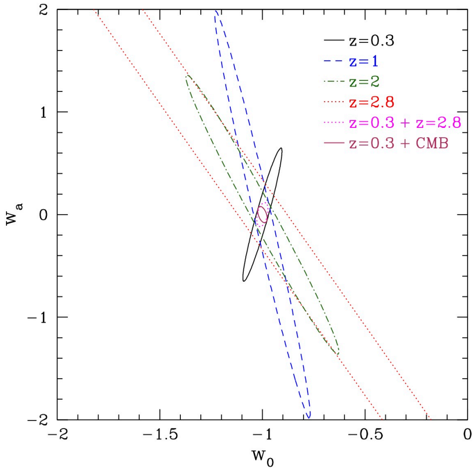
Redshift Drift
Reloaded



Eric Linder

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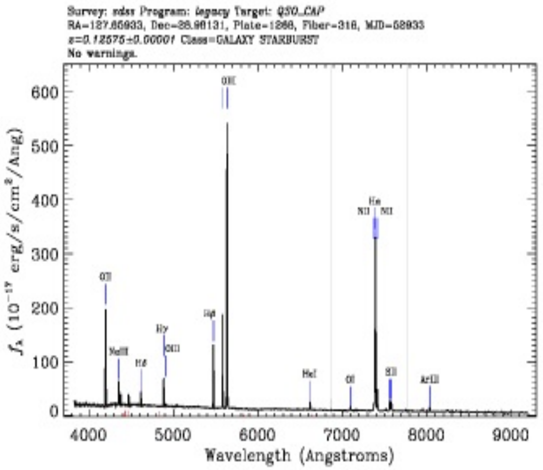
Talk based on

Kim, Linder, Edelstein, Erskine 1402.6614



Redshift Drift

Redshift Drift (seeing the universe expand in our lives: dz/dt_0) known 50 years ago, but is very very challenging.

Direct, kinematic probe of acceleration.
Just like redshift, don't need to know matter density or forces.

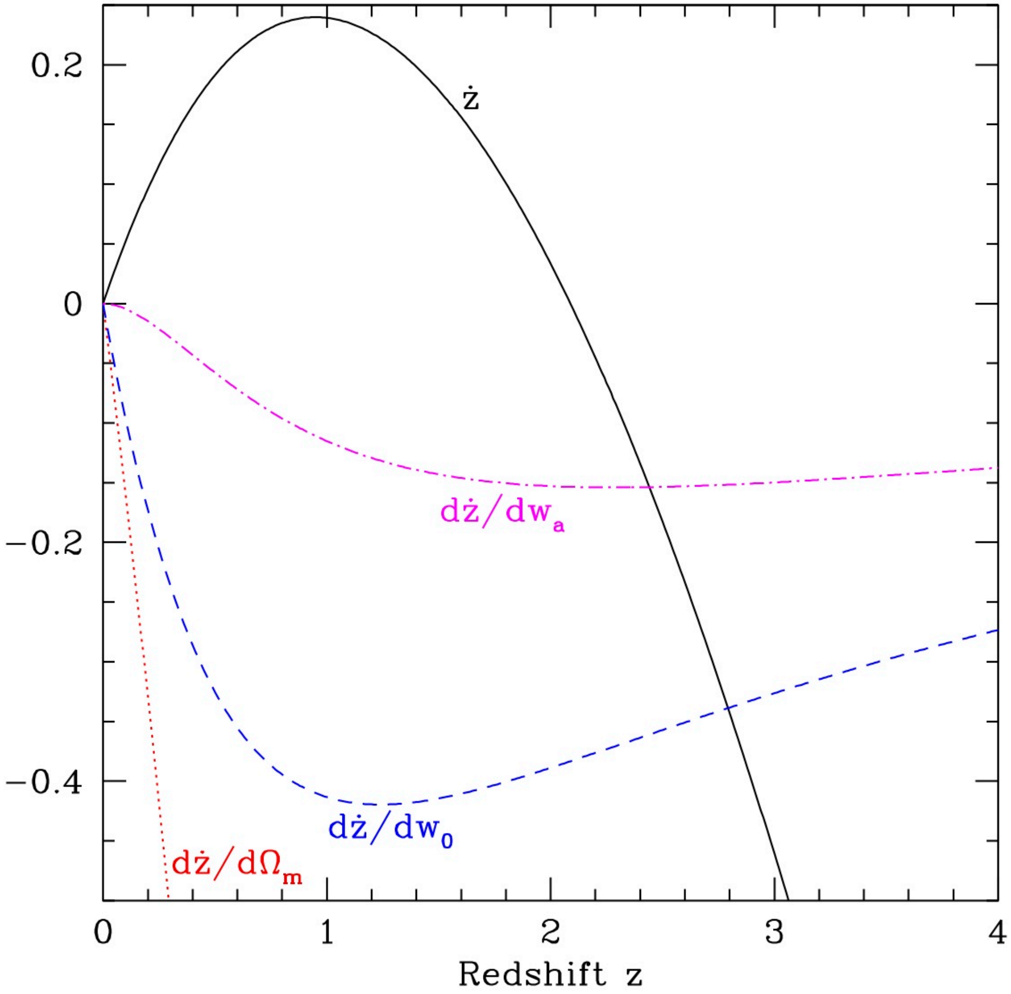
$$\frac{dz}{dt_0} = \frac{d}{dt_0}\left[\frac{a(t_0)}{a(t_e)} - 1\right] = \frac{\dot{a}(t_0) - \dot{a}(t_e)}{a(t_e)}$$

$$= (1+z)\,H_0 - H(z)$$

Sandage 1962; McVittie 1962; Linder 1991,1997

Redshift Drift Cosmology

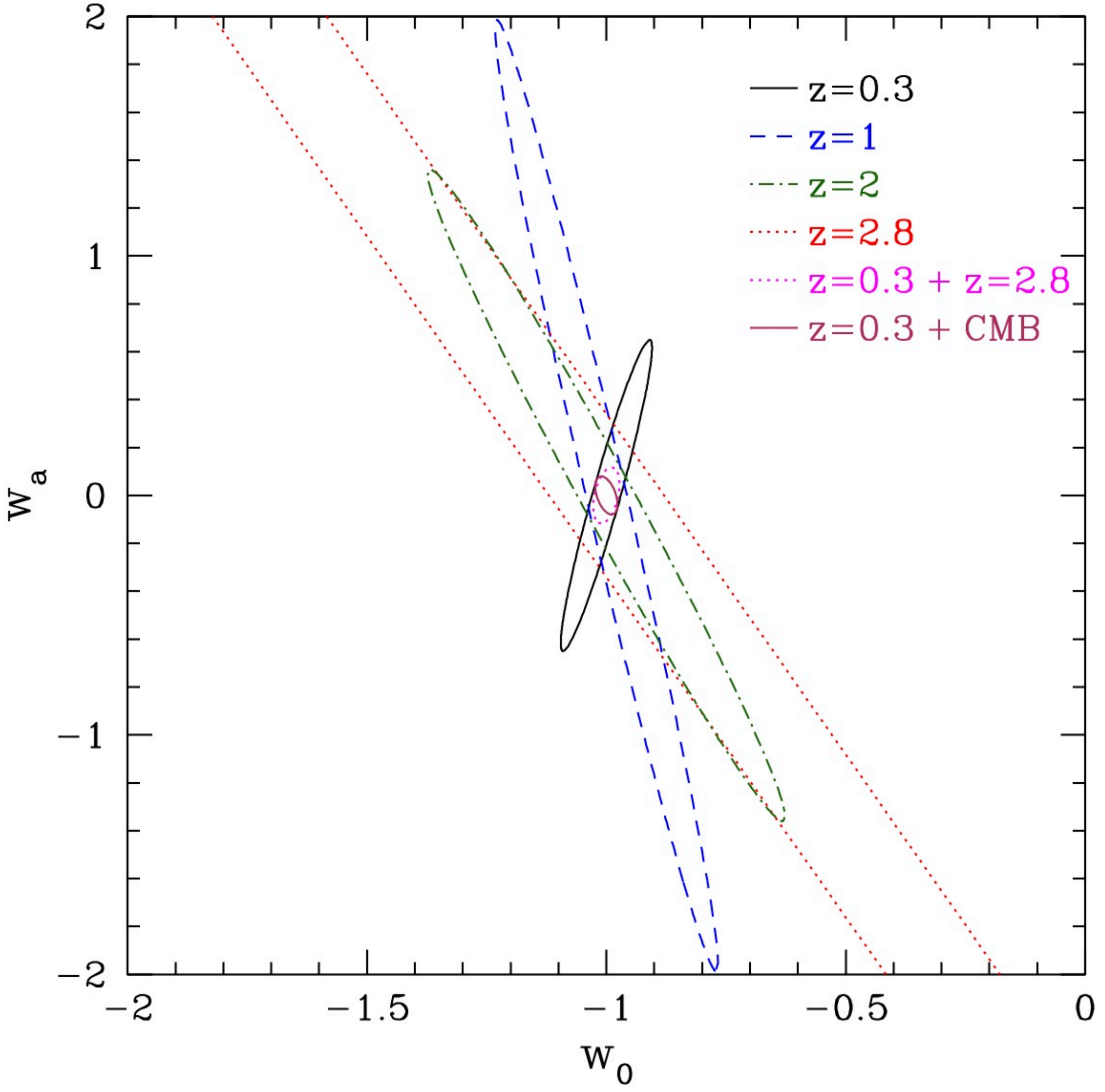
Direct measure of acceleration, but is it a good cosmological probe?



- No strong covariance
- Steep rise in sensitivity at low redshift
- Over observing time dt have drift of $dz < H_0\, dt = 10^{-10}\, h(dt/yr)$

Redshift Drift Cosmology

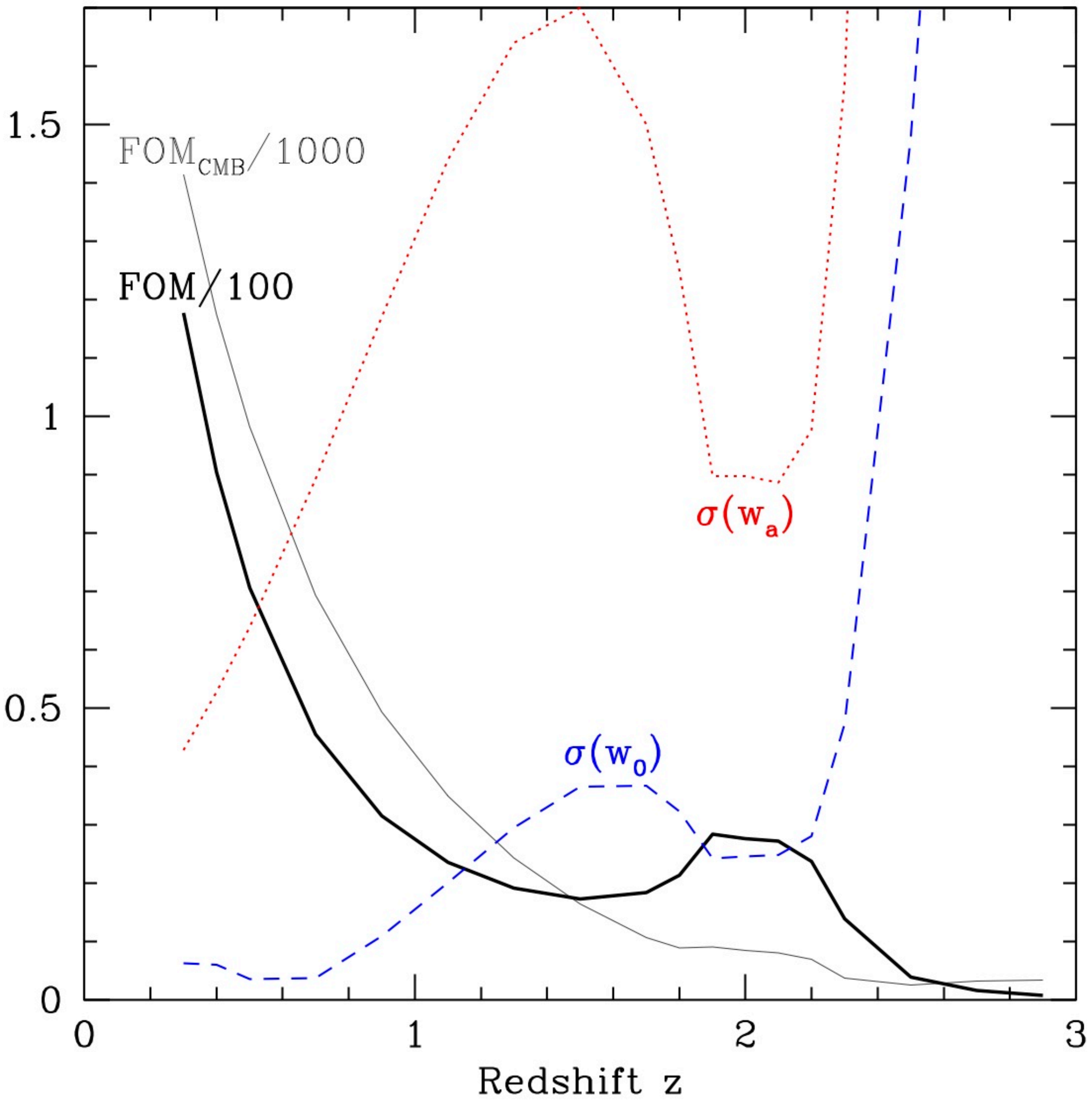
If you can measure it, it's a fantastic new probe!



- **Key new element** is to measure it at **low z**, not at peak or high z.
- **Orthogonal**, highly complementary!
- Low+high z is best, can do with **low z + CMB**.

Redshift Drift and Dark Energy

Let's dream about 1% measurements, at z, z±0.1, z±0.2.



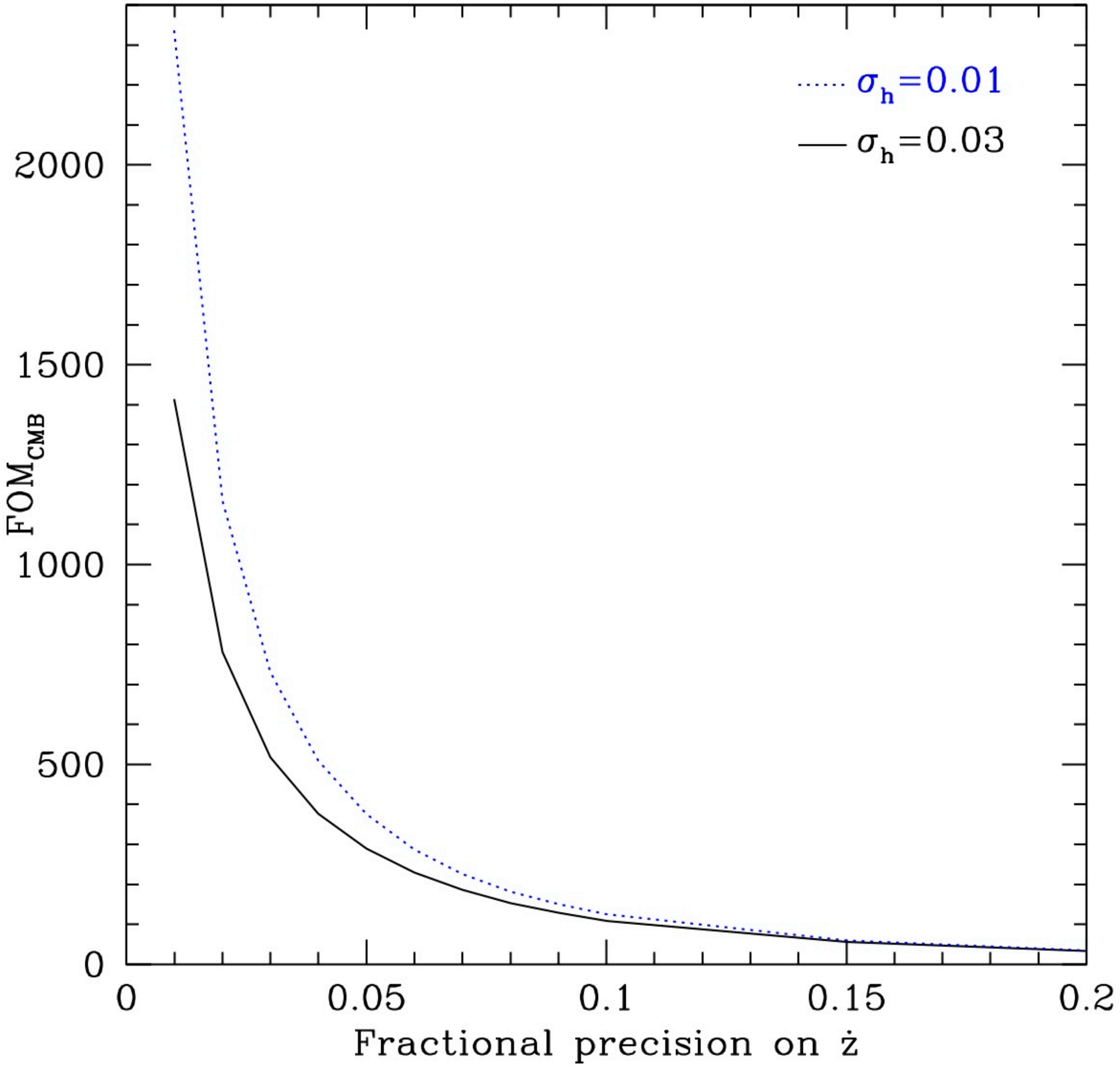
- Low z definitely wins.

- Figure of merit from zDrift is ~100.

- FOM from zDrift +CMB is ~1000!

Redshift Drift and Dark Energy

What if we descope our dream?



- Even at 5% get respectable result: FOM ~ 300.

- Improving prior on h helps.

Astrophysical Systematics

What challenges arise from astrophysics?

$$1+z=\frac{(g_{\mu\nu}k^{\mu}u^{\nu})_e}{(g_{\mu\nu}k^{\mu}u^{\nu})_o}$$

Inhomogeneous gravitational potentials.

Deviations due to inhomogeneities (lensing).

Peculiar acceleration.

$$\begin{aligned}\frac{dz}{dt_o} \;=\; & \frac{\dot{a}_o-\dot{a}_e}{a_e}+2[\dot{\psi}_e-(1+z)\dot{\psi}_o]+\frac{2}{a_e}\partial_1(\psi_e-\psi_o)\\ & -(\dot{\psi}_e-\dot{\phi}_e)+(1+z)(\dot{\psi}_o-\dot{\phi}_o)-H(z)\,(\phi_o-\phi_e)+H_0\,(1+z)[a_ok_o^0]^{(1)}\end{aligned}$$

$$\boxed{\dot{u}\sim\frac{\psi}{L}\sim H\,\frac{H^{-1}}{L}\,\psi\sim H\left(\frac{40\,\mathrm{kpc}}{L}\right)\left(\frac{\psi}{10^{-5}}\right)}$$

Astrophysics

1% accuracy requires reduction of systematics by 2-3 orders of magnitude to reach dz~10^{-12} in 1 year.

Be patient.

Look widely (array of sources).

Be clever.

Crazy Idea 1: Cosmic pulsers

Use many signals. Precision scales as N^{-2}.

Cosmic pulsars? (Thornton et al 1307.1628, z~0.5-1)

BH+BH inspiral (GW)?

New time domain survey discoveries?

Radial BAO

Uncrazy Idea: differential radial BAO (drBAO)

Use many sources, and let the universe do the time leverage (~Hubble time).

$$\mathrm{drBAO} = \mathrm{rBAO}(z_2) - \mathrm{rBAO}(z_1) = s\,(H_2 - H_1)$$

Hubble drift, not redshift drift, with interesting properties. And comes for free in BAO surveys!

Probe	Quantity	Marg.	Sign Flip
z drift	$(1+z)\,H_0 - H(z)$	H_0	$w_{\rm tot} = -1/3$
drBAO	$s\,[H(z_2) - H(z_1)]$	s	$w_{\rm tot} = -1$

Crazy Idea 2: Strongly lensed quasars + LyA

Many sources, many signals, ~year delay in 1 night. Wide field surveys, differential z measurement.

Instrumental Systematics

Redshift accuracy very challenging: calibration, drift, PSF, line shape.

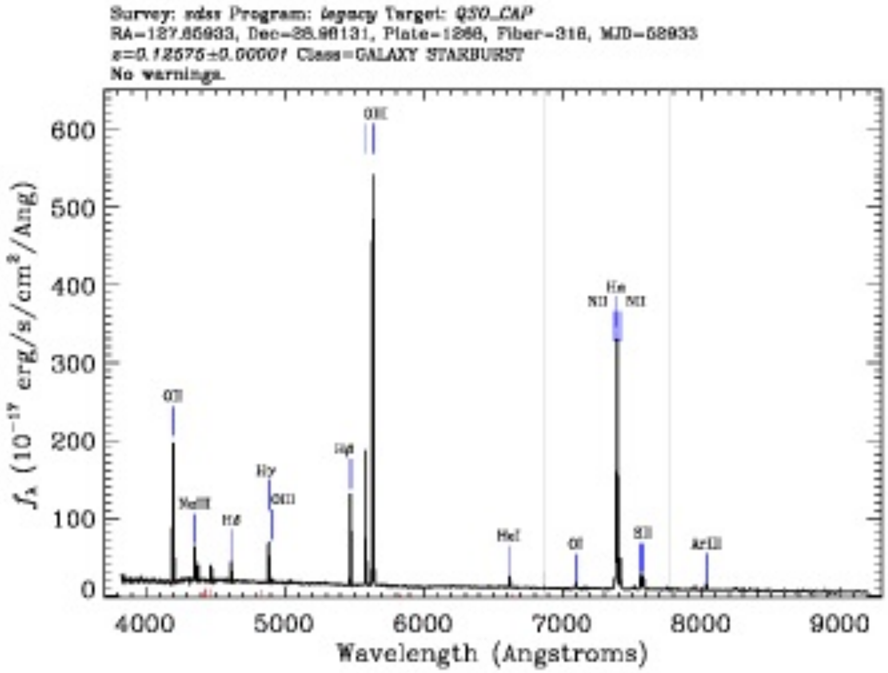
Strong gains from bright, well known, narrow lines and differential measurement.

Low redshift ELGs with [OII], [OIII] doublets are great! Also in cosmology sweet spot, well surveyed, and in field (low peculiar acceleration).

Wavelength differences redshift the same as wavelength so measure differentially (doublet).

Interferometers give differential measurements that cancel some instrument systematics.

ELG sources



SDSS target

Plate	Fiber	z	Doublet	Δv ($\mathrm{km\,s^{-1}}$)	Flux 1 ($\mathrm{erg\,s^{-1}cm^{-2}}$)	Flux 2 ($\mathrm{erg\,s^{-1}cm^{-2}}$)	Continuum ($\mathrm{erg\,s^{-1}cm^{-2}\AA^{-1}}$)
1523	602	0.089	[OIII]	5.14	7.04×10^{-16}	2.13×10^{-15}	1.97×10^{-17}
1935	204	0.098	[OII]	10.054	1.06×10^{-14}	1.28×10^{-14}	2.39×10^{-16}
			[OIII]	10.04	1.96×10^{-14}	5.93×10^{-14}	1.92×10^{-16}
1036	584	0.108	[OIII]	4.55	3.47×10^{-16}	1.05×10^{-15}	4.42×10^{-17}
2959	354	0.120	[OIII]	6.86	1.11×10^{-16}	3.36×10^{-16}	1.51×10^{-18}
1268	318	0.126	[OII]	10.044	5.89×10^{-15}	6.29×10^{-15}	1.77×10^{-16}
			[OIII]	10.04	1.09×10^{-14}	3.32×10^{-14}	1.46×10^{-16}

EDI

Externally Dispersed Interferometer (EDI) is a FTS followed by a dispersion spectrograph.

Measurements include from dispersion and from modulation of arm lengths (“whirl”).

delay

$$I(\sigma)_{\Delta\tau} = [B(\sigma)\,(1+\cos(2\pi\,(\tau+\Delta\tau)\,\sigma+\phi_y))$$

Initial phase

input spectrum

$$\otimes \mathrm{PSF}(\sigma)]\ \text{III}\left(\frac{\sigma}{p}\right),$$

discrete sampling

Calibration from local phase and frequency so no absolute flux or PSF systematics.

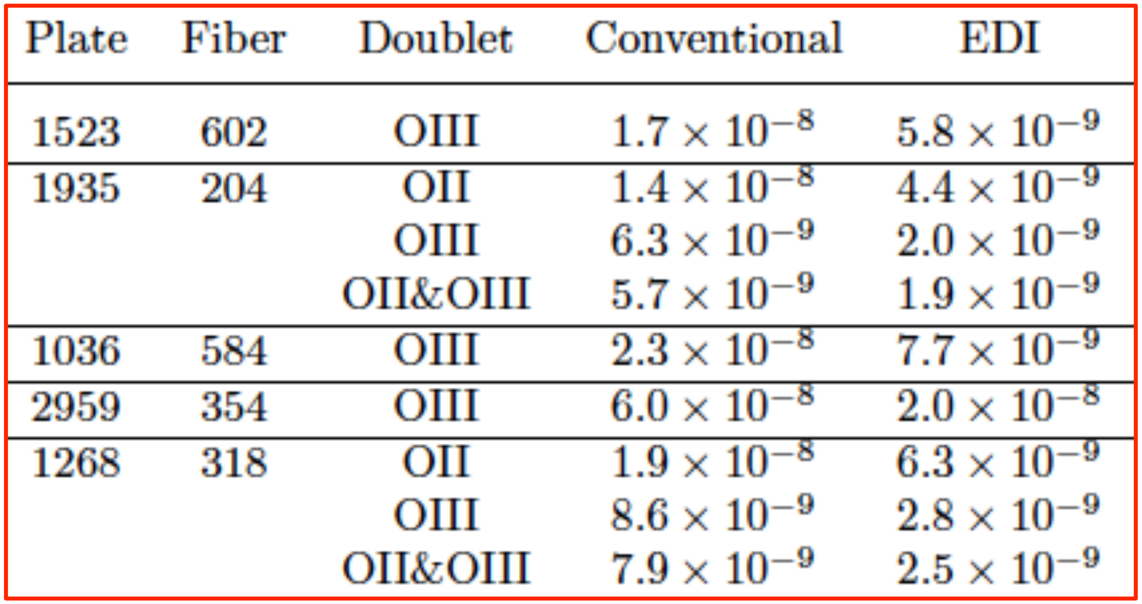


Plate	Fiber	Doublet	Conventional	EDI
1523	602	OIII	1.7×10^{-8}	5.8×10^{-9}
1935	204	OII	1.4×10^{-8}	4.4×10^{-9}
		OIII	6.3×10^{-9}	2.0×10^{-9}
		OII&OIII	5.7×10^{-9}	1.9×10^{-9}
1036	584	OIII	2.3×10^{-8}	7.7×10^{-9}
2959	354	OIII	6.0×10^{-8}	2.0×10^{-8}
1268	318	OII	1.9×10^{-8}	6.3×10^{-9}
		OIII	8.6×10^{-9}	2.8×10^{-9}
		OII&OIII	7.9×10^{-9}	2.5×10^{-9}

Summary & Future

Redshift Drift is kinematic, direct acceleration.

New cosmological probe, orthogonal, good FOM, low redshift.

Synergy with DESI/PFS, Euclid, LSST.

A new time domain! (Hubble time)

10^{-9} for 8 hours on Keck, 1 source. GMT/TMT/EELT?

Collaboration: on crazy ideas.

Best lines: ELG? CO lines? Radio? “Gold” targets.

If not cosmology, then peculiar acceleration maps, atomic line catalogs, exoplanets?