	$0.6-0.8$	771,875	0.706	16.85 ± 0.32	20.08 ± 0.60	-0.420	4.0
LRG3+ELG1	$0.8-1.1$	1,876,164	0.930	21.71 ± 0.28	17.88 ± 0.35	-0.389	6.5
ELG2	$1.1-1.6$	1,415,687	1.317	27.79 ± 0.69	13.82 ± 0.42	-0.444	2.7
QSO	$0.8-2.1$	856,652	1.491	—	—	26.07 ± 0.67	1.5
Lya QSO	$1.77-4.16$	709,565	2.330	39.71 ± 0.94	8.52 ± 0.17	-0.477	—

Table 1. Statistics for the DESI samples used for the DESI DR1 BAO measurements used in this paper. For each tracer and redshift range we quote the number of objects ($N_{\rm tracer}$), the effective redshift ($z_{\rm eff}$) and effective volume ($V_{\rm eff}$). Note that for each sample we measure either both $D_{\rm M}/r_{\rm d}$ and $D_{\rm H}/r_{\rm d}$, which are correlated with a coefficient r, or $D_{\rm V}/r_{\rm d}$. Redshift bins are non-overlapping, except for the shot-noise-dominated measurements that use QSO (both as tracers and for Lyα forest).

Spectroscopic survey proposal II: Redshift Desert Survey

Photometric catalog

- galaxies with i_{limit}=24 (z_{max} ~1.7)

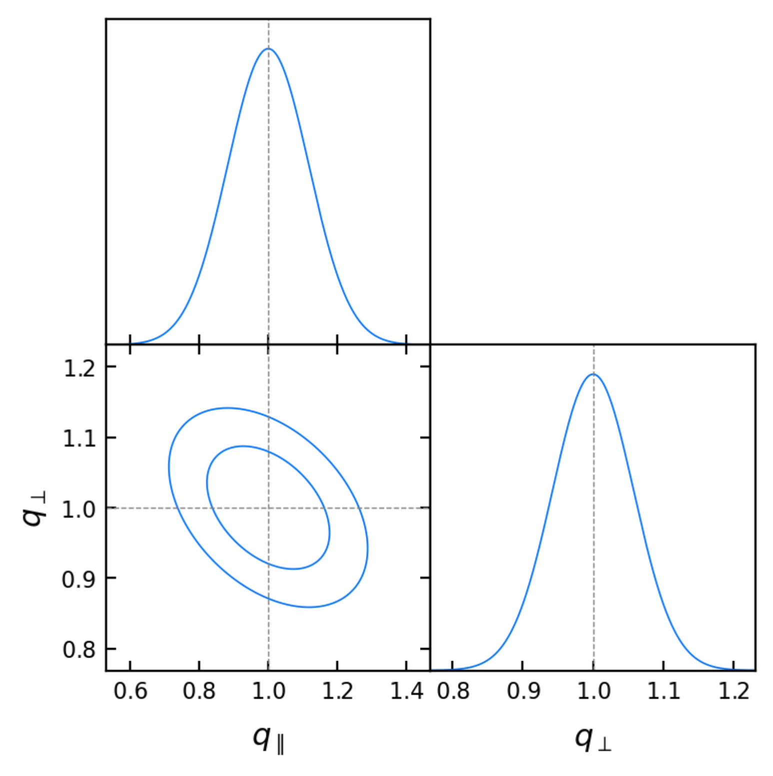
  → n_{sky} = 80,000 gal/deg^2

Spectroscopic survey

- 200 nights with ~8 hr exposures, multiplexing of 20,000 → a flux-limited sample of ~4M redshift desert galaxies covering ~50 deg^2

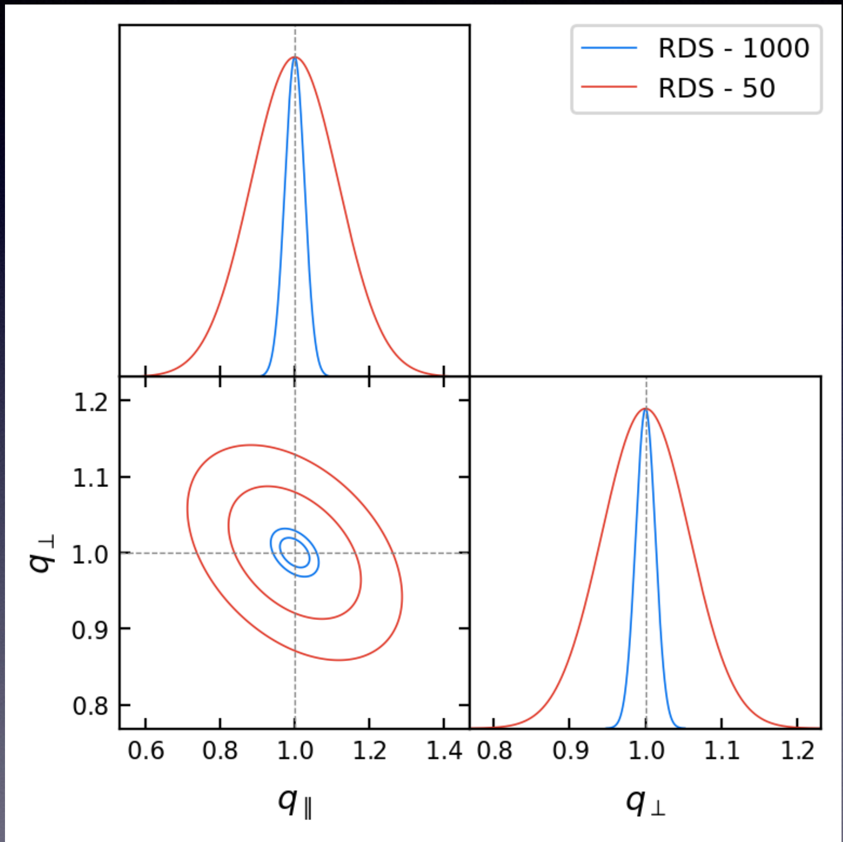
Fisher forecast

- precision on d_A 20%, H(z) 24% in each Δz=0.1 bin, over the range z=1 to 1.7

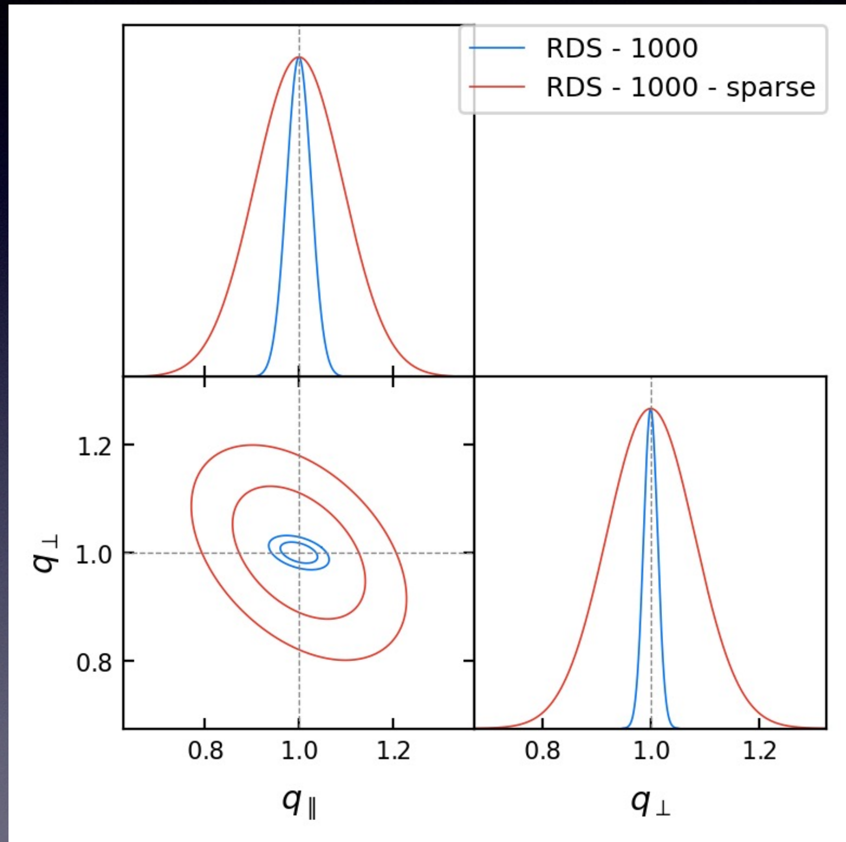


By Cris Sabiu

Forecasts



Increase area to 1000 deg^2, same number density



Increase area to 1000 deg^2, only 1000 gal/deg^2

Plan

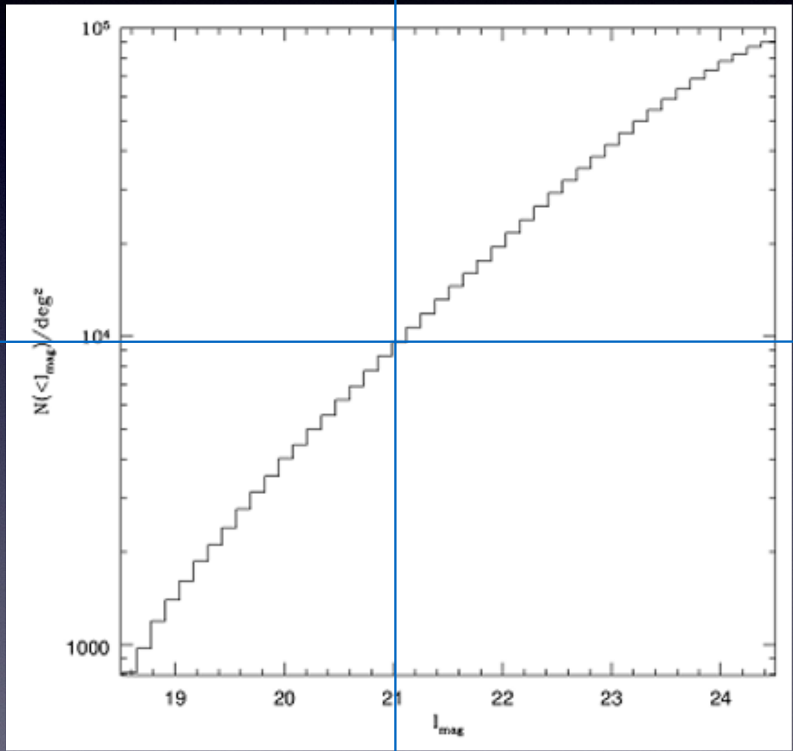
1. Start with exposure time calculator
2. Predict number of line emitters for a given exposure time, with given redshift distribution
3. Simulation BAO effectiveness using Fisher forecast
4. Optimise survey strategy for redshift desert

Summary

- The 2030s will see more large-area, multiplexed, spectroscopic galaxy surveys, for example: MSE, MegaMapper, DESI-2, Spec-S5, etc
- These will be important for resolving the cosmological challenges presented to us by the current standard candle, ruler and shape data (that the mysterious dark energy might not be Λ)
- A Redshift Desert Survey (RDS) could be performed on 9.2m a telescope system with multiplexed spectrograph to measure the expansion of the Universe using BAO and AP in the range $0.9 < z < 1.7$ (or higher)
- Precision of BAO measurement is a balance between number count of galaxies and area coverage
- A better exposure time calculator will allow us to optimise the survey strategy

Hubble Depth Survey

- Main sources of error on standard ruler come from survey volume (sample variance) and galaxy number density (shot noise)
- While survey volume cannot be significantly increased beyond DESI, galaxy number density can, increasing to deeper mag limit
- Hubble Depth Survey up to z~1.1, covering 27,000 deg^2 (WIDE) and 5,000 deg^2 (DEEP)
  - HDS-DEEP: mag limit down to *i* = 22 → n = 20,000 gal/deg^2, with 1-2 hr exposures
  - HDS-WIDE: mag limit down to *I* = 20 → n = 4,000 gal/deg^2 with 0.3 hr exposures



Cosmological sciences with large volume, dense & deep spectroscopic samples

1. Expansion history of the universe

   Large V, high n & deep z → resolve the cosmological tensions

2. Initial conditions of the universe

   Large V & high n → measure the high-order moments accurately
   → test models to generate the primordial density fluctuations

3. Large-scale structures in the universe

   High n & deep z → cosmic zoology/environmental sciences
   → cosmological parameters from growth of structures

2. Initial conditions of the universe

Large volume & dense redshift survey → Linear regime sciences

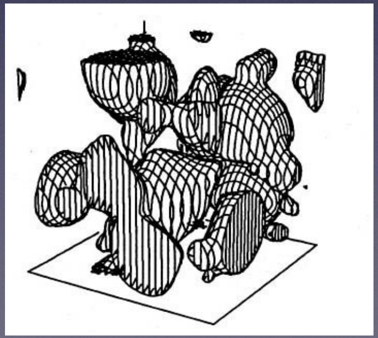
- Power spectrum on very large scales

  Large volume HDS → Matter-radiation density equality epoch

  Expansion and energy density evolution before decoupling. Cosmological parameters

- Gaussianity of the initial matter fluctuations

  On large scales, LSS is still in its primordial state & the large dense HDS will allow measurment of the non-Gaussianity of the initial matter fluctuations with high precision



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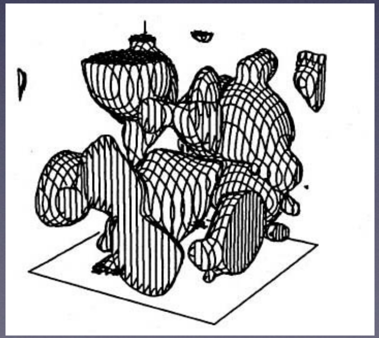

3. Large-scale structures in the universe

Dense 3D map of LSS → LSS sciences and cosmic zoology

- Development of the cosmic web from redshift desert to the present with a large dynamic range

  Connection between the initial conditions and the cosmic web

- Co-evolution of LSS and galaxies

  Constraining on cosmology and galaxy formation mechanisms.

Large-scale peculiar velocity map in the local universe

- Growth factor

  HDS giving spectra with R~6000 → accurate densely-sampled s_v & v_{pec} map

- Kinematics within galaxy clusters, groups, & galactic satellite systems

  Constraining DM and DE in the universe