Gravitational Waves and Cosmic Growth Combined

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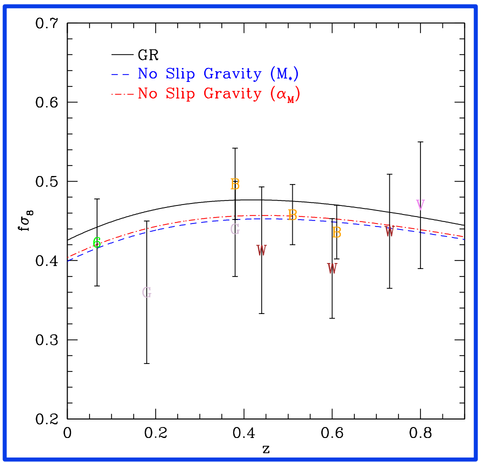
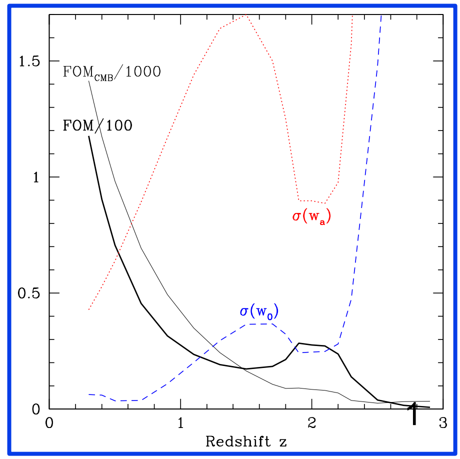
Probing the Universe with Multimessenger Astrophysics

27 Sep 2022





Two Windows

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Two windows to test the cosmological framework:

- Gravitational waves
- Large Scale Structure

GW distances probe cosmology, but it'll be a while until they reach the precision of current probes.

GW are great at probing "spacetime friction".

This is like the Hubble friction $H(z)$ that acts on LSS growth, but arises from changing gravitational strength, specifically $M_{Pl}(z)$.

D_{GW} vs D_{EM}

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Spacetime friction damps the GW amplitude, changing the inferred distance $h \sim D_{GW}^{-1}$.

$$\ddot{h} + (2 + \alpha_M)\mathcal{H}\dot{h} + c_T^2 k^2 h = 0$$

Horndeski $\alpha_M = d \ln M_{Pl} / d \ln a$ (running of Planck mass) damps h, so changes the inferred D_{GW}.

Is gravity the same at all cosmic times?

If not, then $D_{GW}(z) \neq D_{EM}(z)$.

Nishizawa 1710.04825, Arai & Nishizawa 1711.03776, Belgacem+ 1712.08108, Amendola+ 1712.08623, Linder 1801.01503

Gravitational Waves and Cosmic Growth

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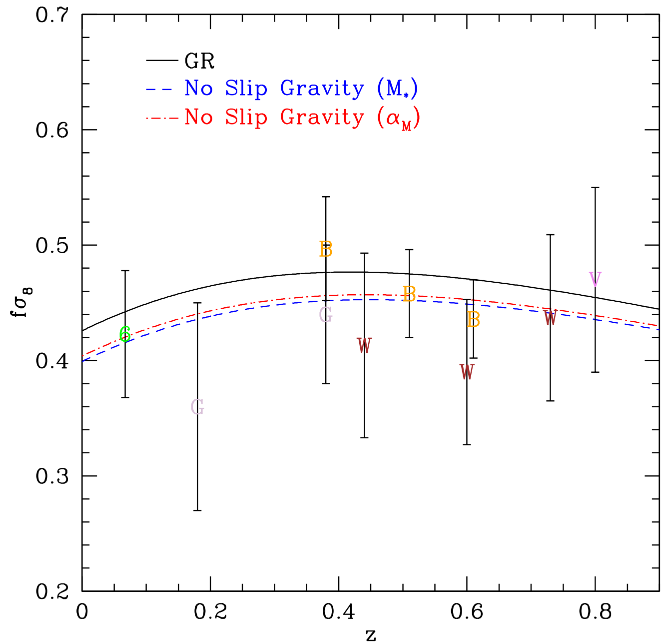
But $M_{Pl}(z)$ also affects growth, so GW distance tied to growth!

Linder 1801.01503

If we detect, e.g., a suppression in growth, then this can be checked vs GW distances different than GR.



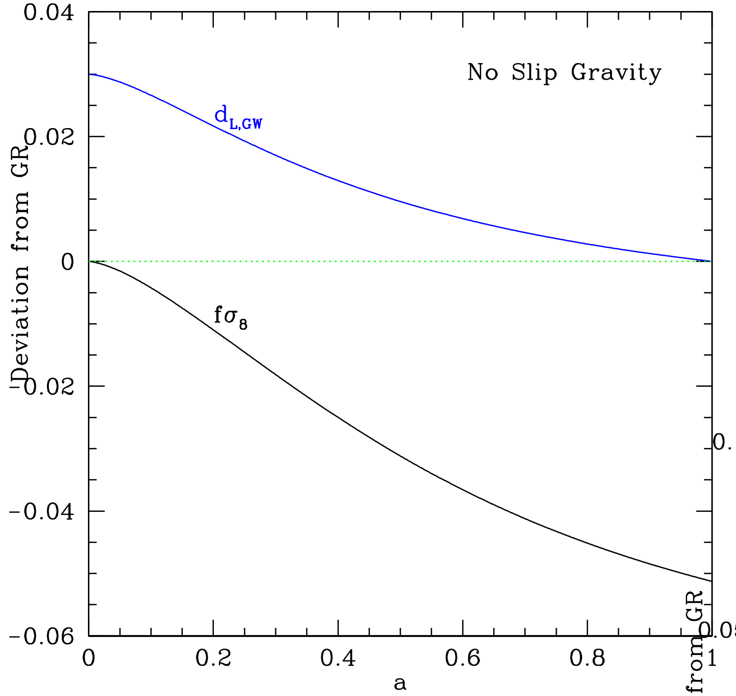
Example: No Slip Gravity (1 free function) **fits growth from redshift space distortions better than GR.**

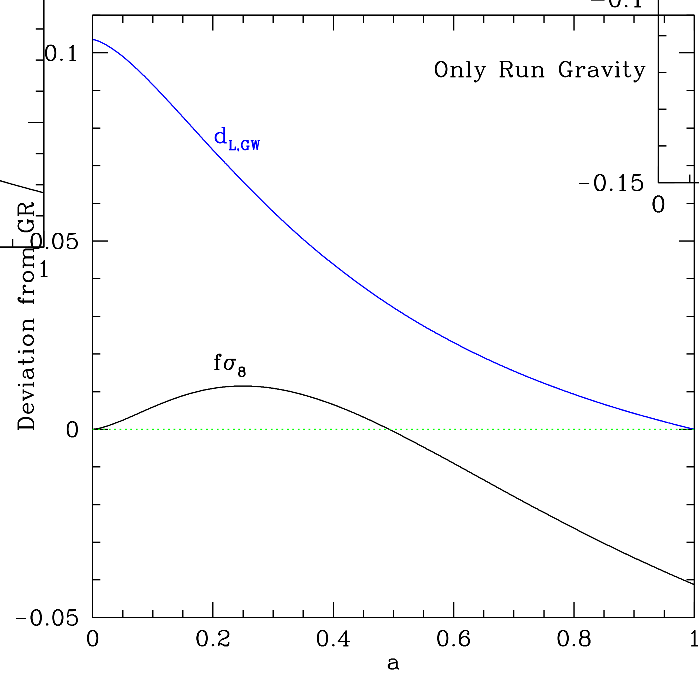
It *predicts* ~5% deviation in GW distances.

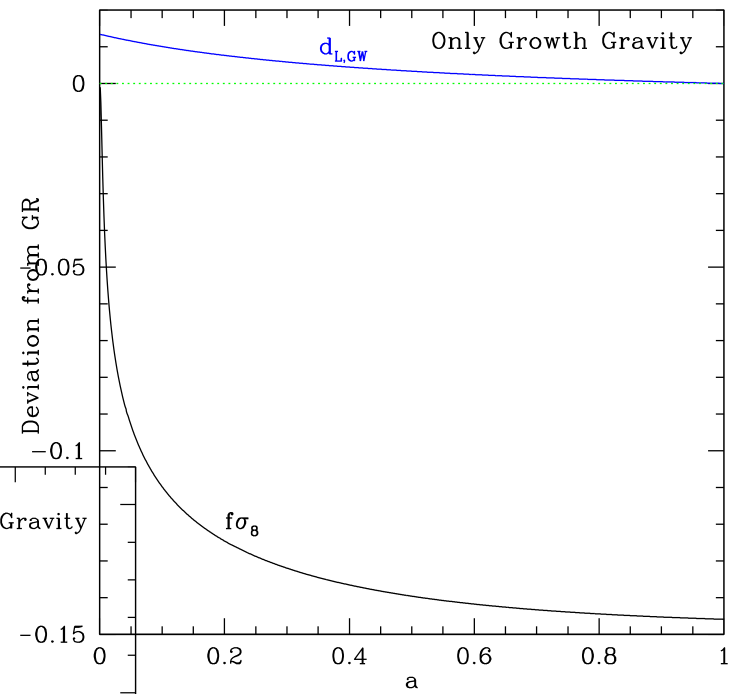
Galaxy surveys have deep complementarity with GW and CMB surveys.

Growth and GW together

Important crosscheck: a deviation from GR in one predicts a *specific* deviation in the other (and systematics are different).







Linder 2003.10453

Joint Analysis to Test GR

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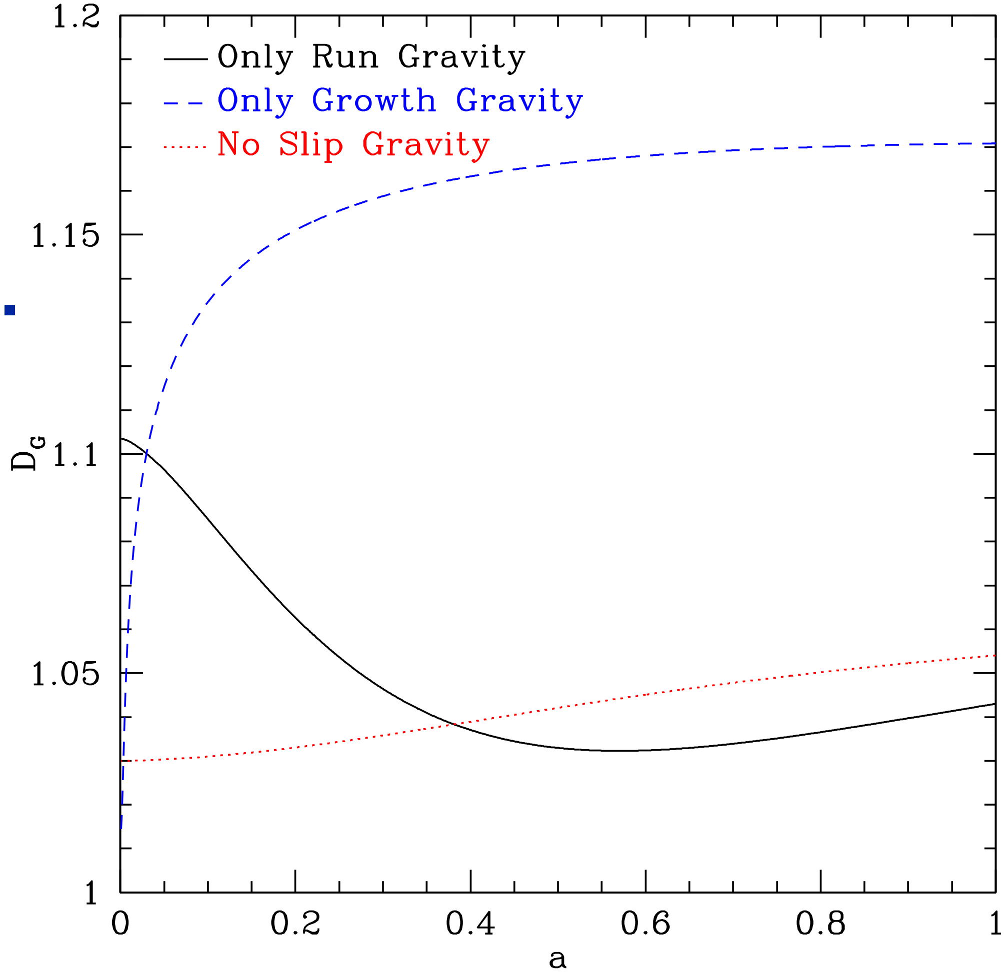
Quantify the conjoined information on GR deviation:

$$D_G(a) = \frac{d_{L,\mathrm{GW}}^{\mathrm{MG}}/d_L^{\mathrm{GR}}}{f\sigma_8^{\mathrm{MG}}/f\sigma_8^{\mathrm{GR}}}$$

For GR this is 1 for all z. For MG model it has a specific redshift dependence predicted.



A New History

Probing the gravity history of the universe through the running of the Planck mass, using both GW and large scale structure, is an exciting prospect!

Is gravity the same at all cosmic times?

- ***Joint analysis D_G: GW vs growth – predictive.***
- ***Important crosscheck for systematics.***

A beautiful example of multimessenger cosmology working together.

Multi-Time Cosmology

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Another new window on the cosmological framework is in *time*.

Real-time Cosmology – Quercellini, Amendola, Balbi, Cabella, Quartin arXiv:1011.2646

Measuring Space-time Geometry over the Ages – Stebbins arXiv:1205.4201

Real-time Cosmology with High Precision Spectroscopy and Astrometry – Snowmass arXiv:2203.05924

Redshift drift $\dot{z}$ was proposed by McVittie and Sandage in 1962. It measures cosmic acceleration directly. It is now within reach technologically!

Redshift Drift + CMB

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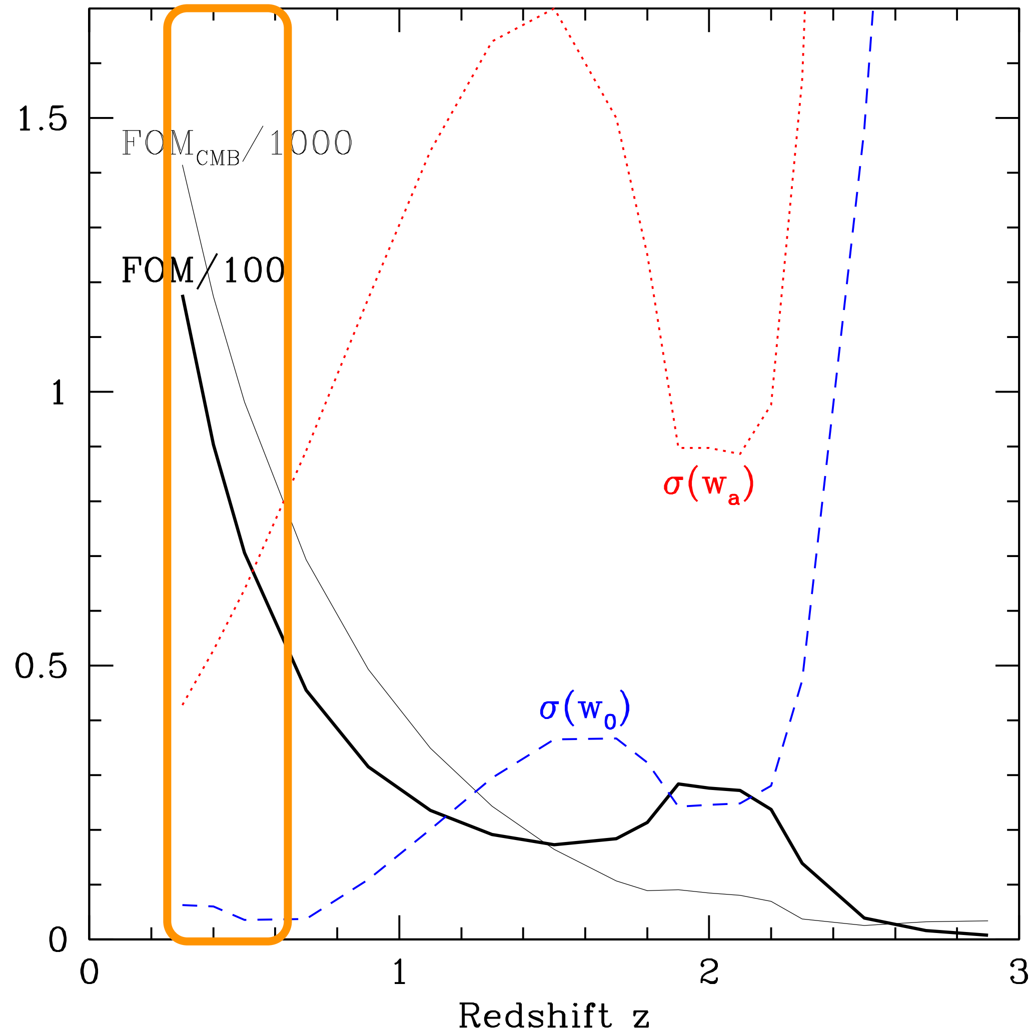
If redshift drift ż can be measured, it has powerful complementarity with CMB.



Leverage ranges from independent crosscheck to 3x above Stage 4.

Optimal range z<0.5.

Need lots of photons, e.g. ELTs.

High *Accuracy* Spectroscopy

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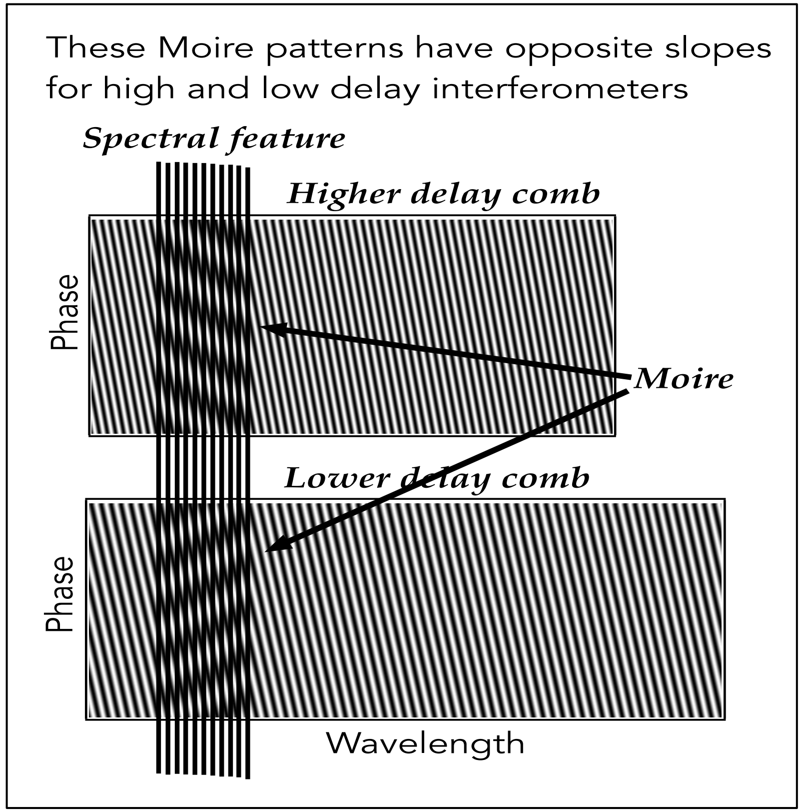
Externally Dispersed Interferometry (EDI) puts an interferometer before the spectrograph.

Crossfading (adjustment of EDI delays) cancels λ drift and other systematics.

The same technology enables

- **Earth mass exoplanet detection from radial velocities**
- **Milky Way structure mapping through stellar accelerations**
- **Dark matter properties through Milky Way gravity mapping**



Erskine+ 1903.05656
Astro2020 white paper

Demonstrated in lab and on sky!

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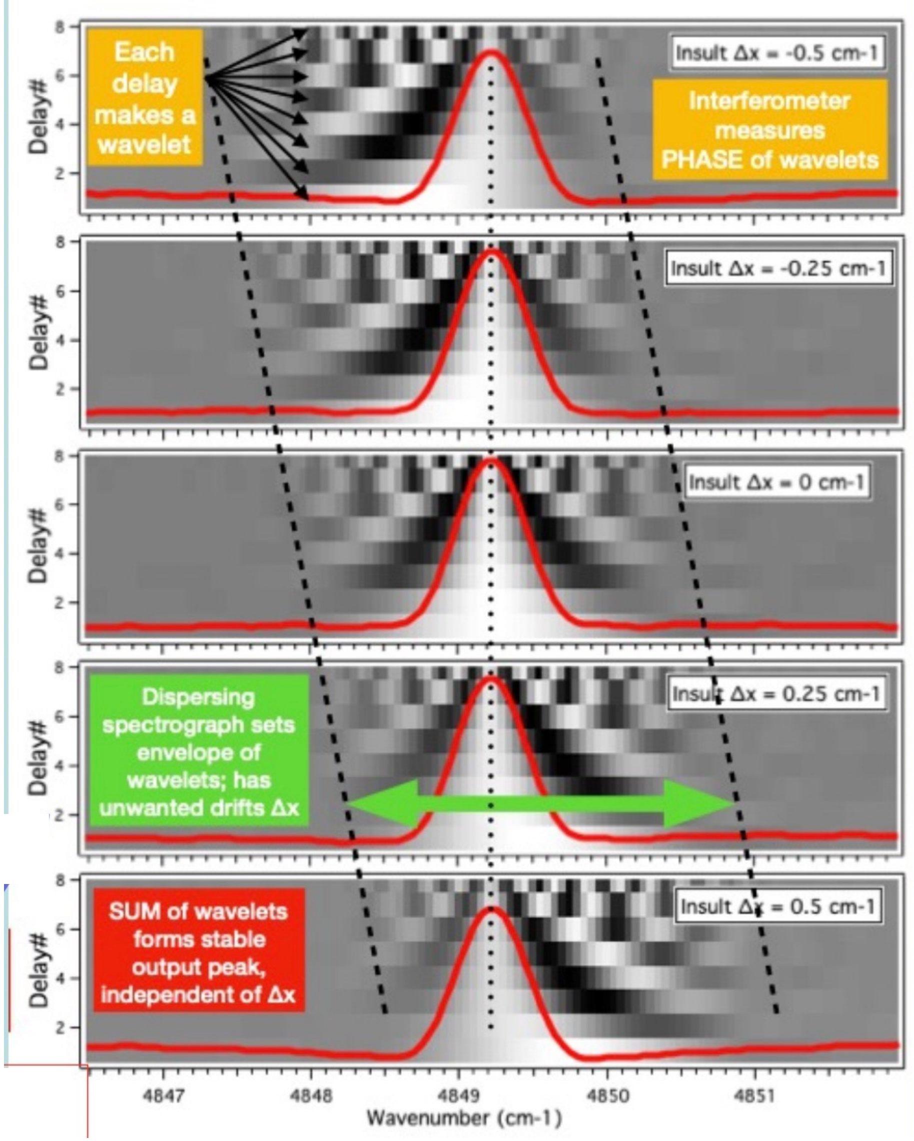

Erskine SPIE 2022

Demonstrated 1000x improvement in λ (i.e. ż) stability.

Also being used for Keck Planet Finder.

Summary

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Spacetime friction can be probed by GW.
A new window on gravity.

Deviation in either GW or growth *predicts* the other.
Important clue, and crosscheck on systematics.

Is gravity the same at all cosmic times?

- ***Joint analysis D_G: GW vs growth – predictive.***

Real-time cosmology – redshift drift $\dot{z}$ – is becoming doable, 60 years after McVittie and Sandage.

- **Optimal range $z<0.5$, but many photons (ELT).**
- **EDI already achieves >1000x gain in performance.**