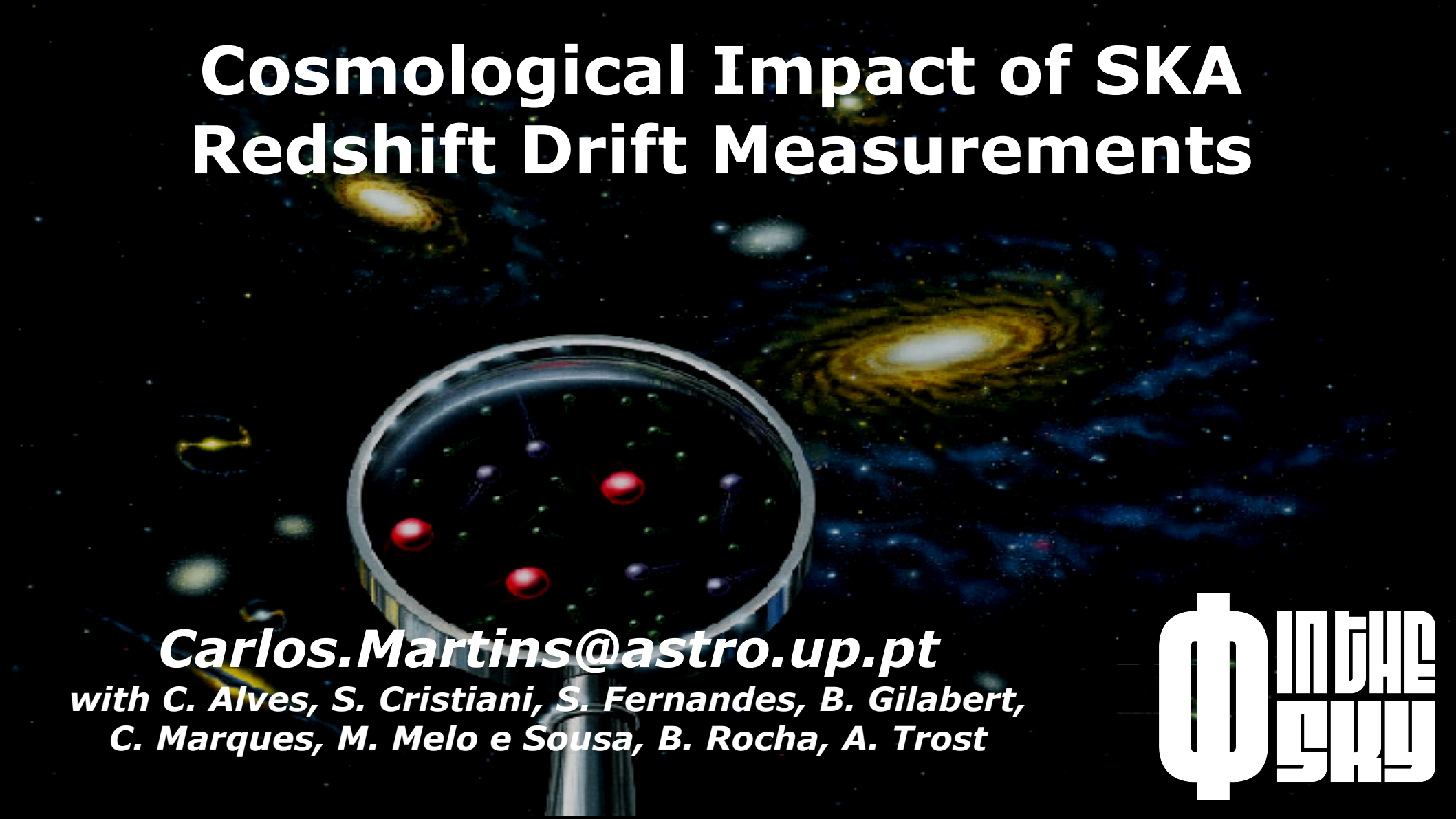
Cosmological Impact of SKA Redshift Drift Measurements



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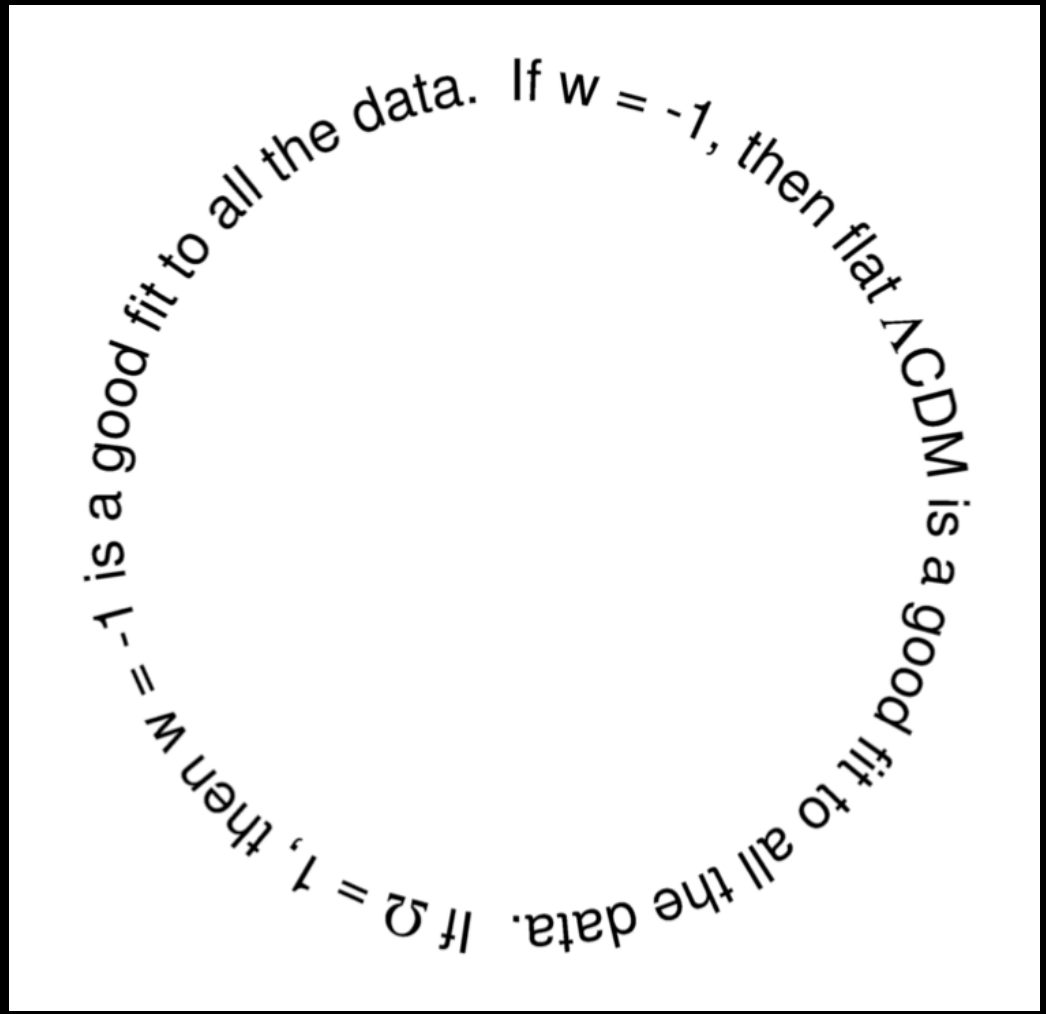
with C. Alves, S. Cristiani, S. Fernandes, B. Gilabert, C. Marques, M. Melo e Sousa, B. Rocha, A. Trost

Φ IN THE SKY

Mind Your Cosmological Priors



The Redshift Drift

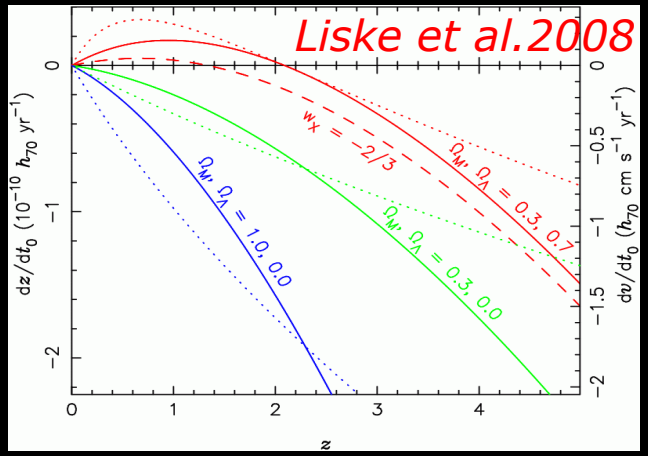
A direct non-geometric model-independent measurement of the universe's expansion history *[Sandage 1962]*

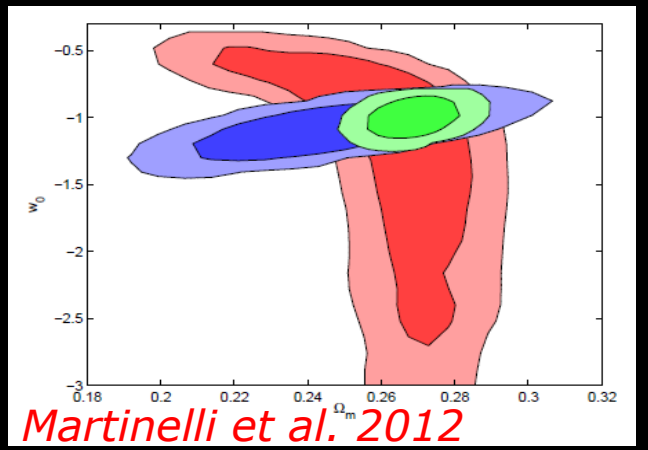
- Watching the universe expand in real time!
- Independent of gravity, geometry or clustering
- Directly comparing different past light-cones
- Signal grows linearly with experiment time

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

SKA can probe z<1 *[Klockner et al. 2015]*

- ELT (directly) probes z>2 *[Liske et al. 2008]*
- Positive drift → SEC violation → Dark energy
- Further (longer-term) possibilities: CMB, GWs





The ESPRESSO Redshift Drift Experiment

Current limits on the redshift drift signal are 1000x larger than the expected signal, and manifestly systematics-dominated

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

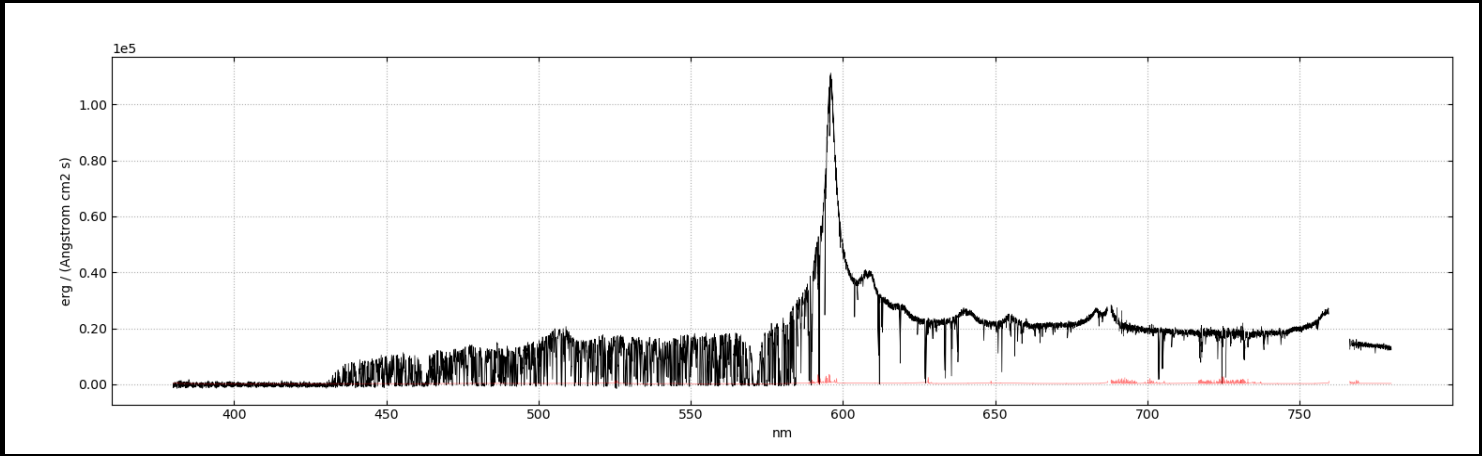
ESPRESSO can improve this by a factor ~10 with an experiment time of 1 year and an observation time of 40h, for 2 QUBRICS 'superbright' QSOs

- Test and optimise methodology with real data
- Test ESPRESSO instrument stability
- Two independent experiments at ~same redshift, test addition
- Also 'zeroth epoch' for ANDES Golden Sample (calibration permitting)

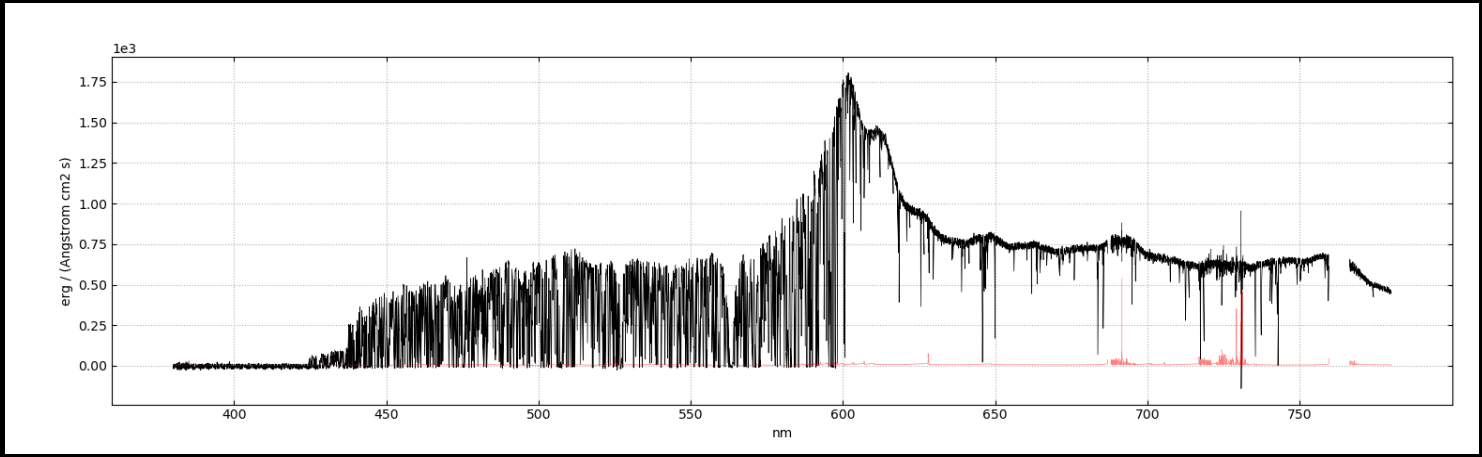
4 ESO programmes (110.247Q, 111.251D, 112.25K7 and 113.26FY; PI Martins), first accepted OB on 22/01/2023, first results soon.

The ESPRESSO Redshift Drift Experiment

Superbright 1
total int.: ∼8.6 h
⟨SNR⟩: ∼60
last obs.: 15/8/23

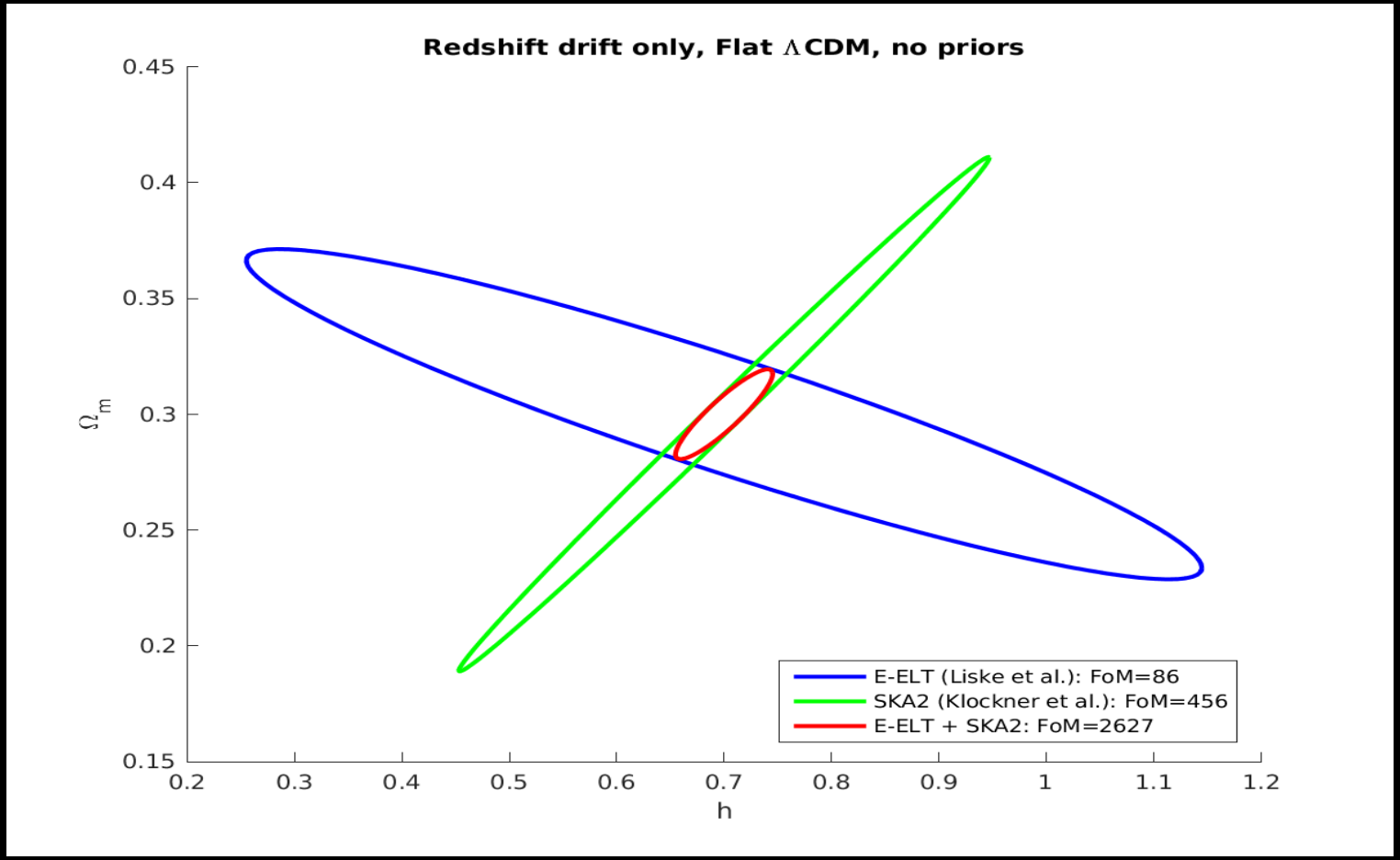


Superbright 2
total int.: ∼12.4 h
⟨SNR⟩: ∼90
last obs.: 5/2/24



The Importance of a Redshift Lever Arm

(Or: Why the SKA is necessary)



Previous 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
- Sensitivity, number counts, hardware, systematics (e.g. observatory motion) etc.

Learned from the new predictions for the ELT; are the SKA forecasts out of date?

- Good topic for someone's thesis?
- Other possibilities: drift of the drift, spatial variations, ...

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

- This is an important test for the (un)expected systematics

PROCEEDINGS OF SCIENCE

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

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[1]Max-Planck-Institut für Radioastronomie (MPIfR), Germany; [2]The University of Western Australia, ICRAR, Australia; [3]Centro de Astrofísica da Universidade do Porto, Portugal; [4]Department of Physics & Astronomy, Johns Hopkins University, Caltech, & JPL, USA; [5]KASI KVN, Korea

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Real-time Cosmography with the SKA

First & second redshift derivatives are powerful ΛCDM paradigm test; cosmographic approach useful *[Martins et al. 2016, Marques et al. 2023]*

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

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

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

- To linear order,

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

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

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

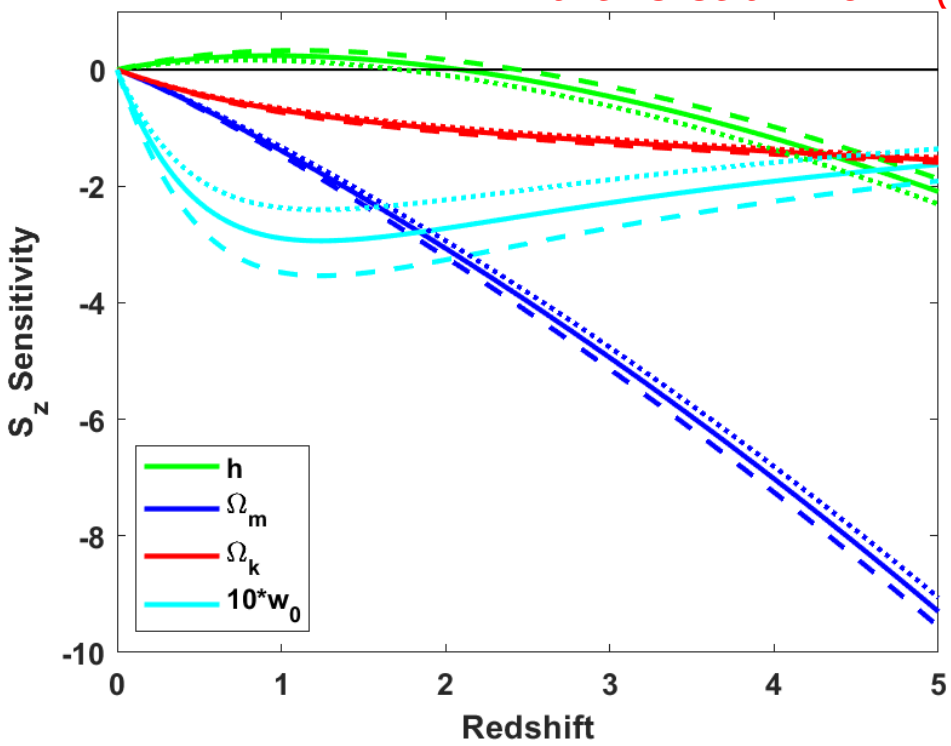
Assuming specs discussed in *[Klockner et al. 2015],* SKA redshift drift measurements can reach σ_{q0}~0.006 and σ_{j0}~0.13 *[Martins et al. 2016]*

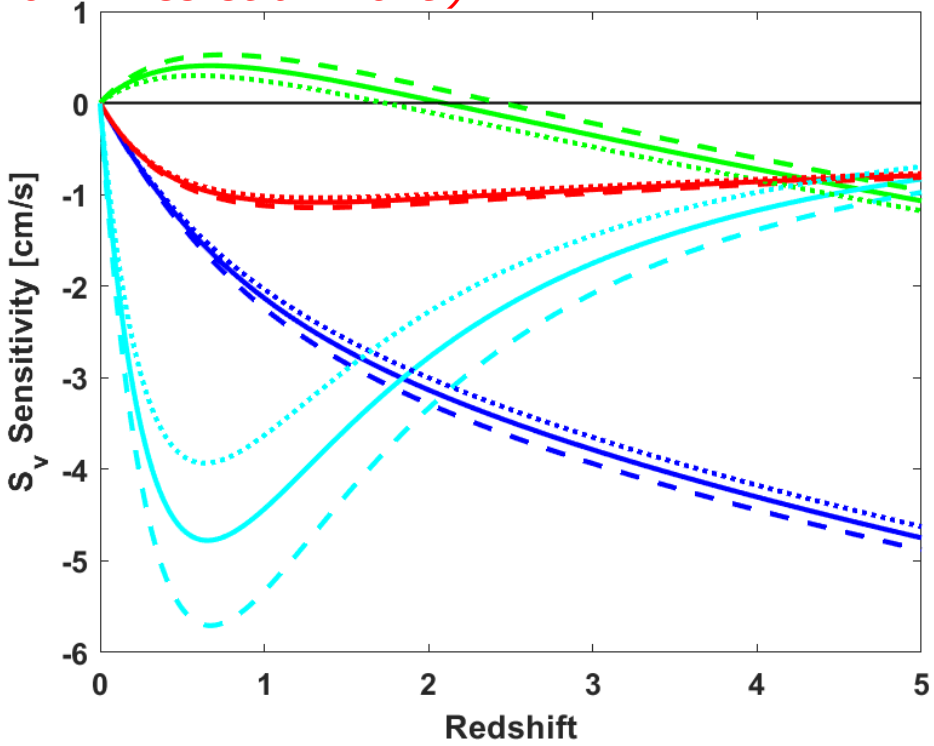
- Optimal way to measure q_0 with both accuracy and precision, which is not possible with traditional distance indicators *[Neben & Turner 2013]*
- A key consistency test: j(z)=1 at all redshifts for a flat ΛCDM universe
- Recall: a positive drift implies SEC violation, hence dark energy

Cosmological Parameter Sensitivity Example

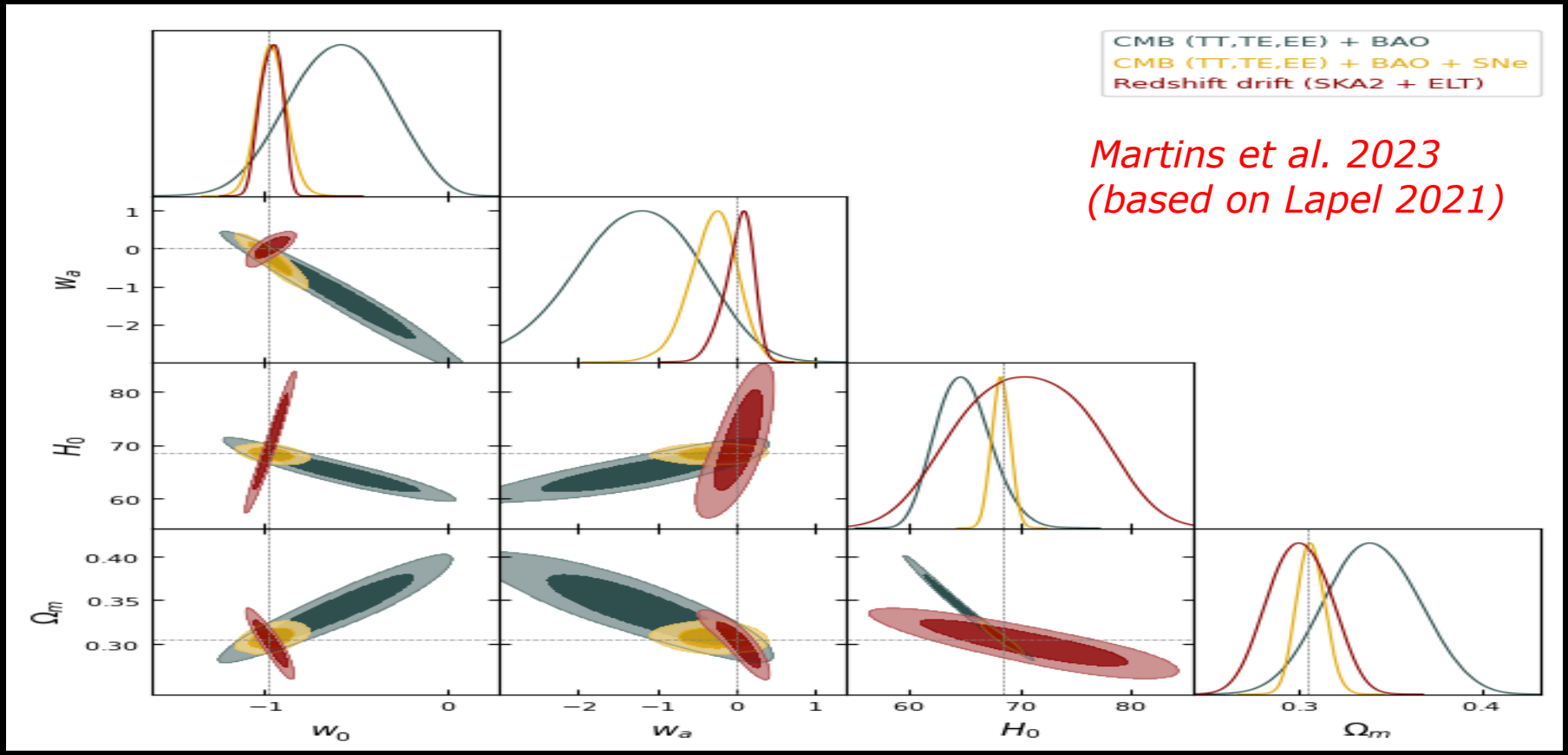
(NB: These mildly depend on assumed fiducial model class)

Martins et al. 2024 (based on Alves et al. 2019)





Synergies: ELT + SKA



ELT differential redshift drift *[Cooke 2020]*, not included in the plot, further enhances these *[Martins et al. under review, Trost et al. in prep.]*

Let's do it!