Watching the Universe's Acceleration Era with the SKAO

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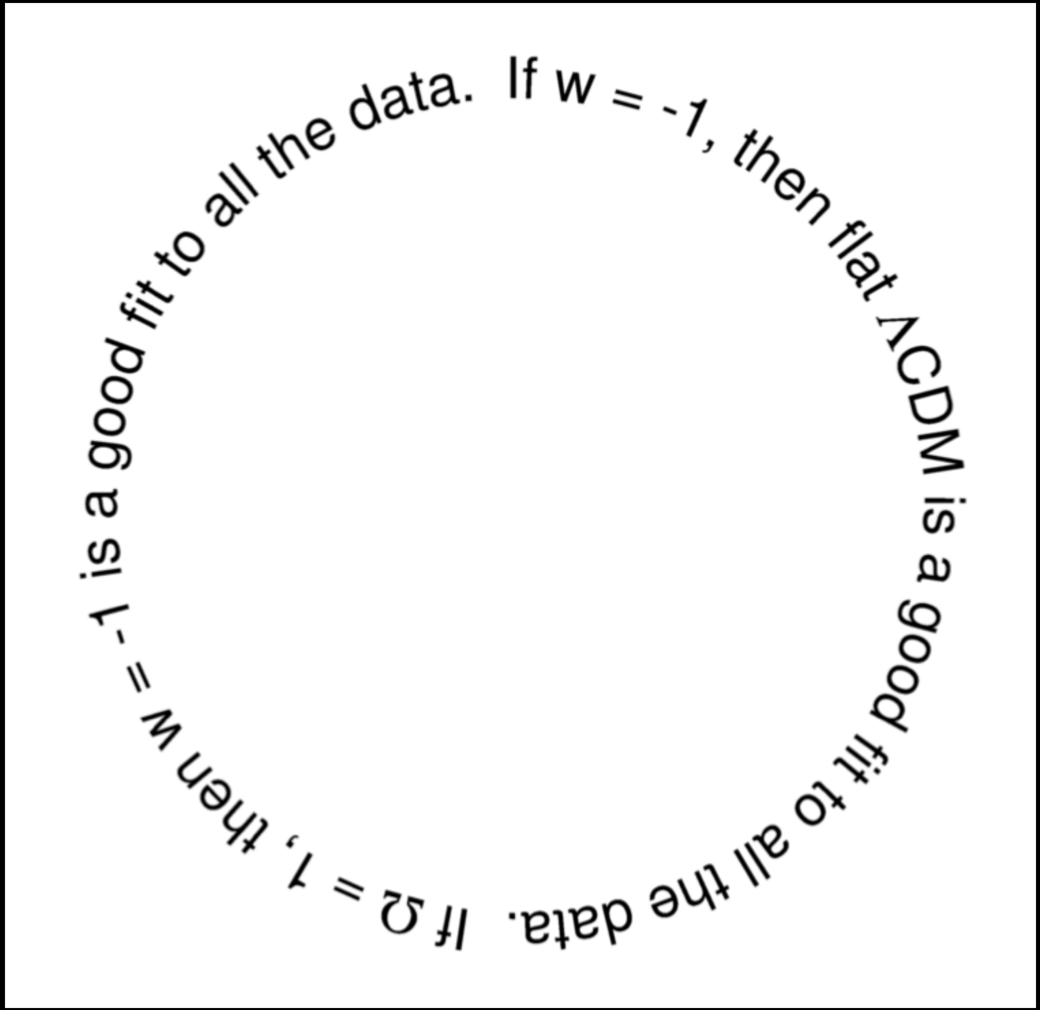
Mind Your Cosmological Priors

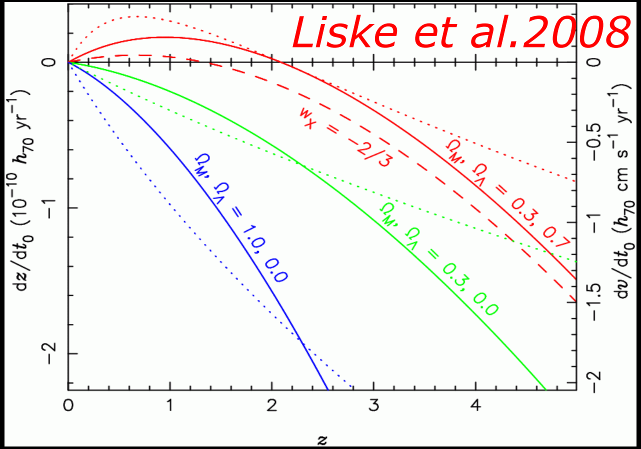


The Redshift Drift

A direct non-geometric model-independent measurement of the universe's expansion history *[Sandage 1962]*

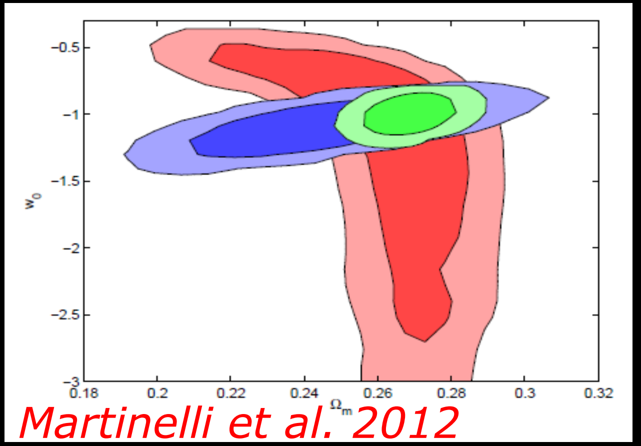
- Watching the universe expand in real time!
- Independent of gravity, geometry or clustering
- Not mapping (present-day) past light-cone, but directly comparing different past light-cones

$$\dot{z} \equiv \frac{\mathrm{d}z}{\mathrm{d}t_{\mathrm{obs}}}(t_0) = (1+z)H_0 - H(z)$$



ELT flagship science driver (for z>2) *[Liske et al. 2008]*, unique tool to close consistency loop and break parameter degeneracies

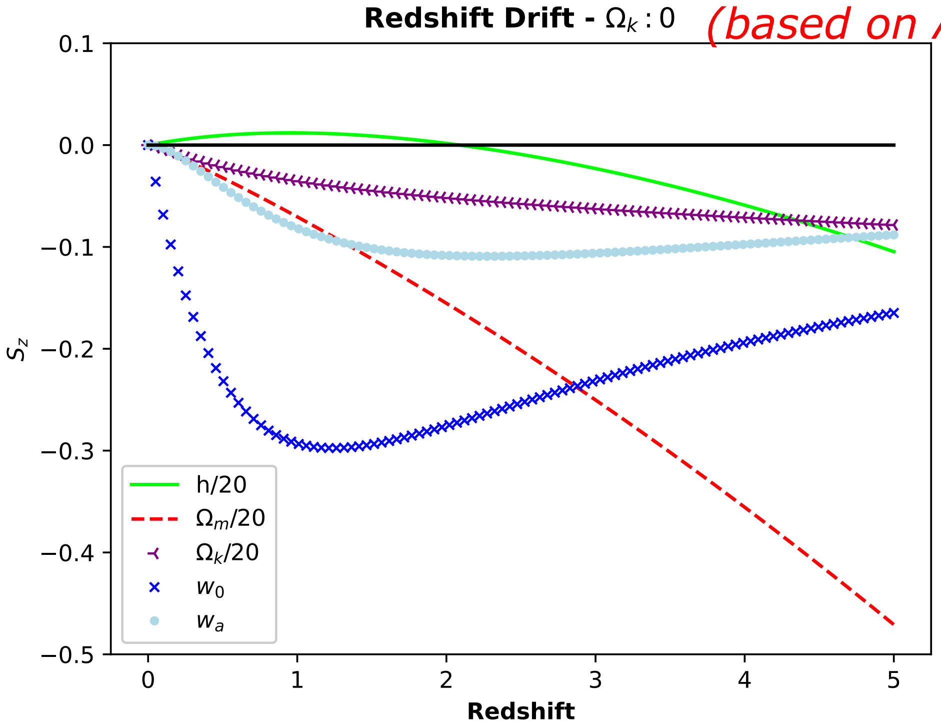
- SKAO can cover z<1 *[Klockner et al. 2015, …]*
- In practice one measures a spectroscopic velocity

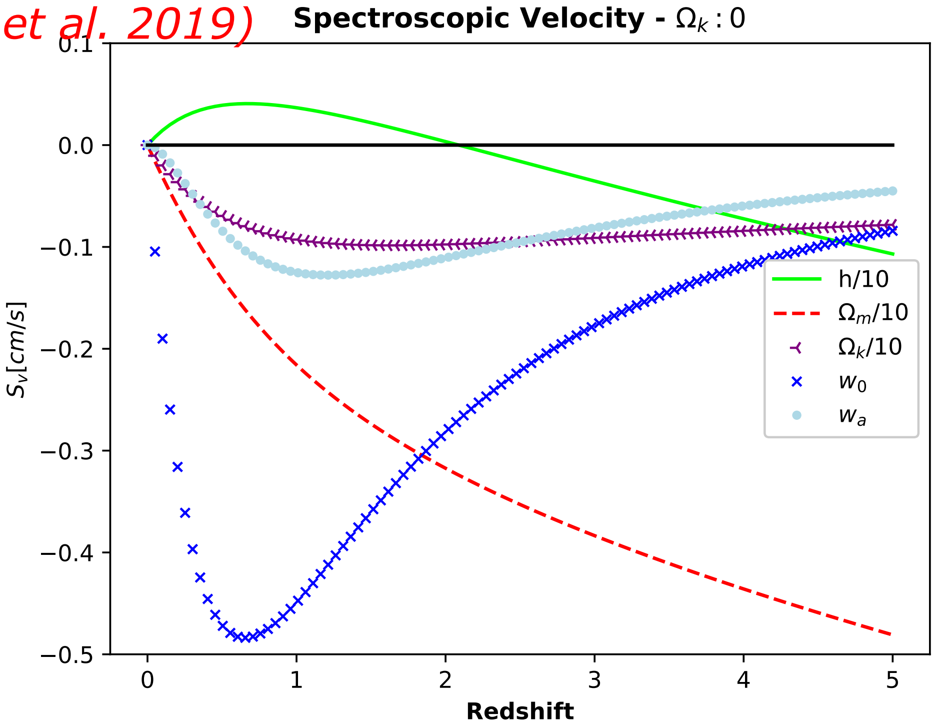


Cosmological Parameter Sensitivity

(for a CPL fiducial model)

Melo e Sousa et al. 2023
(based on Alves et al. 2019)





Real-time Cosmography

First and second redshift derivatives are powerful test of the ΛCDM paradigm; cosmographic approach useful here *[Martins et al. 2016]*

$$Z_1(z) = \frac{1}{H_0}\frac{dz}{dt_0} = 1 + z - E(z)$$

$$Z_2(z) = \frac{1}{H_0^2}\frac{d^2z}{dt_0^2} = \frac{1+q(z)}{1+z}E^2(z) - E(z) - q_0(1+z)$$

$$\frac{dZ_1(z)}{dz} = 1 - E(z)'$$

- To linear order,

$$Z_1 = -q_0 z + O(z^2)$$

$$Z_2 = j_0 z + O(z^2)$$

$$\frac{dZ_1(t_0, z)}{dz} = -q_0 + (q_0^2 - j_0)z + O(z^2)$$

Assuming specs discussed in *[Klockner et al. 2015]*, SKAO redshift drift measurements can reach σ_{q0}~0.006 and σ_{j0}~0.13 *[Martins et al. 2016]*

- Optimal way to measure q_0 with both accuracy and precision, which is not possible with traditional distance indicators *[Neben & Turner 2013]*
- A key consistency test: j(z)=1 at all redshifts for a flat ΛCDM universe
- More broadly, a positive drift implies SEC violation, hence dark energy

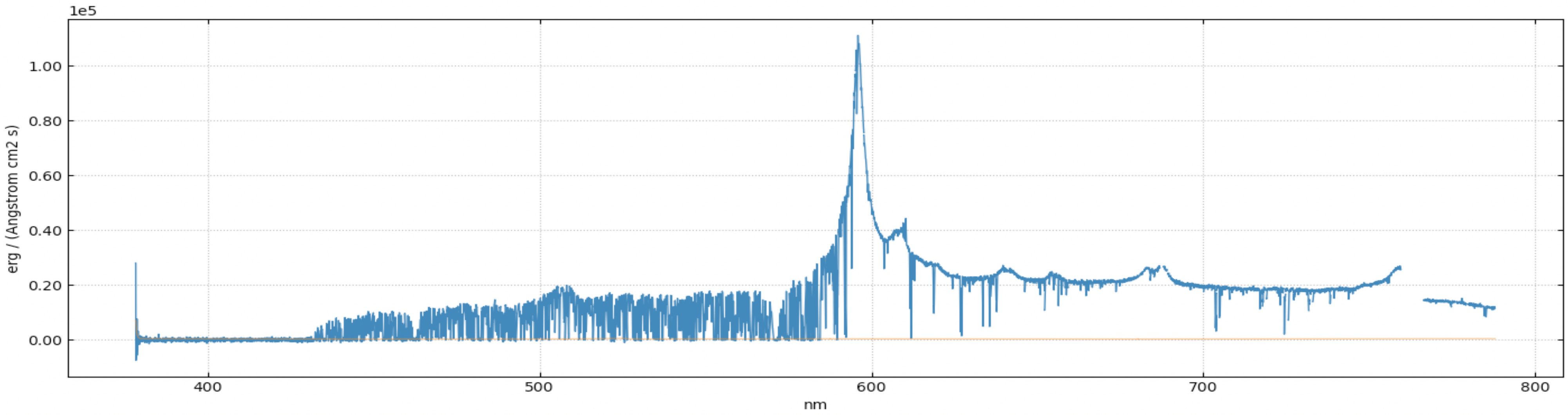
The ESPRESSO Redshift Drift Experiment

Current limits 1000x larger than expected signal, and systematics-dominated

- *[Darling 2012]* in the radio at z<0.7, *[Cooke 2020]* in the optical at z>2

ESPRESSO can improve this by a factor ~10 with an experiment time of 1 year and an observation time of 40h for 2 QUBRICS 'superbright' QSOs

- Test and optimise methodology with real data, test instrument stability
- Two independent experiments, also 'zeroth epoch' for ANDES (calibration permitting)



SKA Forecast Assumptions

Only available estimate of SKA redshift drift sensitivity is *[Klockner et al. 2015]*

- Observe HI signal of ca. 10^7 galaxies up to z~1 at 2+ different epochs
- Observation time ca. 0.5 years, experiment time ca. 12 years – expect $\Delta\nu \sim 0.1$ Hz
- Only feasible with full SKA (as it was in 2014)
- Sensitivity, number counts, hardware, systematics (e.g. observatory motion) etc.

These forecasts are simplistic and out of date, it would be good to improve them to ELT level.

- Can someone do simulations?
- Good topic for someone's thesis?
- For now, proceed with these…

What upper limits can we get now? Existing ones can be improved!

- Relevant Phi in the Sky expertise

PoS PROCEEDINGS OF SCIENCE

Real time cosmology - A direct measure of the expansion rate of the Universe with the SKA

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Available SKA Forecasts

Under previous assumptions, competitive probe of low-z accelerating universe

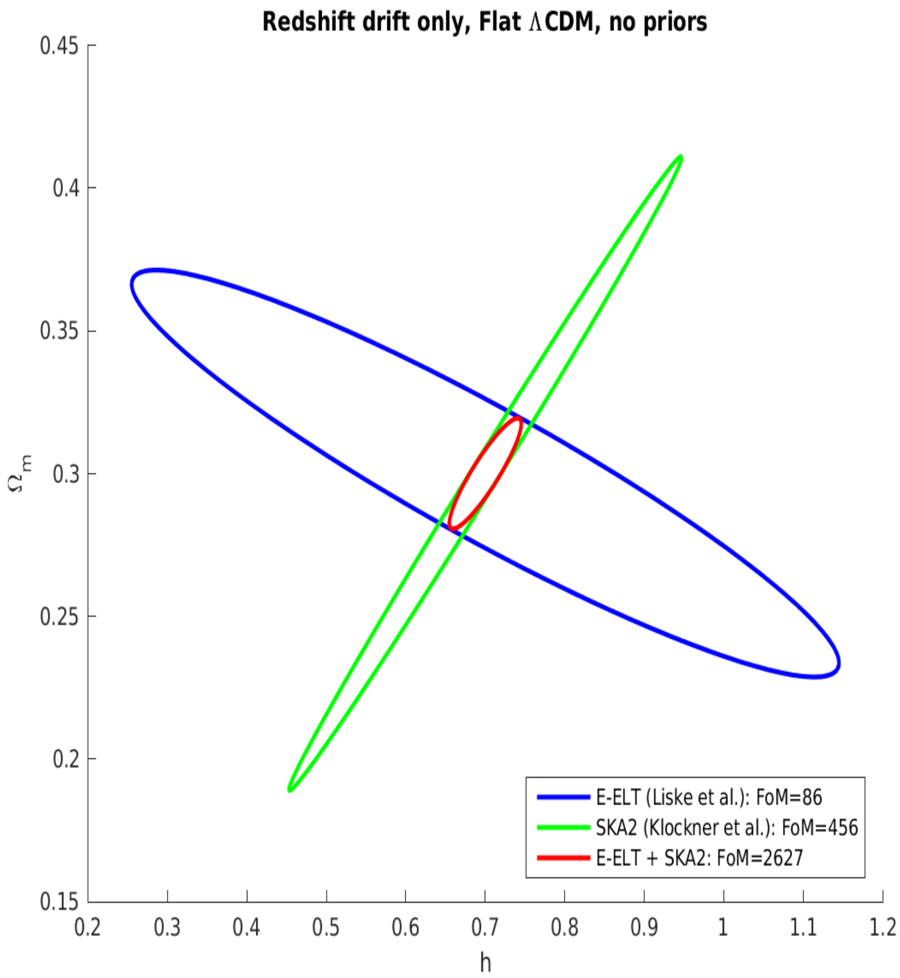
- MCMC in *[Rocha & Martins 2022]*
- FMA in *[Marques et al. 2024]*
- Both cosmograpy and specific cosmological models
- Latter code publicly available

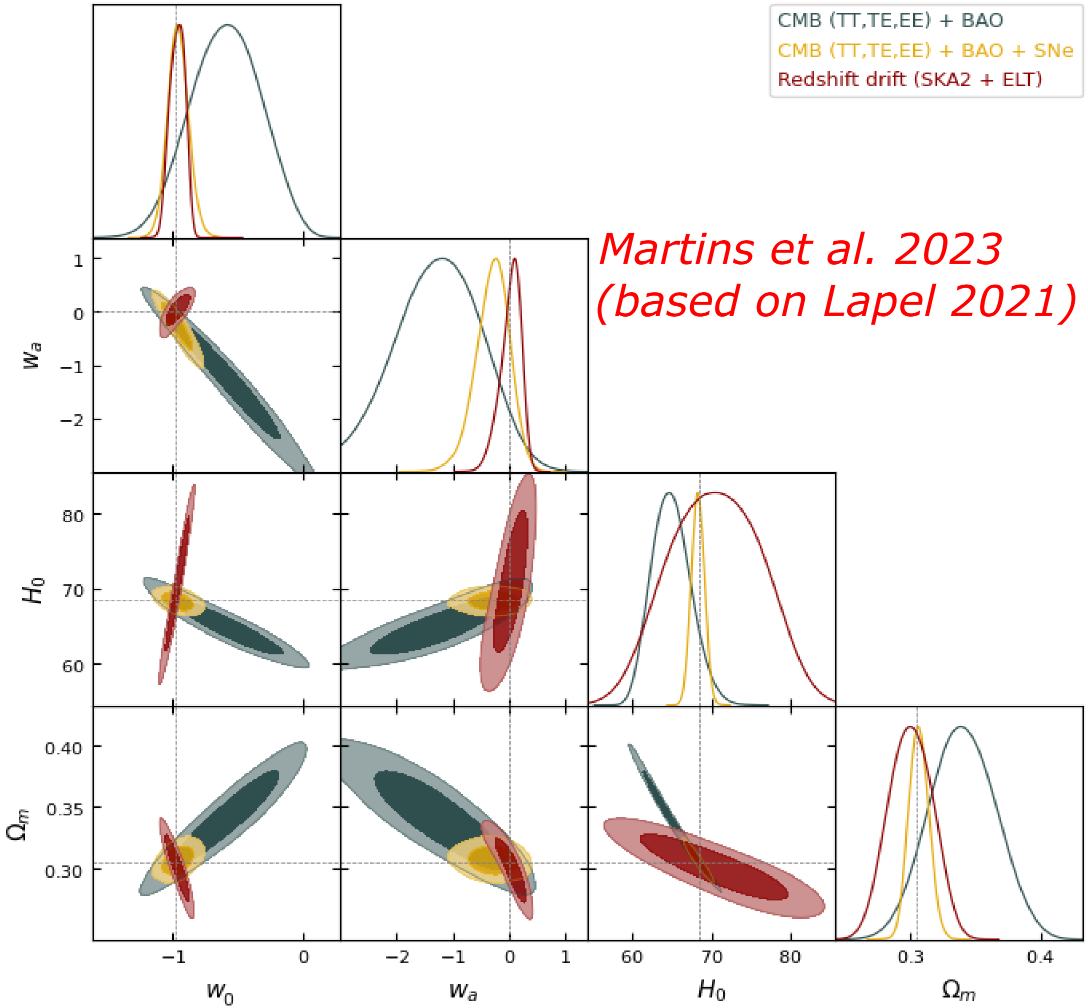
Can think of measuring the drift of the drift, look at spatial variations, etc

		$\sigma_h = 0$			$\sigma_h = 0.05$			$\sigma_h = 0.1$		
	Parameter	$z \leq 0.3$	$z \leq 0.5$	$z \leq 1.0$	$z \leq 0.3$	$z \leq 0.5$	$z \leq 1.0$	$z \leq 0.3$	$z \leq 0.5$	$z \leq 1.0$
ΛCDM	**FoM(w_0, w_a)**	95	139	252	48	62	110	44	50	77
	$\rho(w_0, w_a)$	-0.624	-0.803	-0.905	-0.226	-0.433	-0.761	-0.156	-0.287	-0.609
	$\sigma(w_0)$	0.038	0.034	0.024	0.054	0.051	0.040	0.062	0.062	0.056
	$\sigma(w_a)$	0.230	0.214	0.207	0.352	0.309	0.285	0.376	0.349	0.316
Freezing	**FoM(w_0, w_a)**	118	183	352	50	71	139	44	53	91
	$\rho(w_0, w_a)$	-0.614	-0.805	-0.934	-0.221	-0.432	-0.798	-0.154	-0.288	-0.647
	$\sigma(w_0)$	0.035	0.033	0.027	0.048	0.045	0.035	0.055	0.055	0.048
	$\sigma(w_a)$	0.172	0.151	0.147	0.325	0.254	0.205	0.365	0.317	0.245

		$\sigma_h = 0$			$\sigma_h = 0.05$			$\sigma_h = 0.1$		
	Parameter	$z \leq 0.3$	$z \leq 0.5$	$z \leq 1.0$	$z \leq 0.3$	$z \leq 0.5$	$z \leq 1.0$	$z \leq 0.3$	$z \leq 0.5$	$z \leq 1.0$
n=5	**FoM(q_0, j_0)**	54	90	117	4	7	11	2	3	4
	$\rho(q_0, j_0)$	-0.988	-0.979	-0.969	-0.944	-0.954	-0.940	-0.891	-0.935	-0.935
	$\sigma(q_0)$	0.042	0.029	0.024	0.112	0.098	0.079	0.154	0.152	0.132
	$\sigma(j_0)$	1.226	0.801	0.641	2.736	2.016	1.445	3.196	2.900	2.182
n=4	**FoM(q_0, j_0)**	37	54	245	4	5	18	2	2	6
	$\rho(q_0, j_0)$	-0.983	-0.986	-0.956	-0.940	-0.936	-0.942	-0.890	-0.908	-0.938
	$\sigma(q_0)$	0.045	0.039	0.016	0.112	0.102	0.068	0.156	0.151	0.124
	$\sigma(j_0)$	1.422	1.203	0.368	2.736	2.365	1.063	3.200	2.969	1.822
n=3	**FoM(q_0, j_0)**	83	259	845	4	15	81	2	4	25
	$\rho(q_0, j_0)$	-0.986	-0.959	-0.895	-0.959	-0.948	-0.933	-0.925	-0.943	-0.939
	$\sigma(q_0)$	0.034	0.017	0.009	0.123	0.076	0.041	0.177	0.141	0.077
	$\sigma(j_0)$	0.917	0.355	0.129	2.797	1.207	0.365	3.706	2.171	0.644
n=2	**FoM(q_0, j_0)**	788	1508	4050	42	128	652	11	37	236
	$\rho(q_0, j_0)$	-0.917	-0.865	-0.805	-0.943	-0.937	-0.950	-0.944	-0.942	-0.963
	$\sigma(q_0)$	0.010	0.007	0.005	0.056	0.038	0.023	0.108	0.072	0.043
	$\sigma(j_0)$	0.138	0.078	0.033	0.562	0.259	0.092	1.081	0.483	0.160

Synergies: ELT + SKAO





Martins et al. 2023
(based on Lapel 2021)

Let's do it!