Modified Gravity:
the Landscape post-GW170817

Tessa Baker

University of Oxford

Outline

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- Reasons to look beyond GR.

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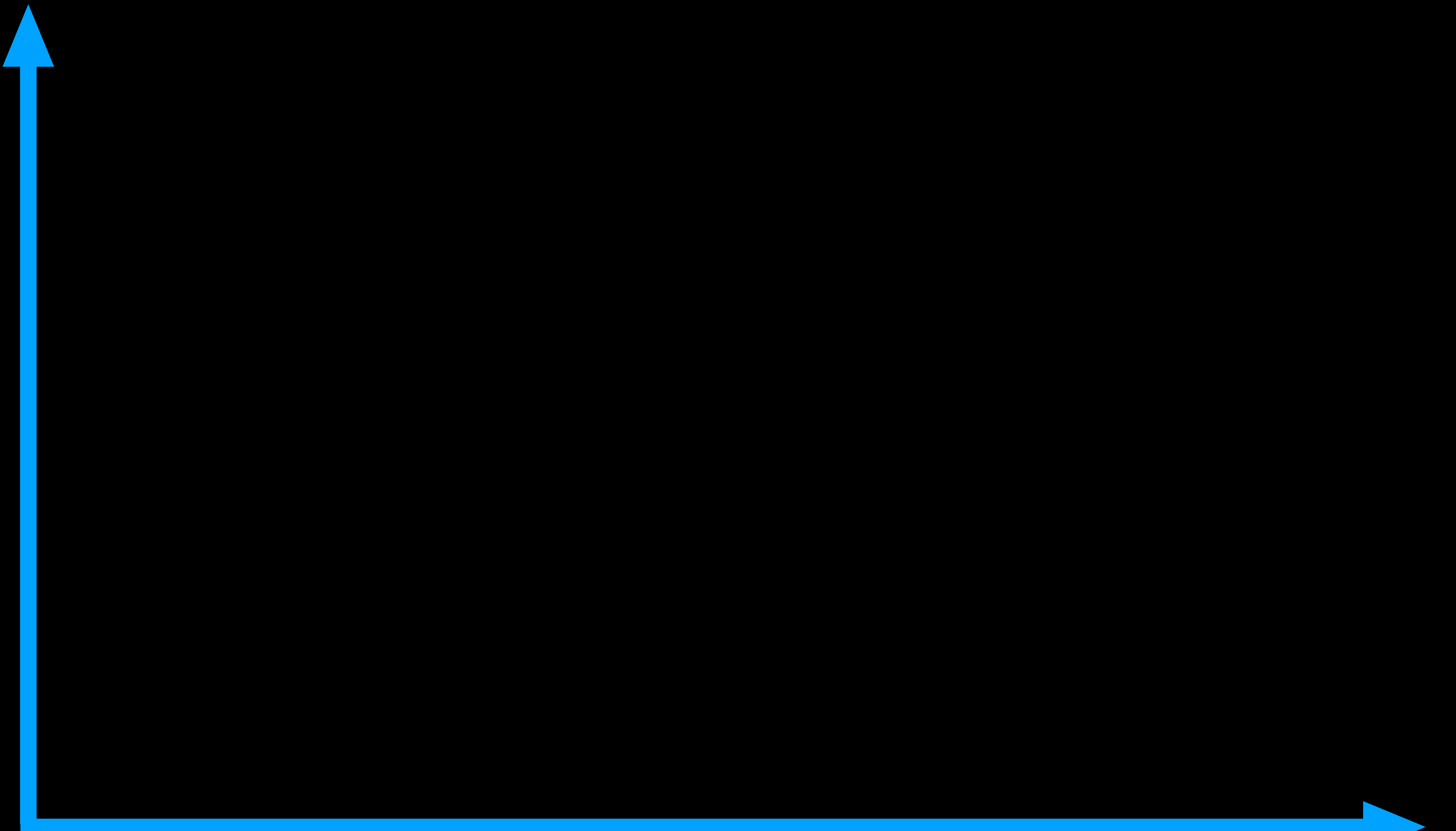
- ✦ What happened with GW170817.

Outline

- Reasons to look beyond GR.
- What happened with GW170817.
- What happens next?

Motivations

Why are we interested in MG?



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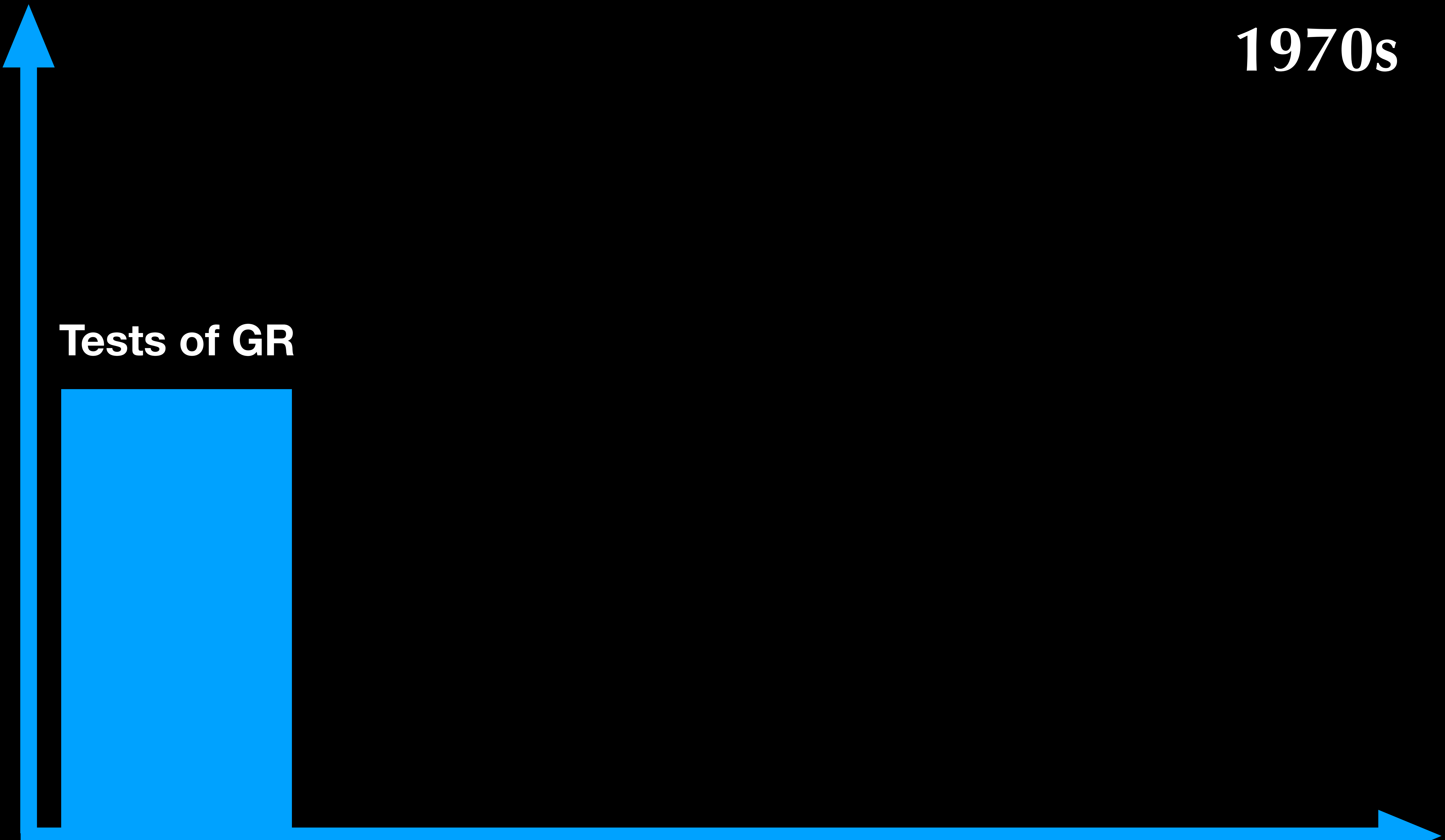

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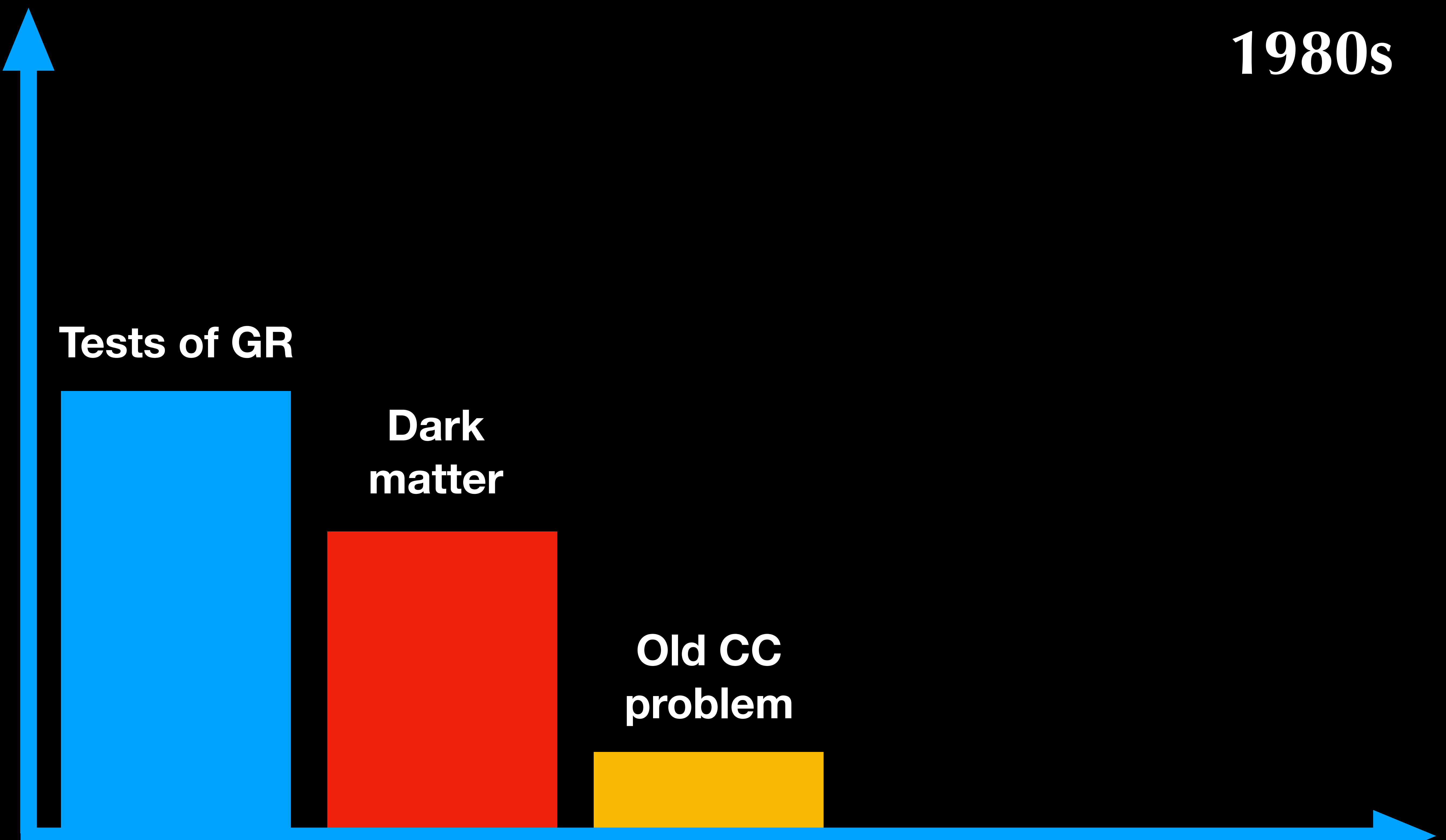

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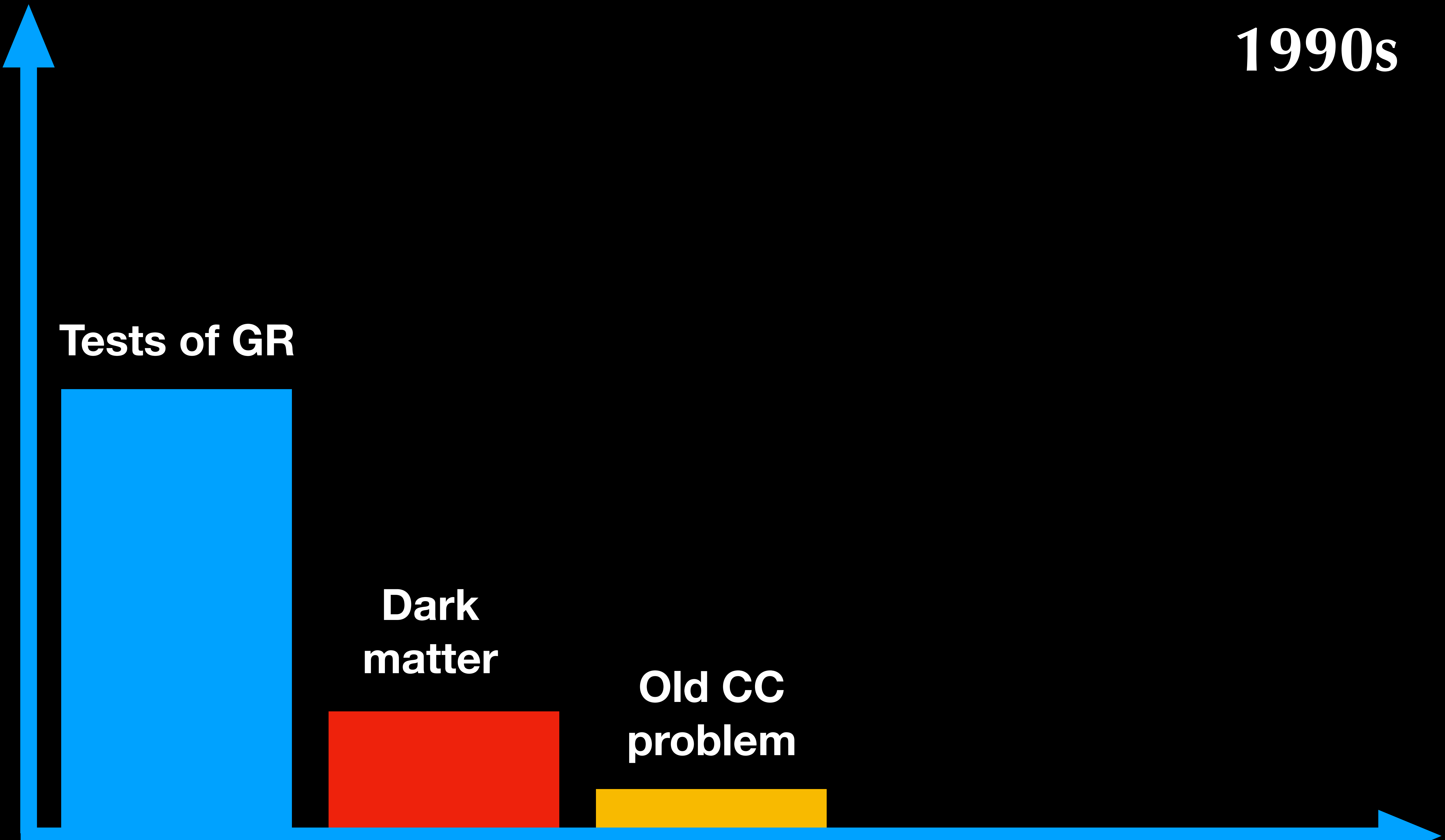

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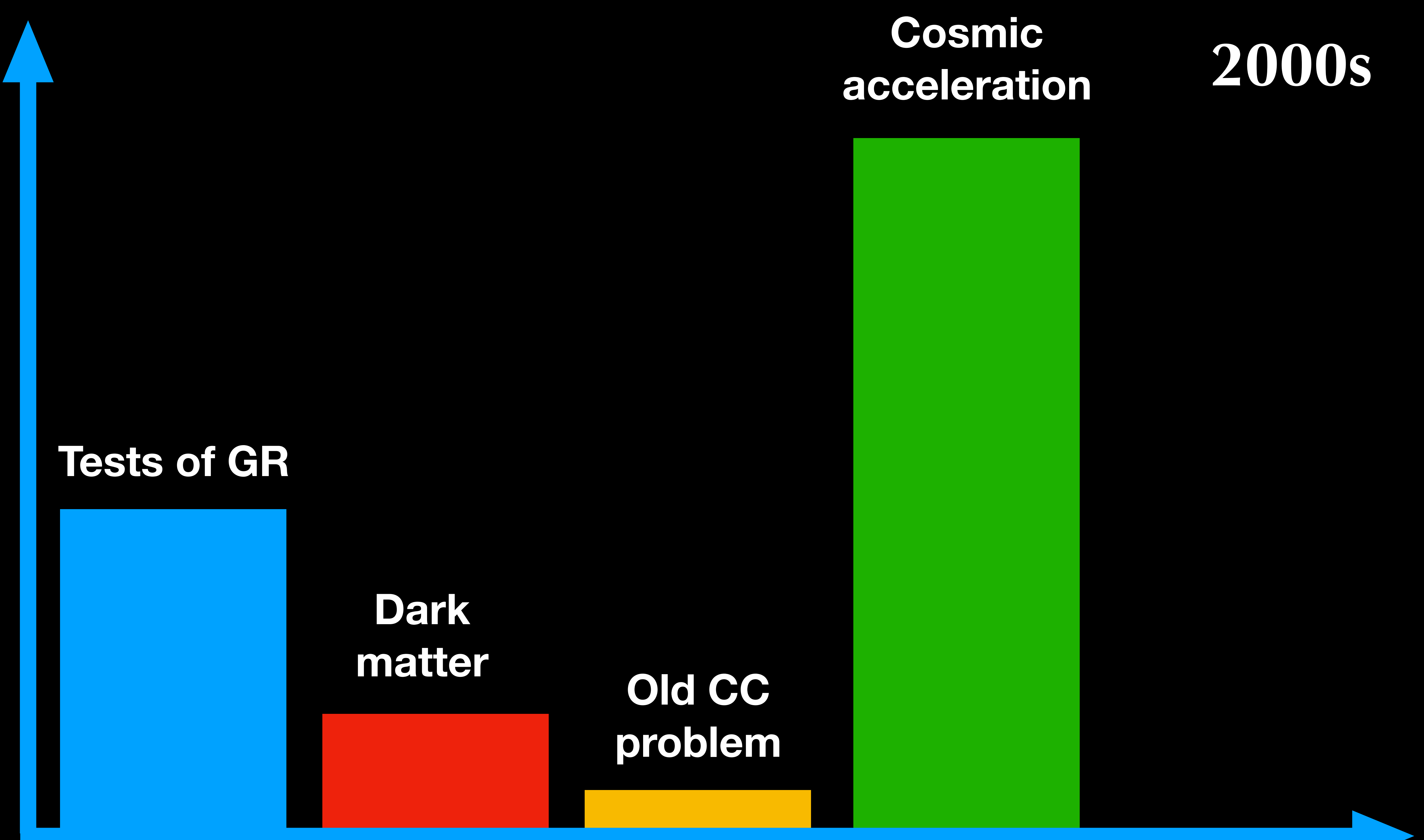

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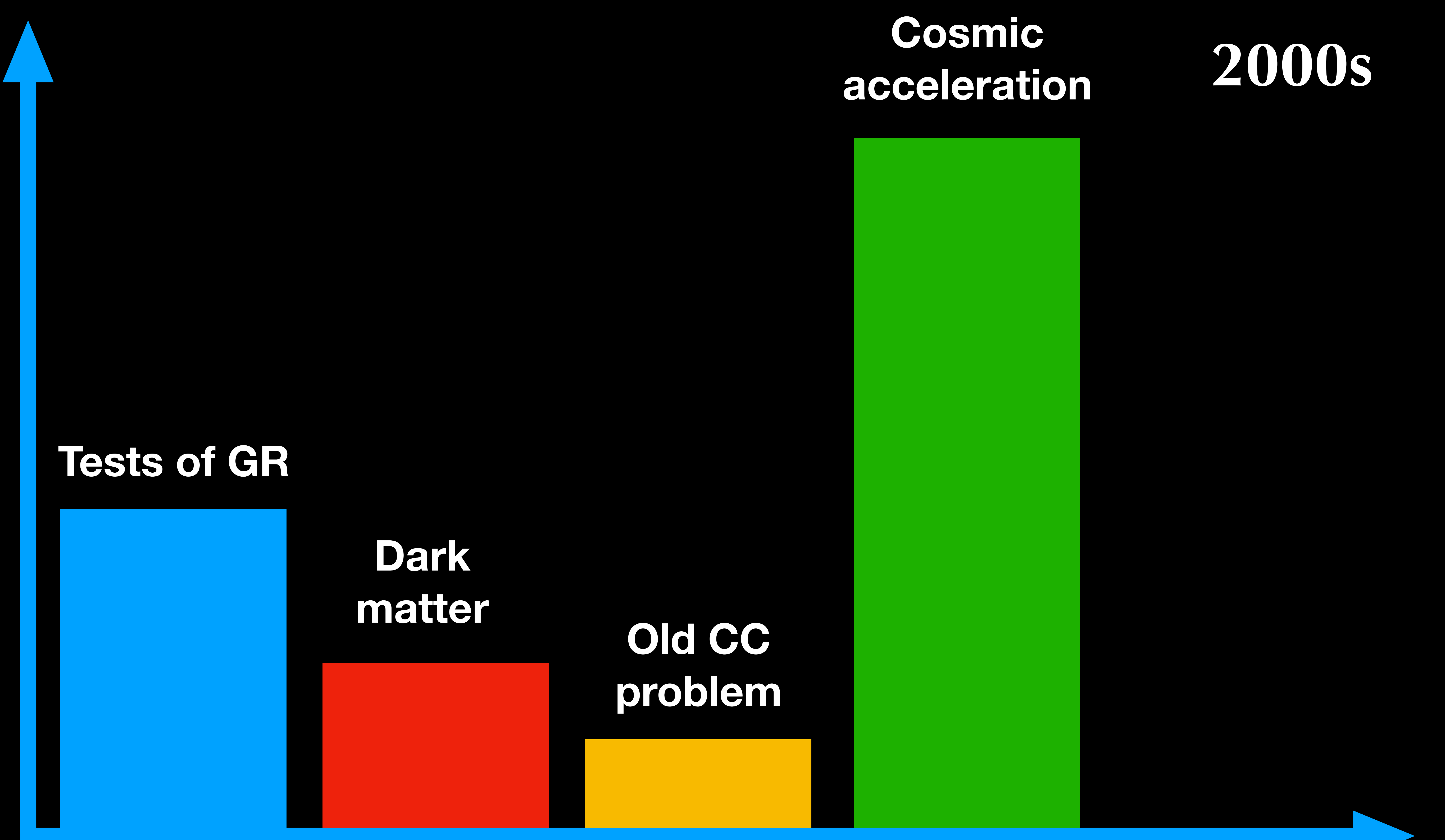

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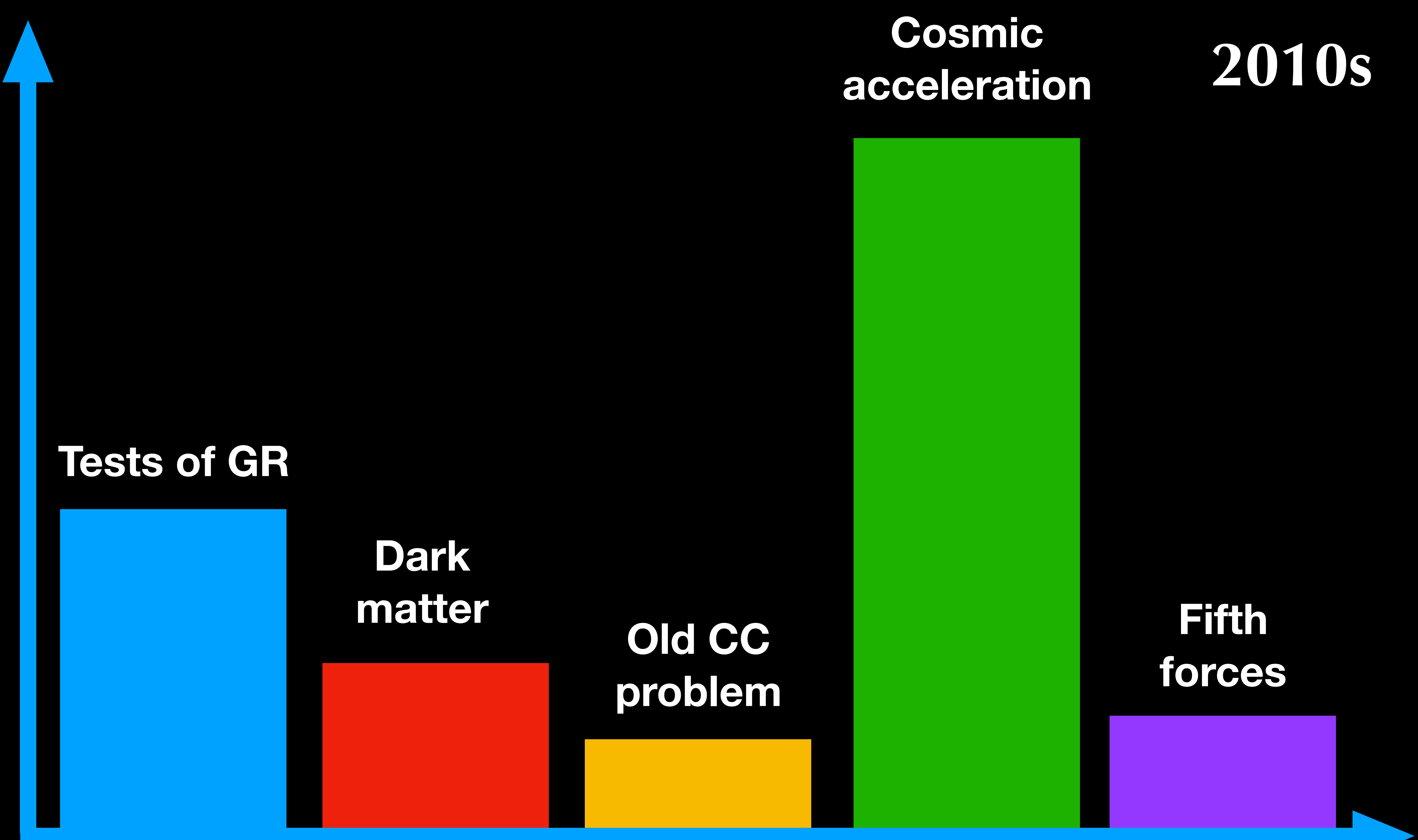

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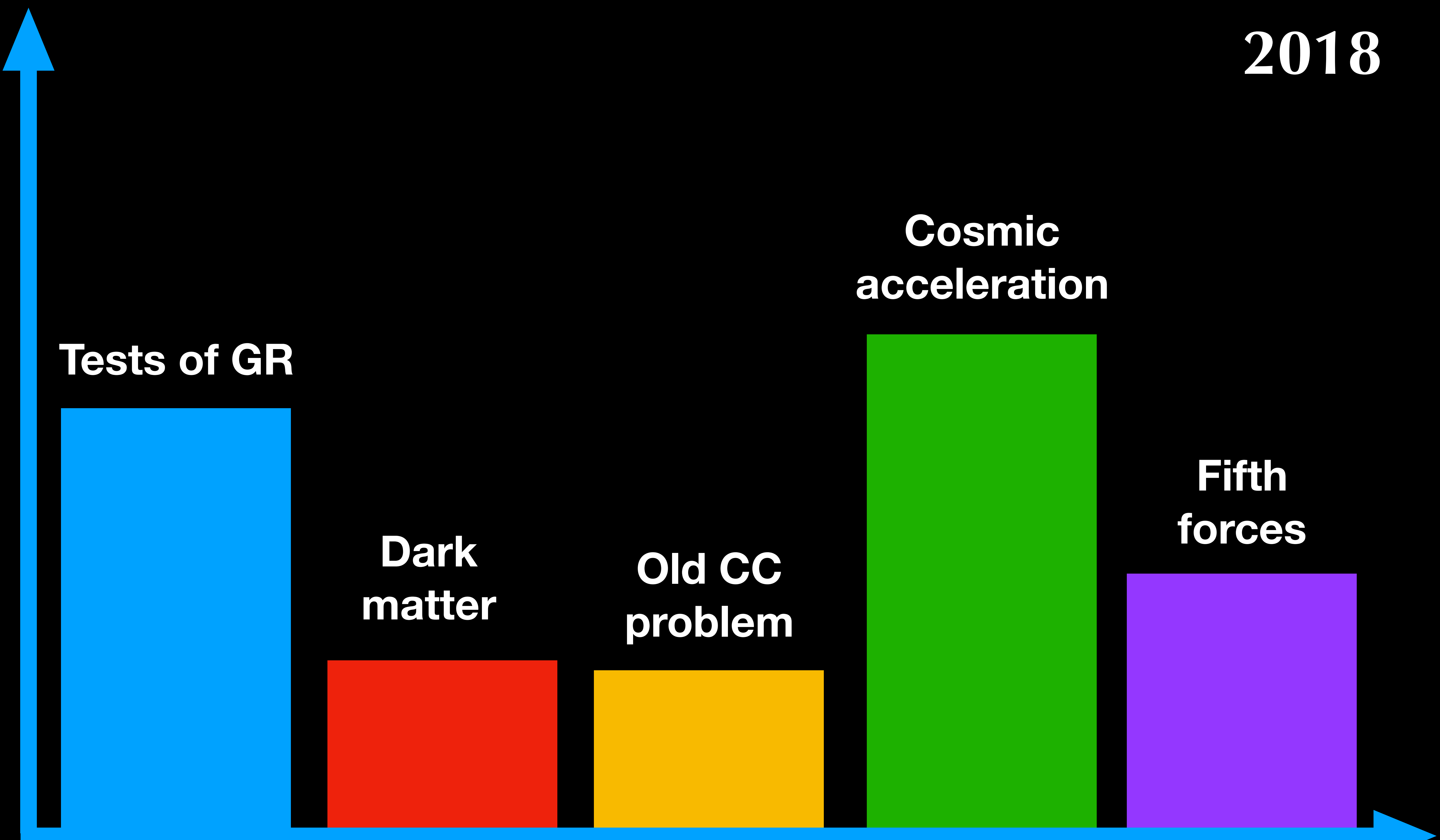

Classification

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Scalar

Vector

Tensor

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k-essence

f(R)

Galileons

KGB

Horndeski

DHOST

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Einstein-Aether

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Generalised Proca

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Gravitational Waves

GW170817 & EM Friends

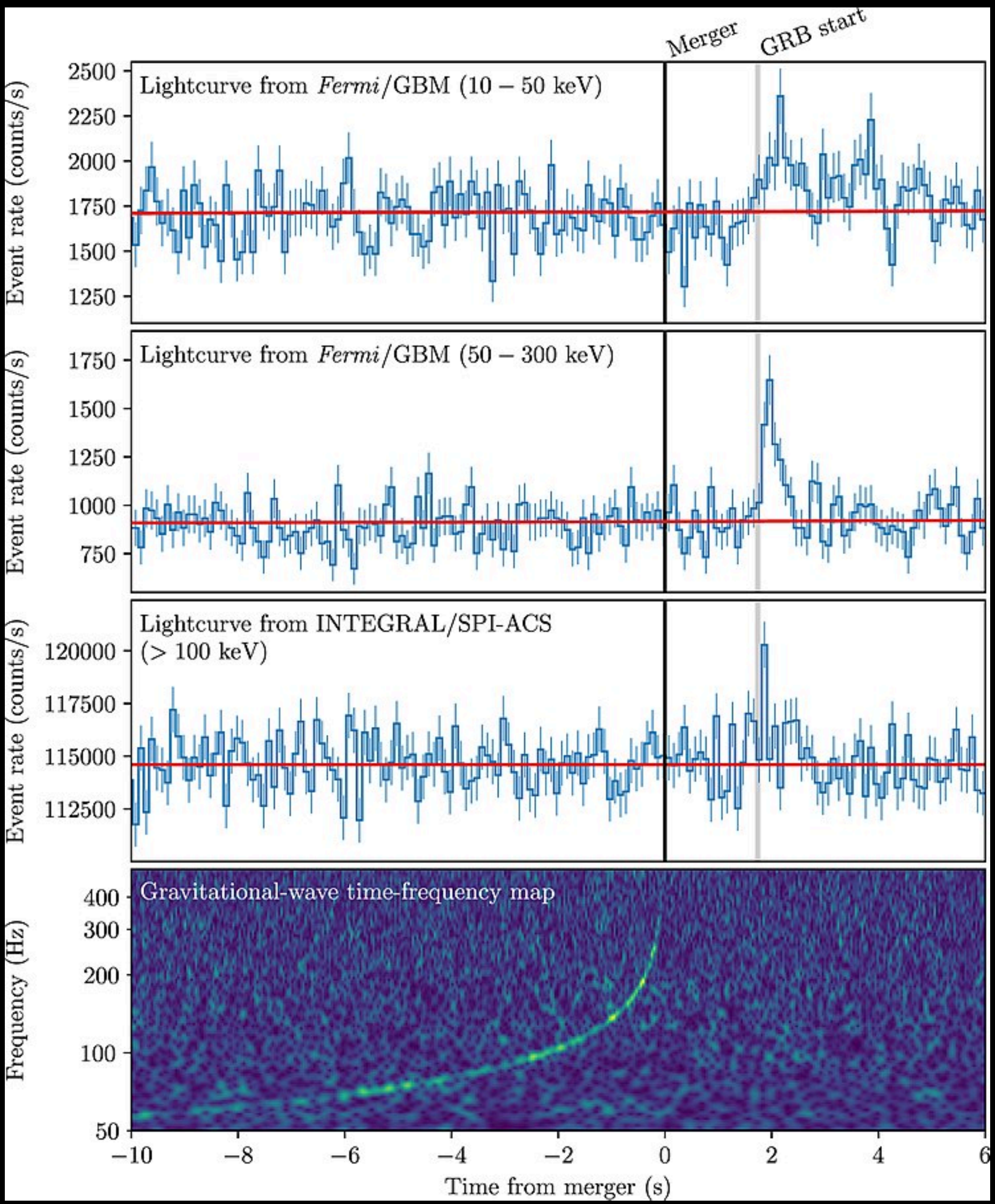

Image: LIGO-VIRGO Collaboration.

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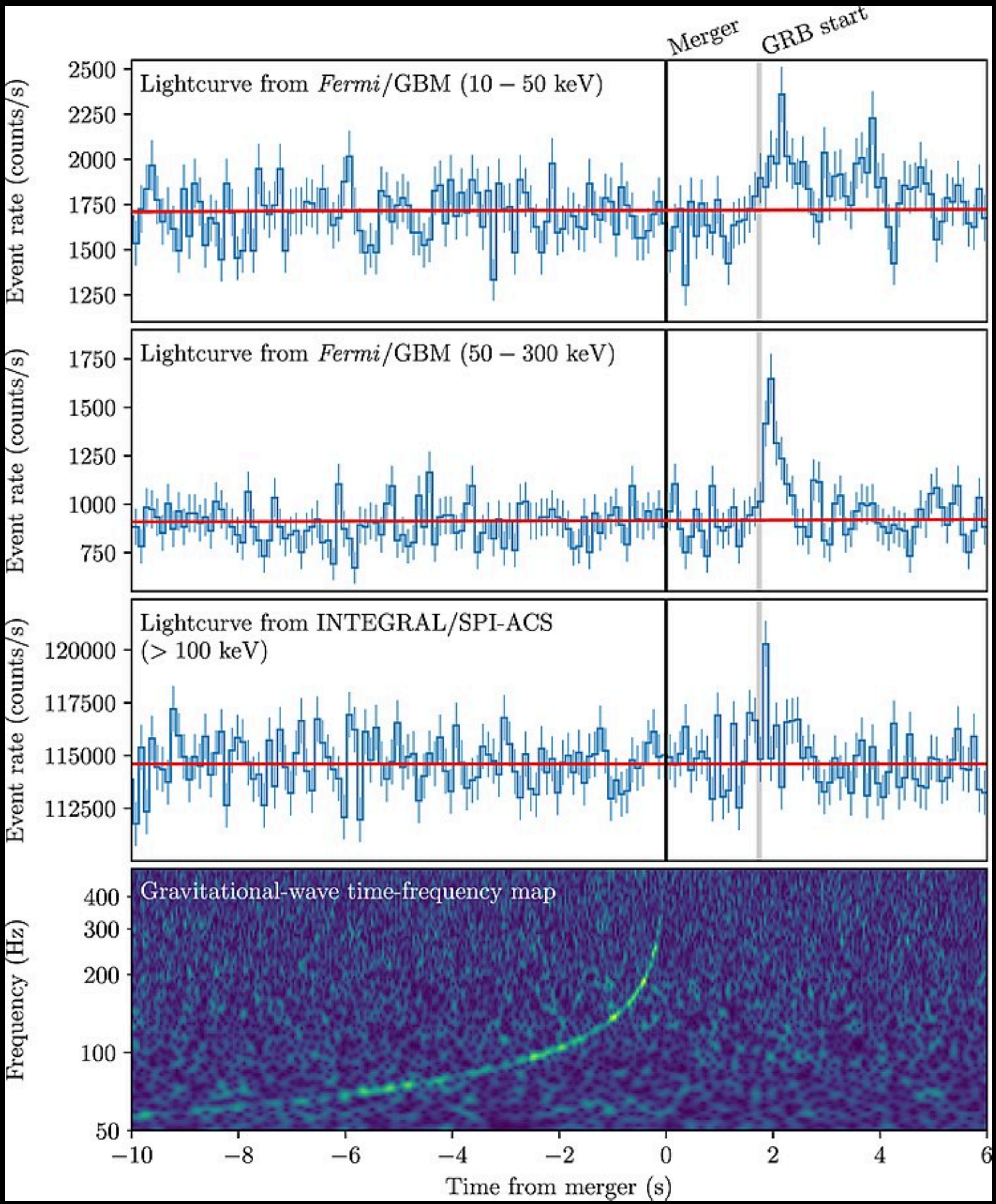

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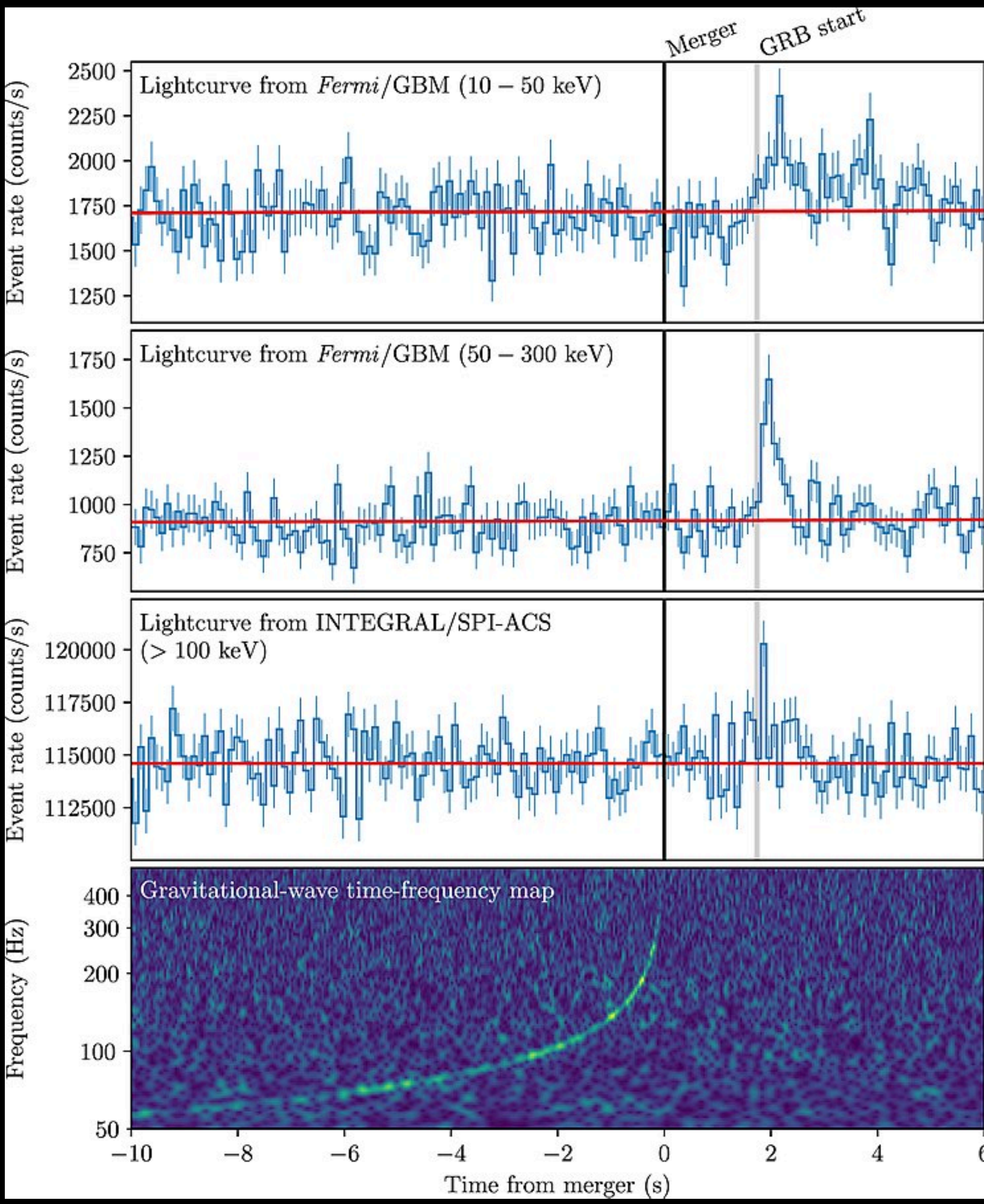

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Derivation found in:

1710.06394, 1710.05877
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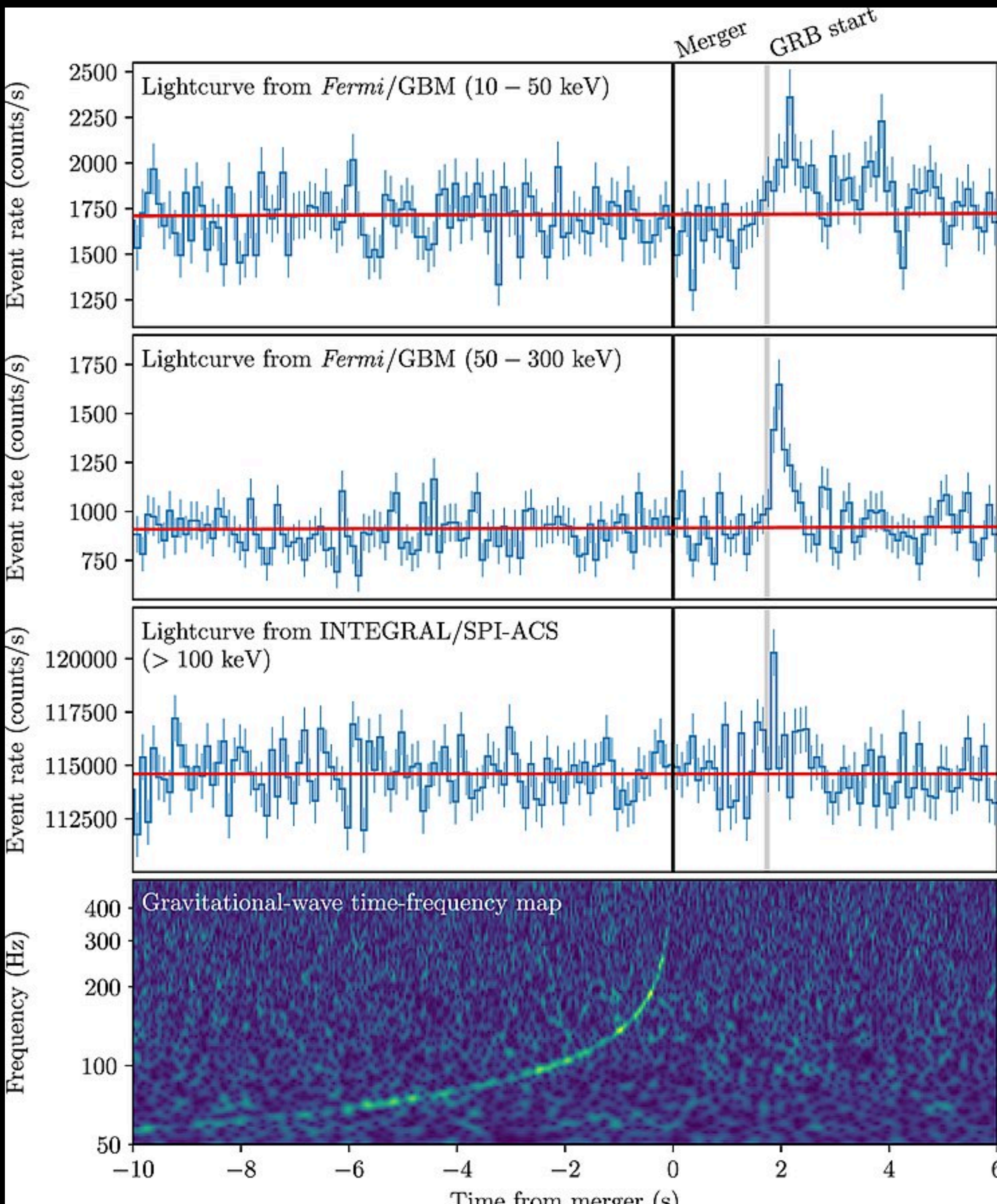

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More conservative:

$$|\alpha_T| \lesssim 10^{-12}$$

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GW170817 & EM Friends

What does this mean for gravity theories?

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Scalar case clearest; full theory is **Horndeski gravity**.

$$S = \int d^4x \sqrt{-g}\ \Sigma_{i=2}^{5}\, \mathcal{L}_i \,+\, S_M$$

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$\Longrightarrow$ f [R] gravity fits the template, so it survives.

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This is not competitive with existing Solar System bounds:

$$m_g \lesssim 10^{-32}\, eV$$

(from Lunar Laser Ranging & Earth-Moon precession)

Image: Yicai Global

Where Next?

Survivors: DHOST

Derivative Higher-Order Scalar-Tensor theories.

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Ben Achour 2016
Langlois & Noui 2016
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GW results fix A_4, A_5 in terms of A_3.

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Vainshtein screening broken *inside* matter:

$$\frac{d\Phi}{dr} = \frac{\tilde{G}M}{r^2} + F(G_4, A_3)\,\tilde{G}\,\frac{d^2 M}{dr^2}$$

Ben Achour 2016
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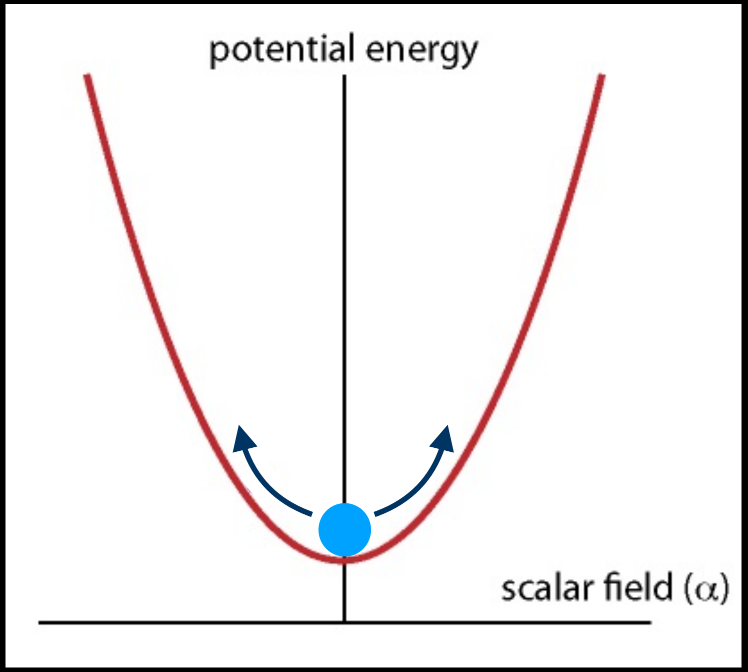
Survivors: frozen fields

Recall for Horndeski:

$$\boxed{\alpha_T(t) = \frac{2X}{M_*^2}\left[2G_{4,X} - 2G_{5,\phi} - \left(\ddot{\phi} - \dot{\phi}H\right)G_{5,X}\right]}$$

On a cosmological background, make: $X = \frac{1}{2}\dot{\phi}^2 \ll H_0^2$

⇒ Frozen/slowly-evolving scalar can have $\alpha_T \simeq 0$.



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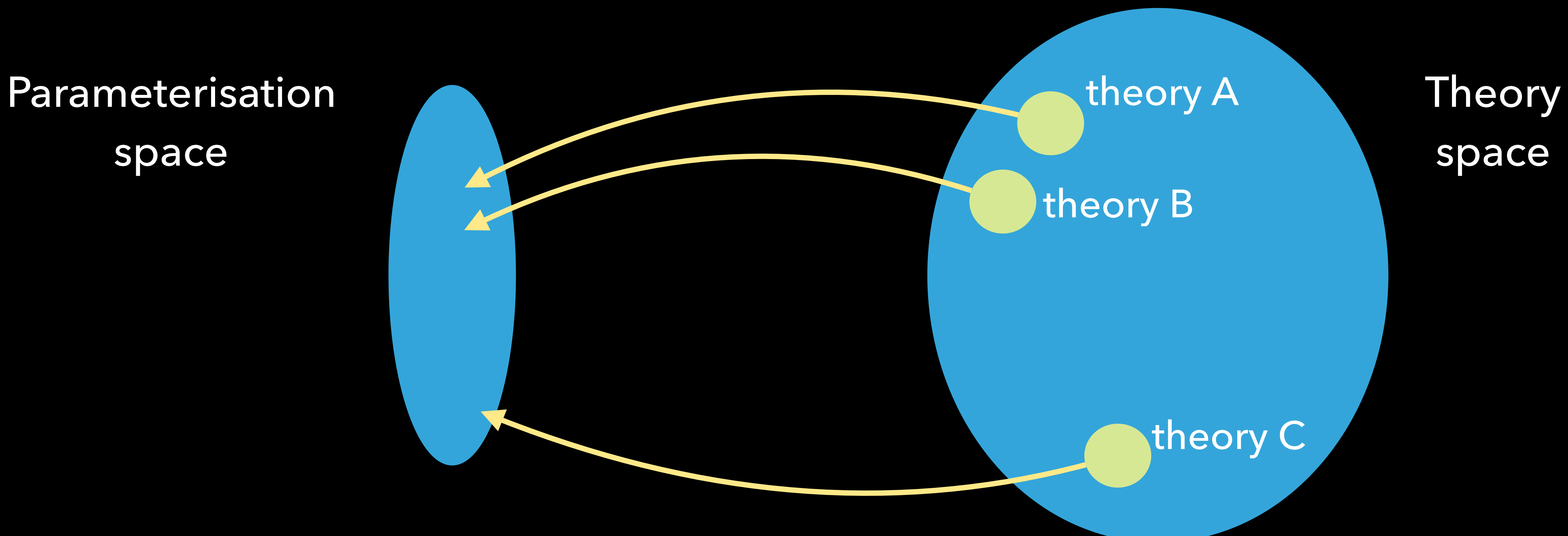

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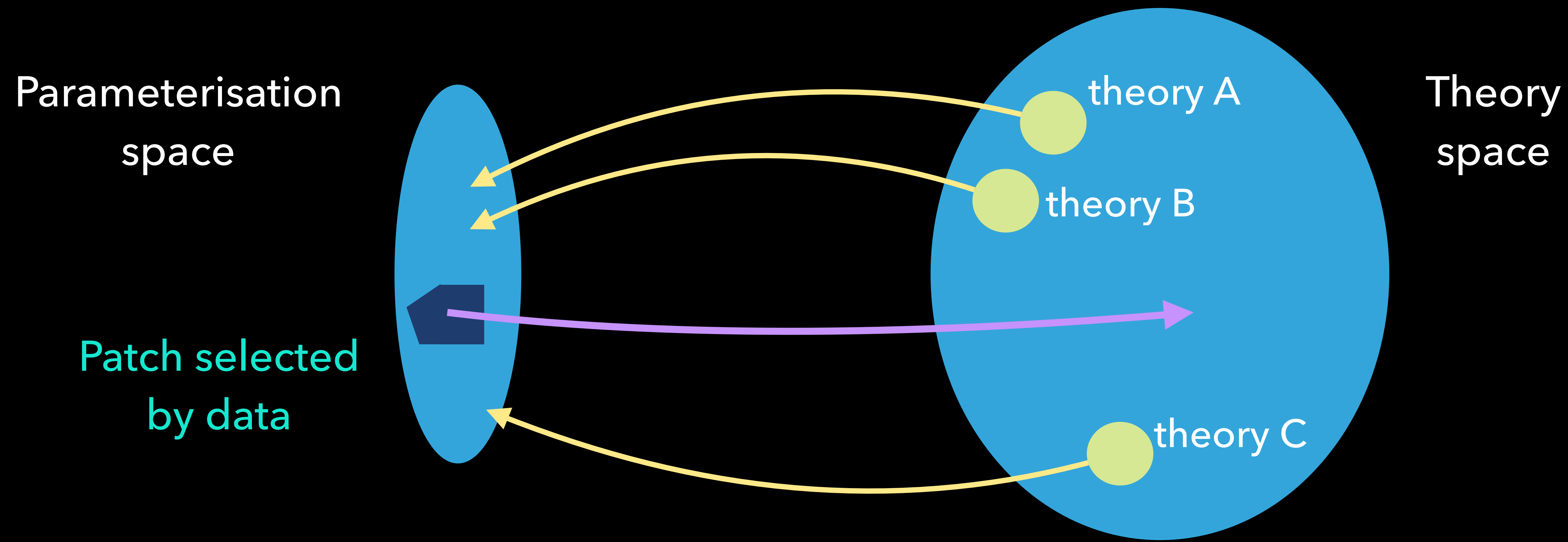

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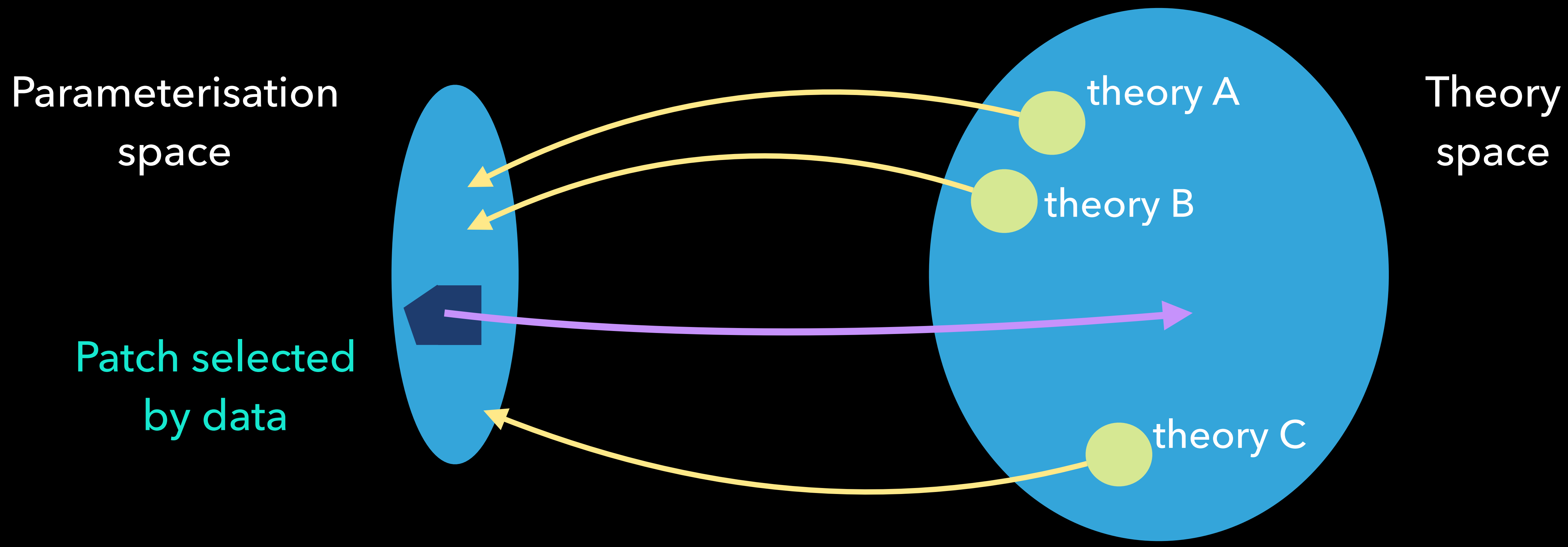

No 100% perfect solution, but can find parameter set for each family of scalar-, vector-, and tensor-tensor theories.

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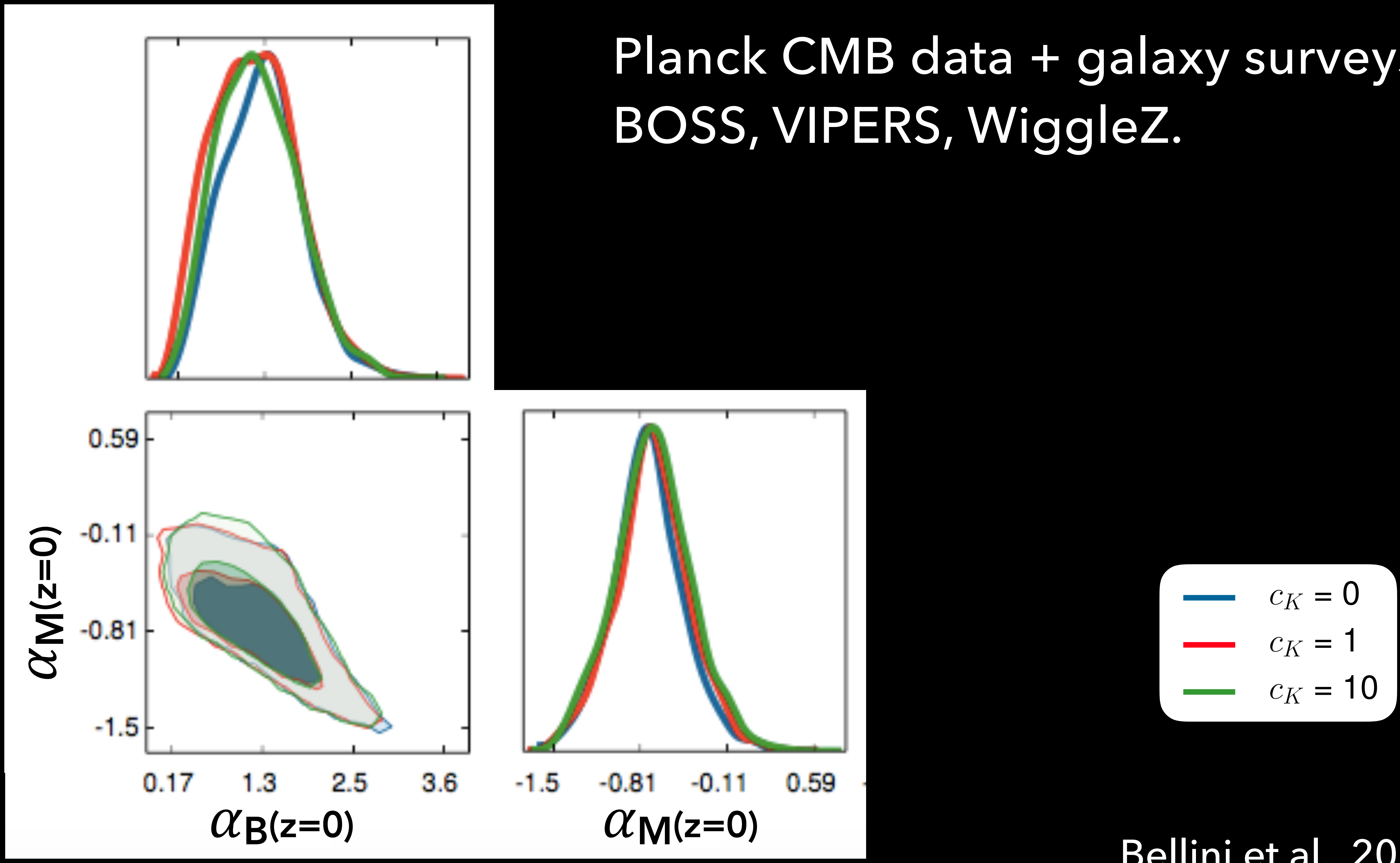
$\alpha_H(t)$: disformal symmetries of the metric.

Current Constraints

Planck CMB data + galaxy surveys: BOSS, VIPERS, WiggleZ.



Bellini et al., 2015.

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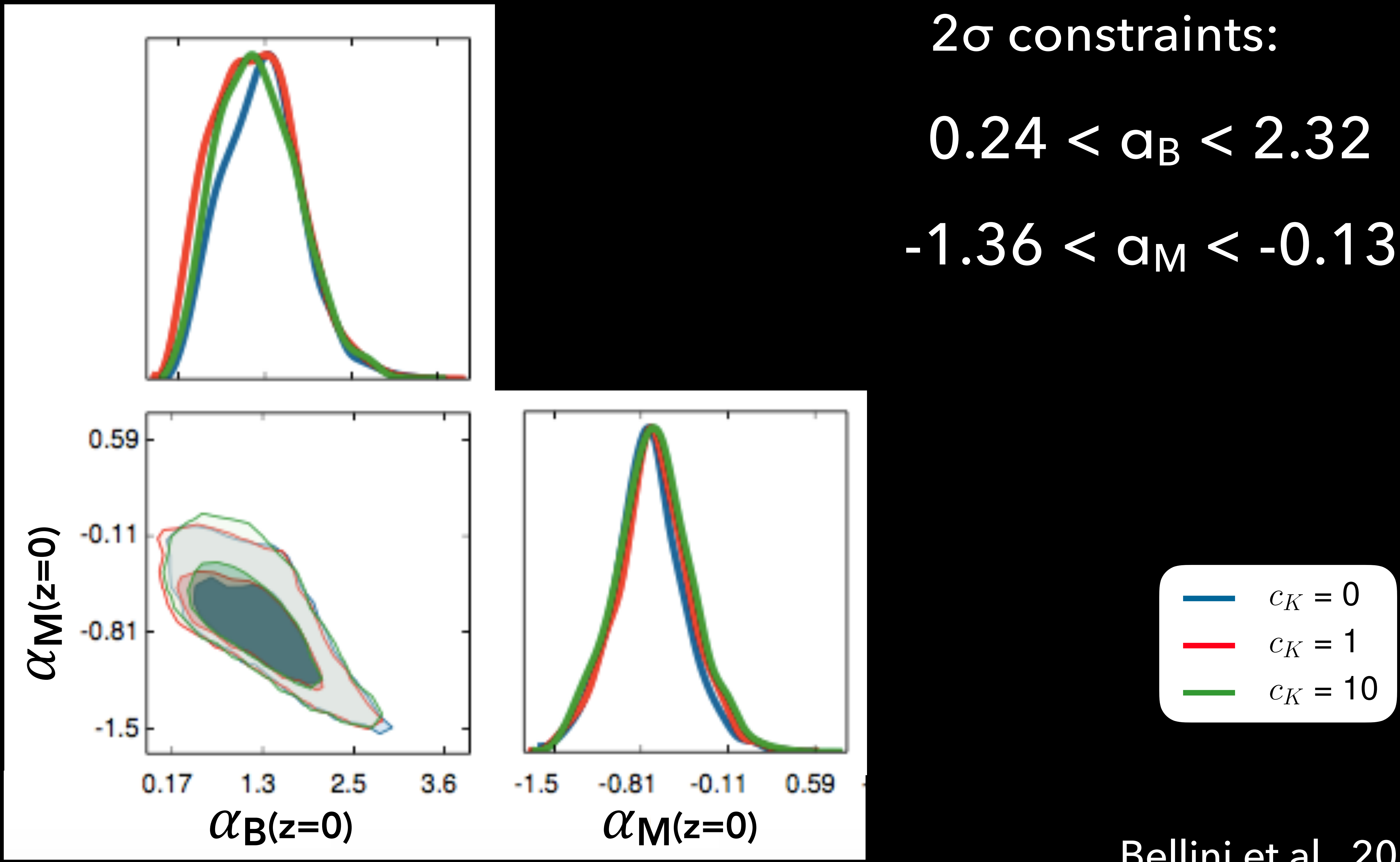


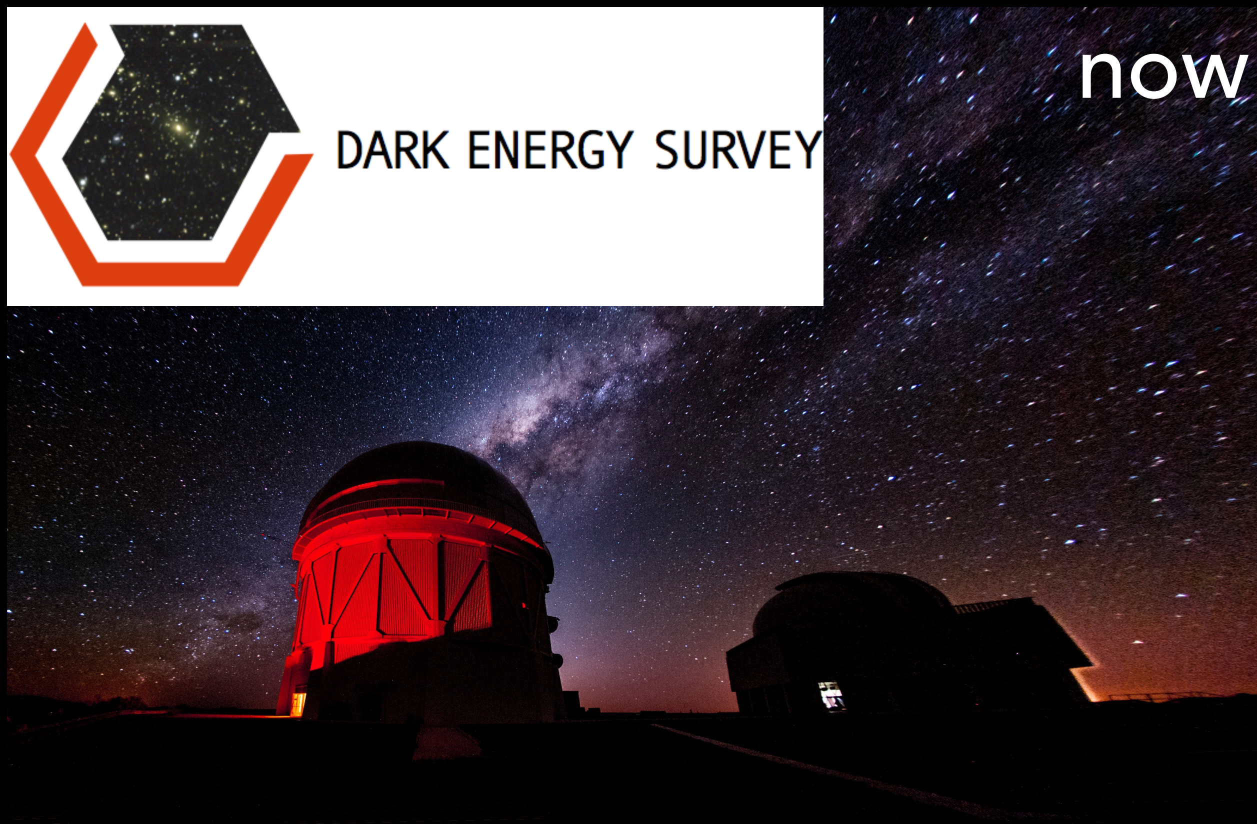
2σ constraints:

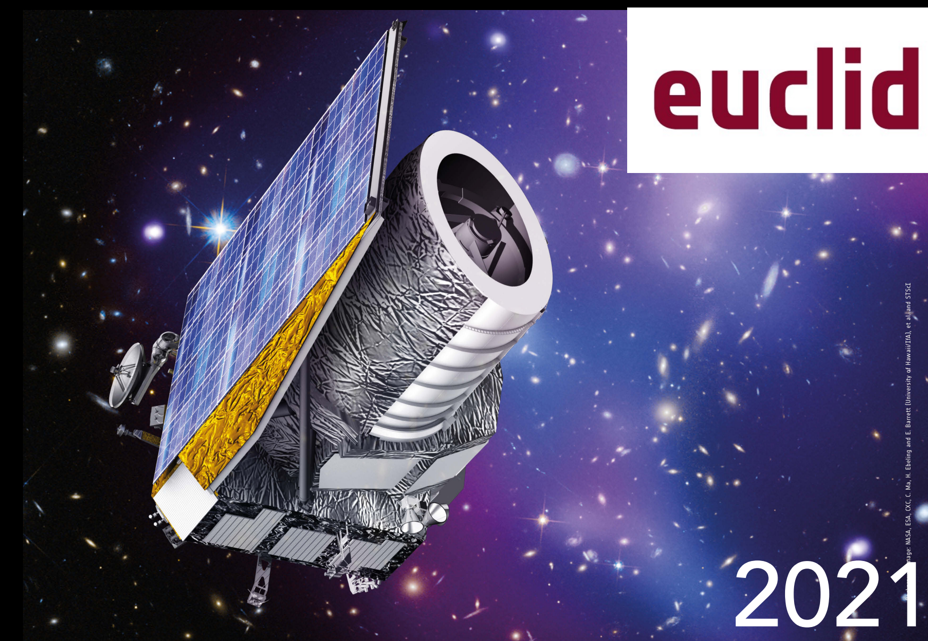
$0.24 < \alpha_B < 2.32$

$-1.36 < \alpha_M < -0.13$

Bellini et al., 2015.

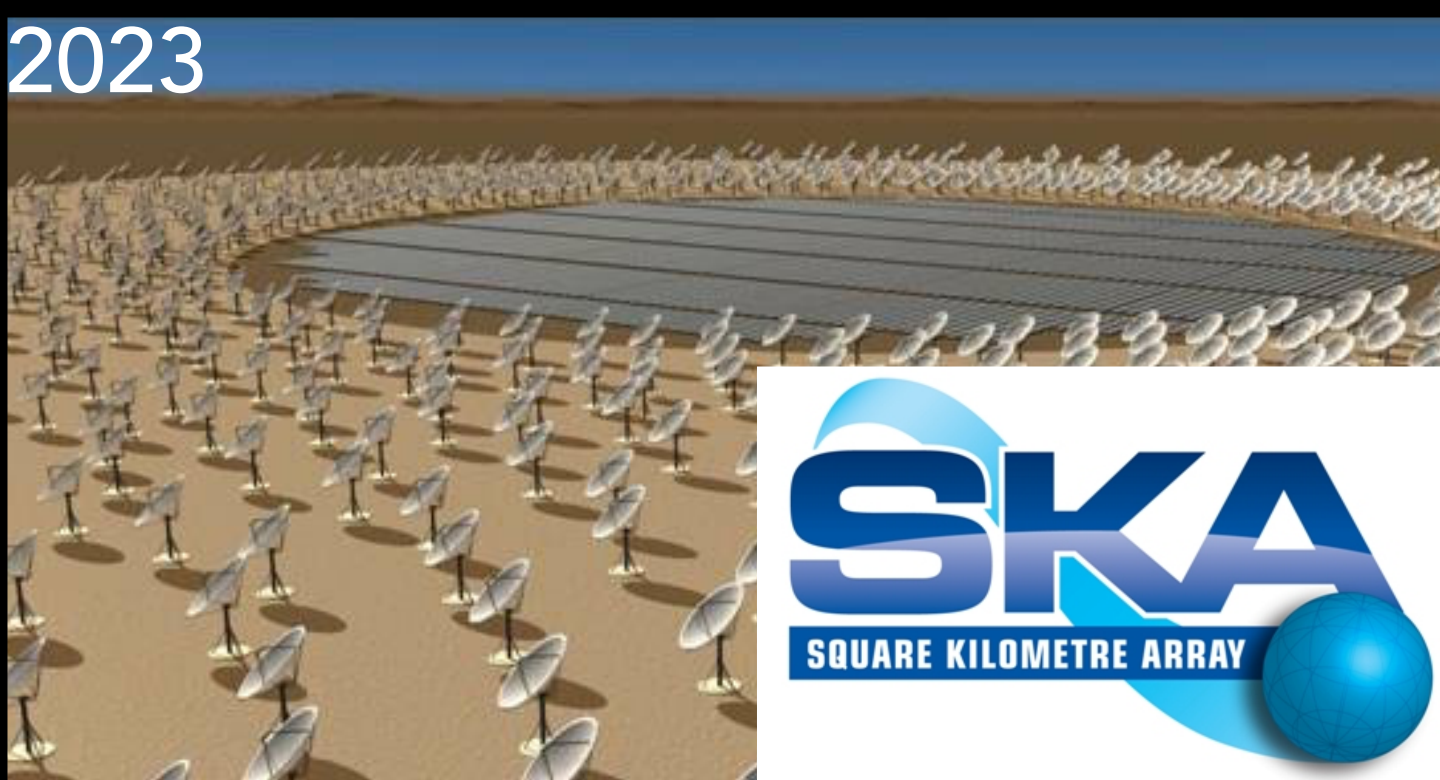
Experiments

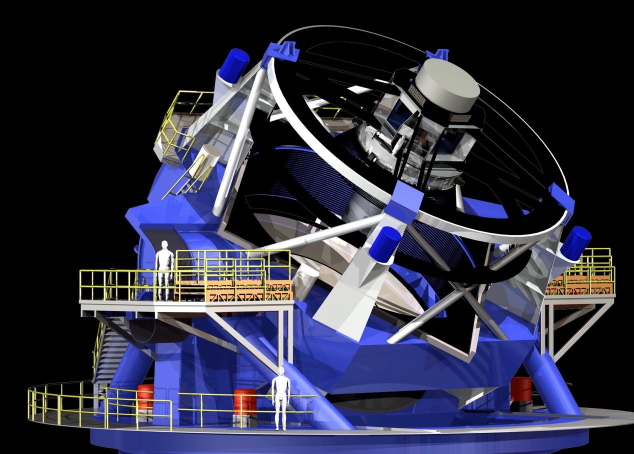




LSST

Large Synoptic Survey Telescope





2021

Conclusions

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- GW results have pruned the model space and sparked new growth areas.

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Conclusions

- MG is alive and well, BUT motivations no longer focus solely on cosmic acceleration.
- GW results have pruned the model space and sparked new growth areas.
- Parameterised tests are emerging as the smart way to test for new, unknown physics.

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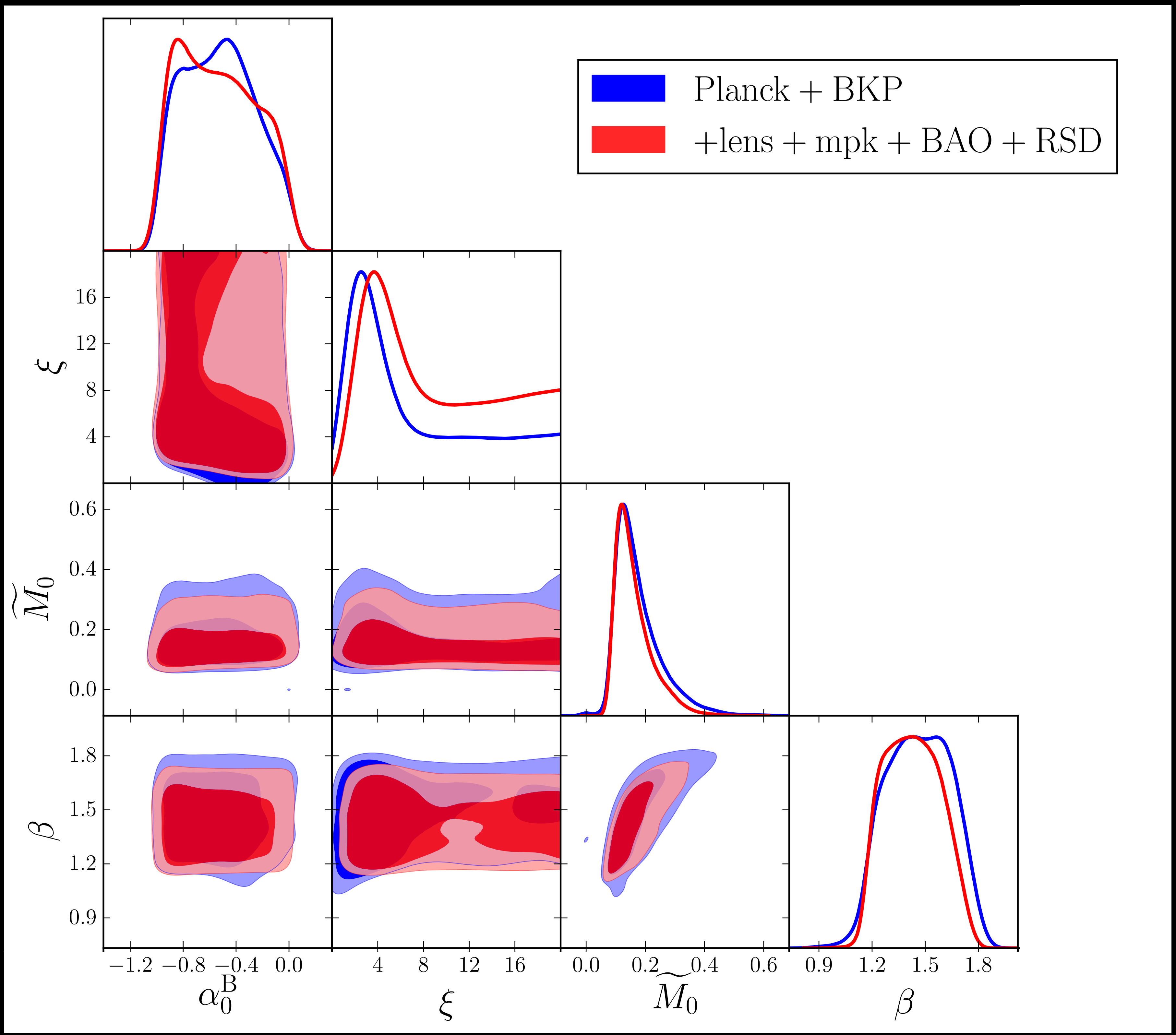
Current Constraints



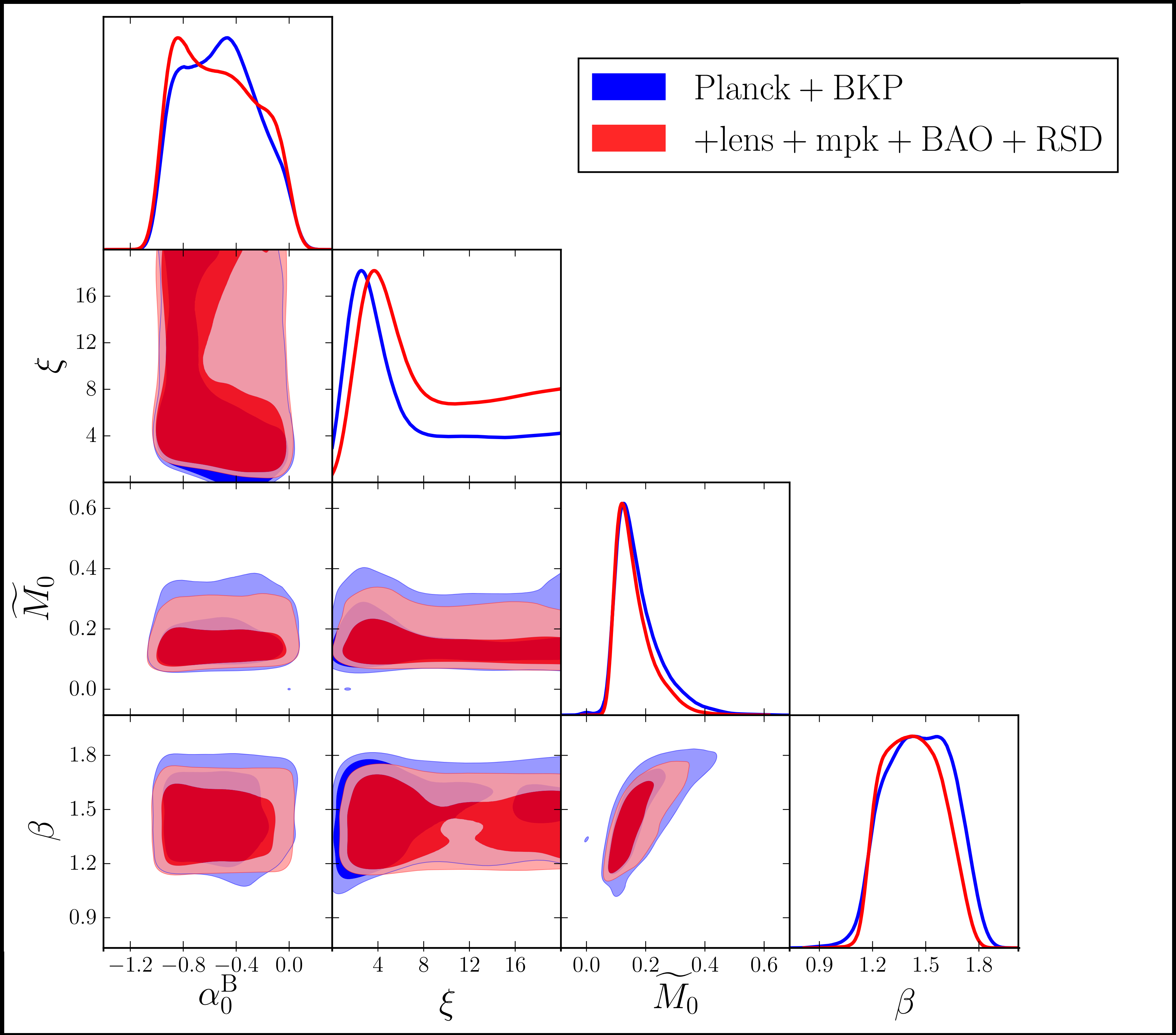
$$\alpha_B(z) = \alpha_0^B\, a^{\xi}$$

$$\frac{\delta M(z)}{M_{Pl}} = \tilde{M}_0 a^{\beta}$$

SDSS (galaxy survey) + Planck CMB + BOSS BAOs & RSDs + lensing data.

Kreisch & Komatsu, 1712.02710

THE CURRENT STATE OF PLAY



$$\frac{\delta M(z)}{M_{Pl}} = \tilde{M}_0 a^{\beta}$$

$$\alpha_B(z) = \alpha_0^B\, a^{\xi}$$

Caution: stability conditions lead to non-trivial contours.

Kreisch & Komatsu, 1712.02710