Status on the disformally coupled galileon from cosmological data and GW170817

Clément Leloup – CEA/Irfu/DPhP Cosmology group

Outline

I. Presentation of the galileon model

II. Methodology and datasets

III. Results

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The galileon model

- Simple principles for a successful extension of General Relativity :
  - Additional scalar field : π
  - Galilean symmetry in Minkowskii space-time :

$$\pi \to \pi + c + b_\mu x^\mu$$

  - 2^{nd} order e.o.m in π derivatives : avoid Ostrogradski ghosts
  - Direct couplings to matter : conformal and/or disformal

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Disfavoured by Neveu et al. 2016

The galileon model

- Most general action :

$$\mathcal{S}\left[\phi, g, \pi\right] = \mathcal{S}_{SM}\left[\phi, g\right] + \int d^4x\sqrt{-g}\left[\frac{M_P^2}{2}R - \frac{1}{2}\sum_{i=1}^{5}\frac{c_i}{M^{3(i-2)}}\mathcal{L}_i - \frac{M_P}{M^3}c_G G^{\mu\nu}\pi_{;\mu}\pi_{;\nu}\right]$$

$$\mathcal{L}_1 = \pi$$

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$$\mathcal{L}_3 = X\Box\pi$$

$$\mathcal{L}_4 = X\left[2\left(\Box\pi\right)^2 - 2\left(\pi_{;\mu\nu}\pi^{;\mu\nu}\right) - \frac{1}{2}XR\right]$$

$$\mathcal{L}_5 = X\left[\left(\Box\pi\right)^3 - 3\left(\pi_{;\mu\nu}\pi^{;\mu\nu}\right)\Box\pi + 2\left(\pi_{;\mu}^{;\nu}\pi_{;\nu}^{;\rho}\pi_{;\rho}^{;\mu}\right) - 6\left(\pi_{;\mu}\pi^{;\mu\nu}G_{\nu\rho}\pi^{;\rho}\right)\right]$$

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Five galileon parameters

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Non-linear lagrangians ($\mathcal{L}_3$, $\mathcal{L}_4$, $\mathcal{L}_5$)

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Non-linear lagrangians (→ $\mathcal{L}_3$, $\mathcal{L}_4$, $\mathcal{L}_5$)

- Non-linear lagrangians necessary to screen the galileon at small scales (Vainshtein effect)

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Methodology and datasets

- Cosmological background evolution :

$$\frac{dH}{d\ln a} = \frac{\omega\gamma - \lambda\beta}{\sigma\beta - \alpha\omega}$$

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If $B = x_0$: $\boxed{\bar{x}_0 = 1}$

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- Two classes of galileon models :
  - Full galileon : $\{\bar{c}_2, \bar{c}_3, \bar{c}_4, \bar{c}_5, \bar{c}_G, \bar{x}_0\}$

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Fixed by flatness condition at z=0 :

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  - attractor solutions
  - additional relation on the $\bar{c}_i$ parameters
  - analytic solutions for the background evolution

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- Galileon predictions obtained using our own modified version of Boltzmann code CAMB

Methodology and datasets

- MCMC exploration of the parameter space against cosmological observations

  → Our own modified version of CosmoMC

  → Reject sets of parameters that fail stability conditions

- CMB : Planck 2015 TTTEEE+lowP+lensing
- BAO : 6dF, MGS, BOSS DR12
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- A posteriori comparison to GW speed constraint from GW170817

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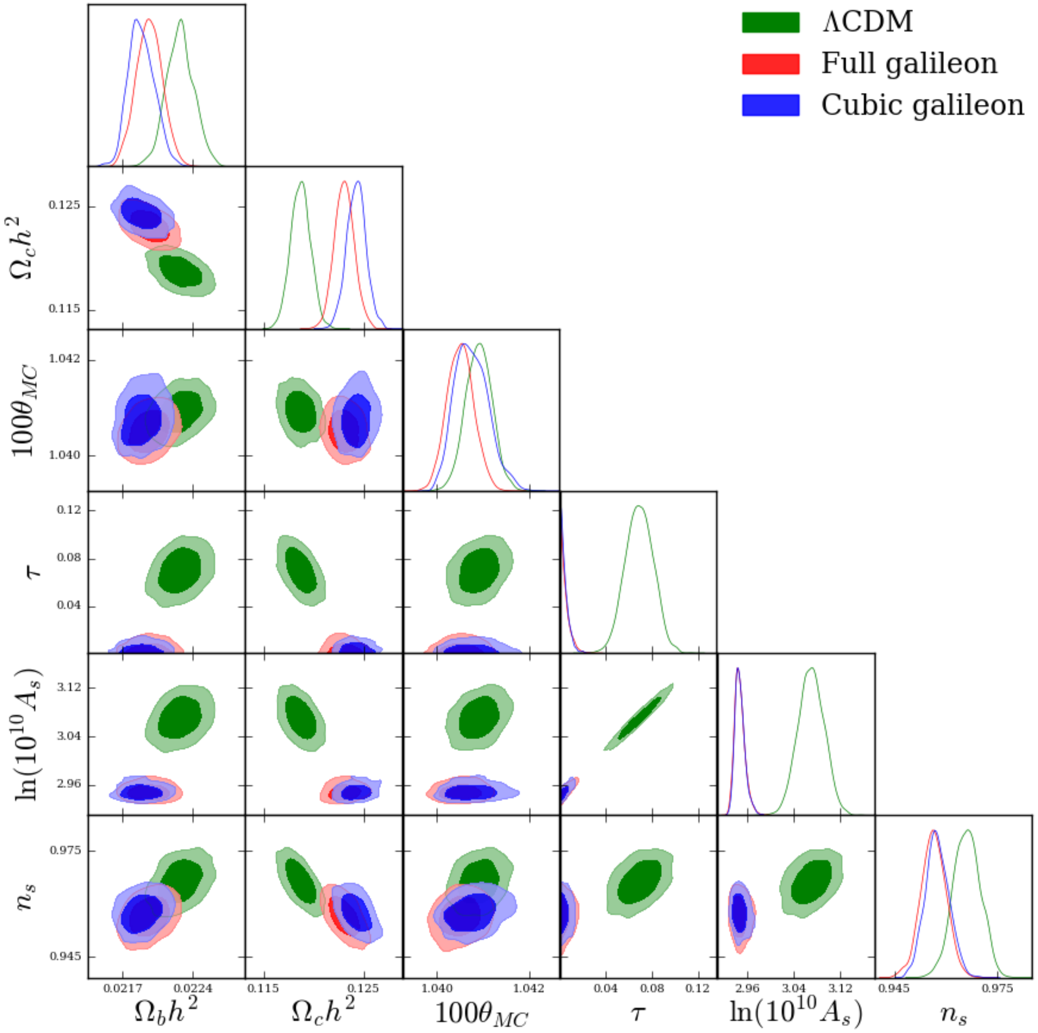
Results

- Fit to combined cosmological data (CMB+BAO+JLA) :



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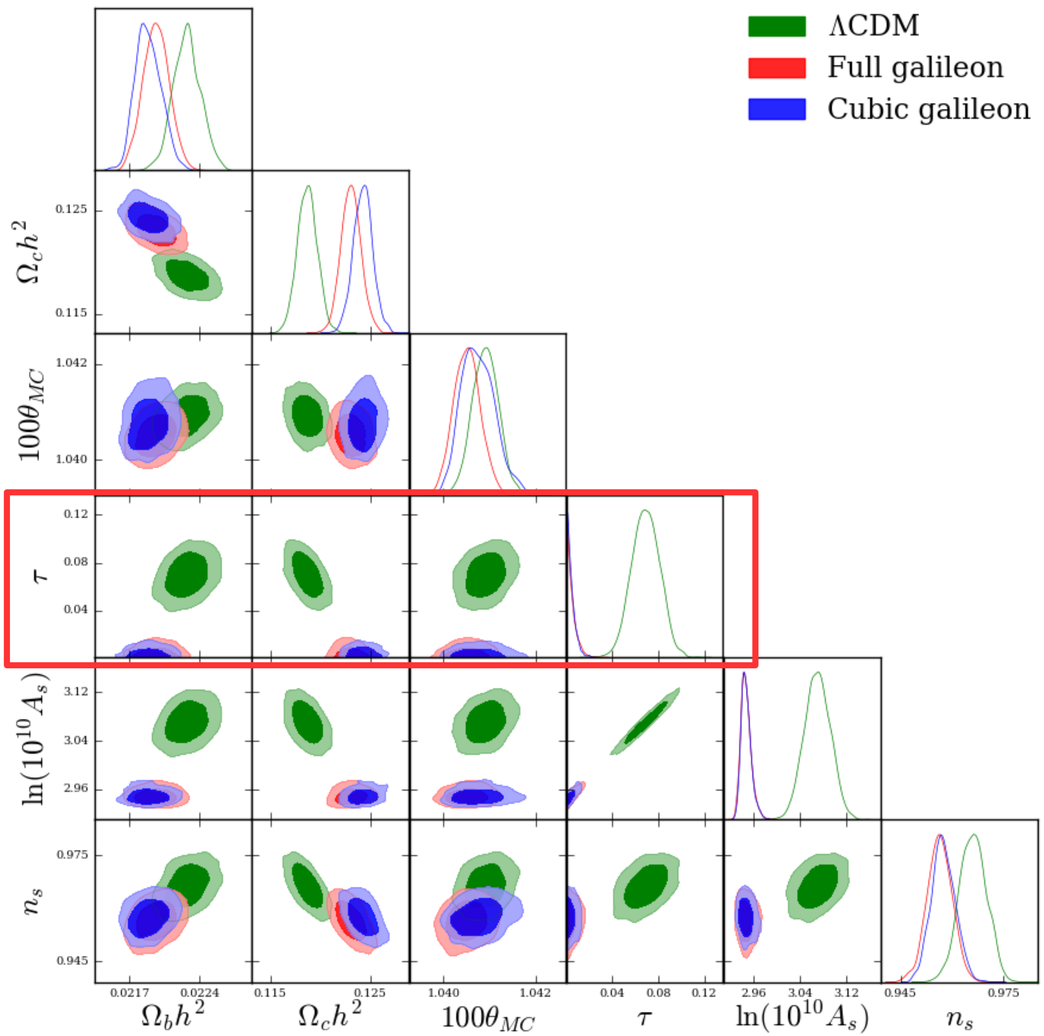

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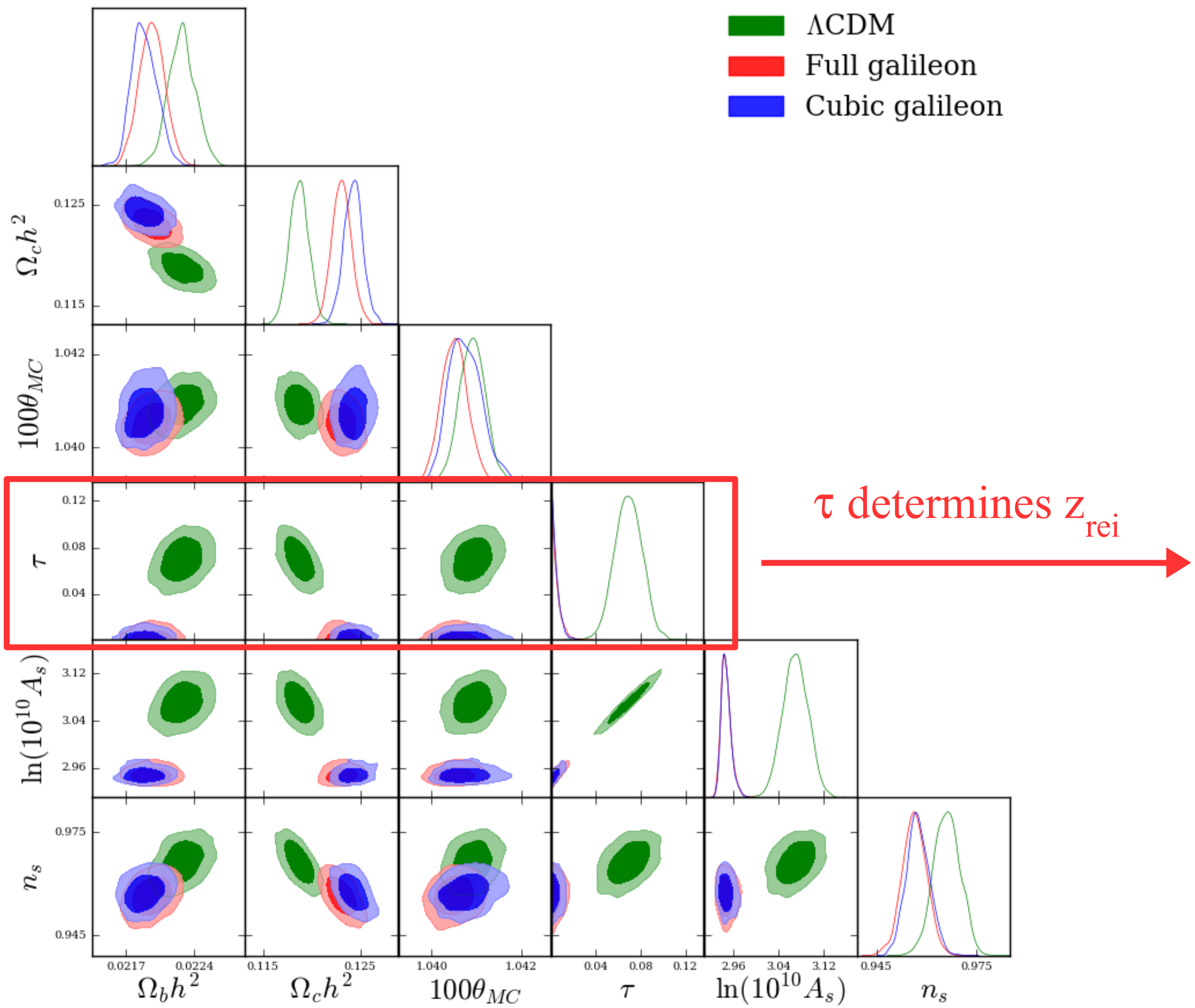

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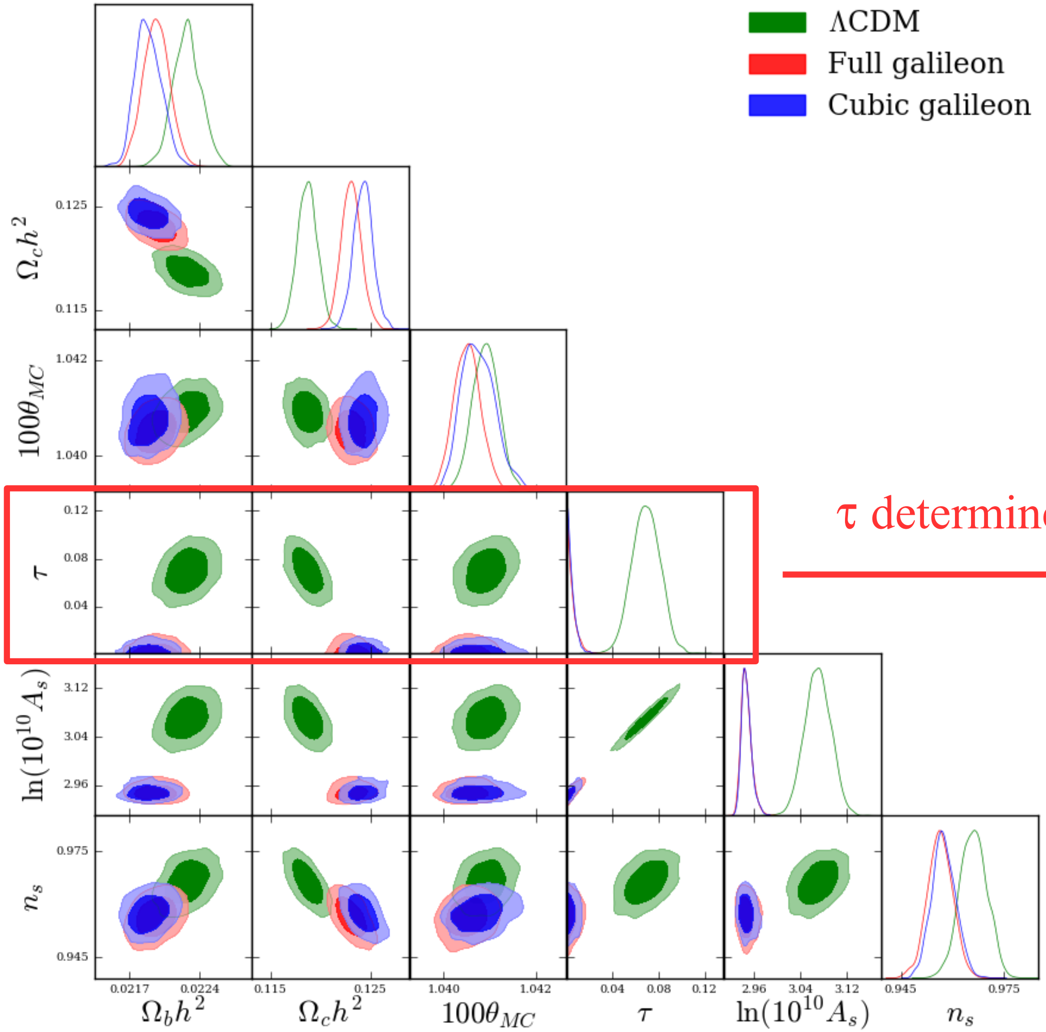
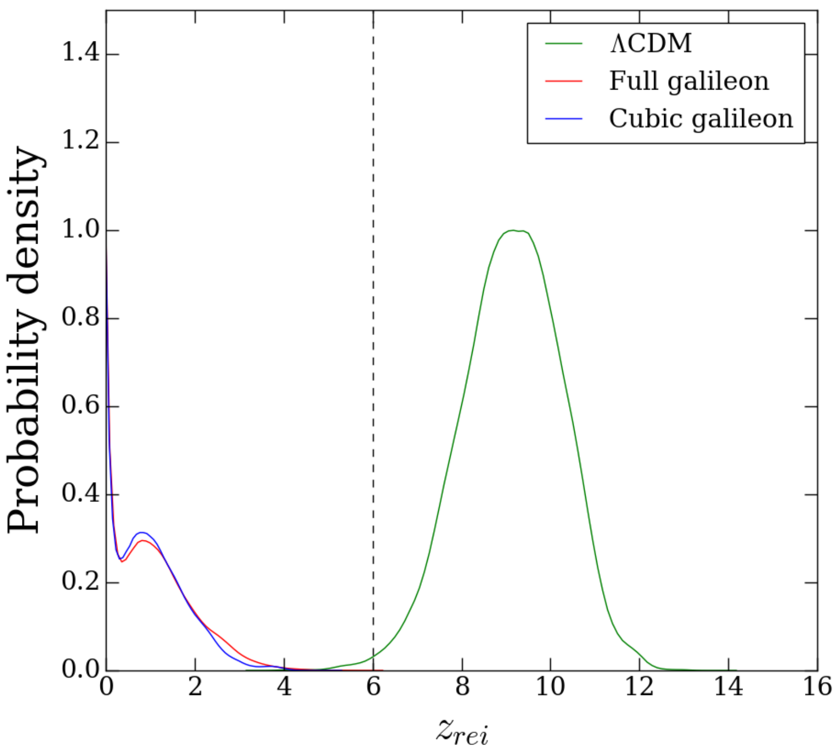


τ determines z_{rei}



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	χ^2(CMB)	χ^2(BAO)	χ^2(JLA)
ΛCDM	12946	5.6	706.7
Full galileon	12966	30.4	723.3
Cubic galileon	12993	29.9	723.6

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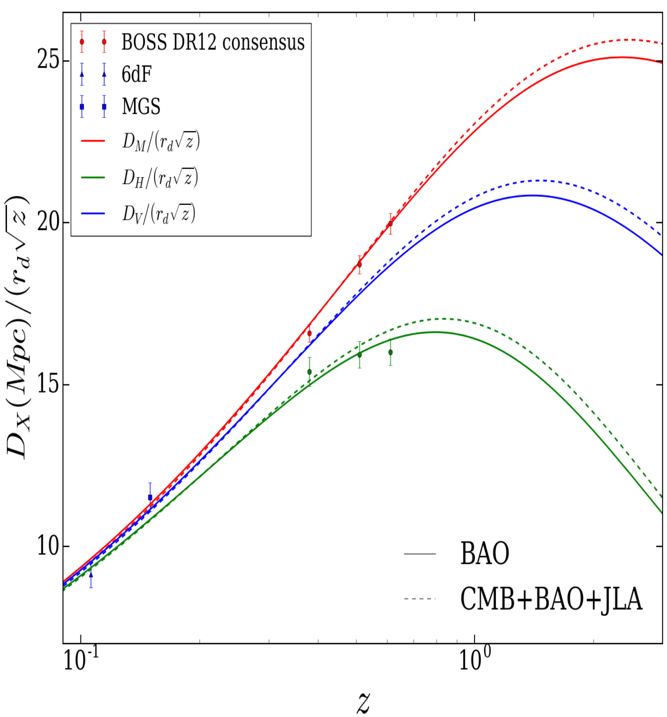

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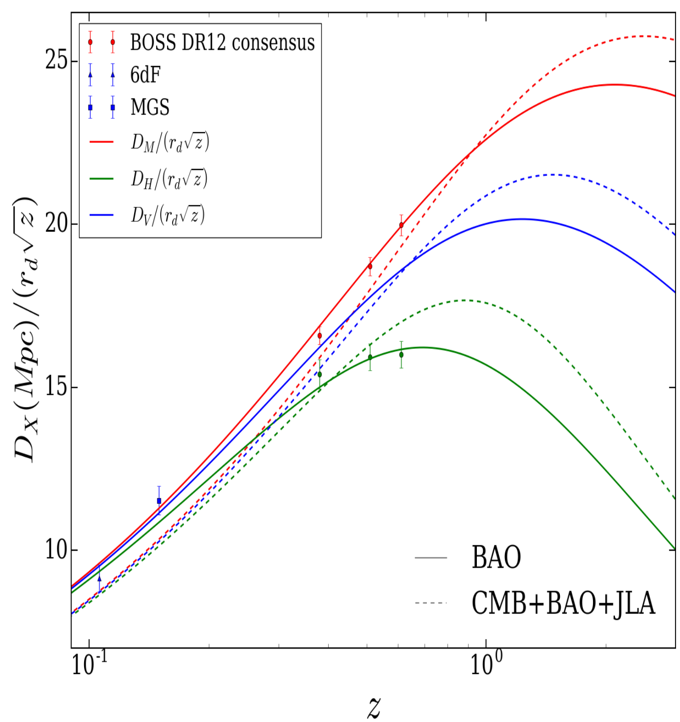
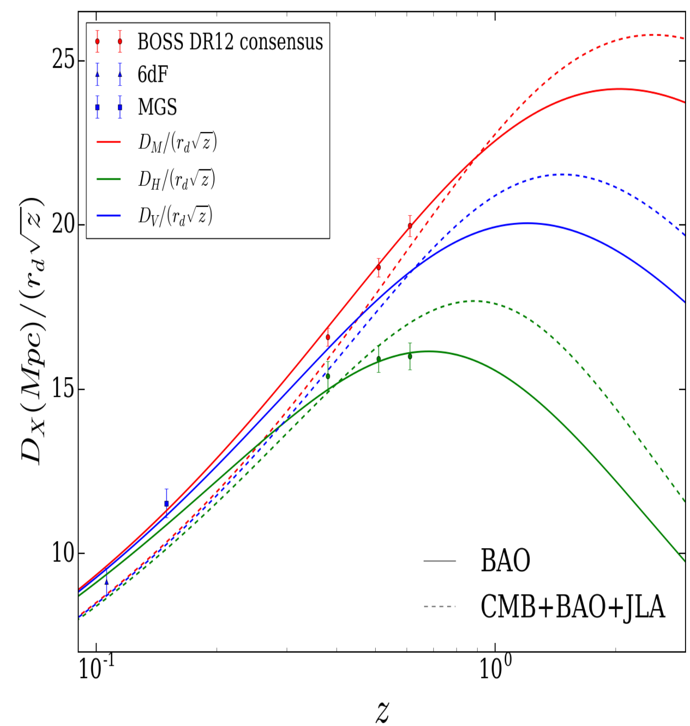


Full galileon



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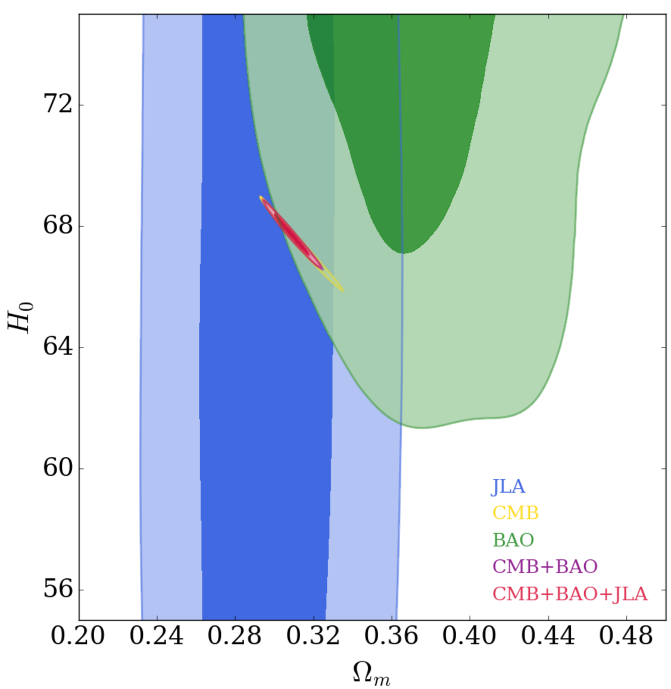
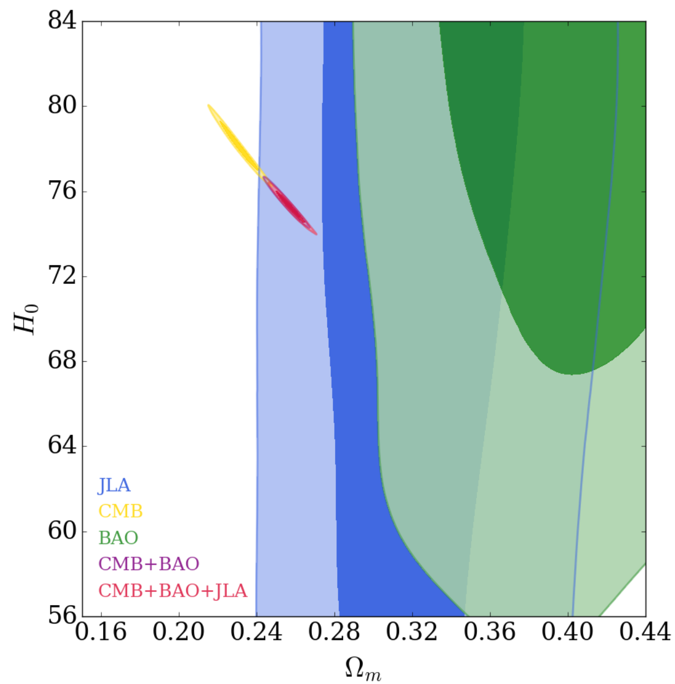


ΛCDM



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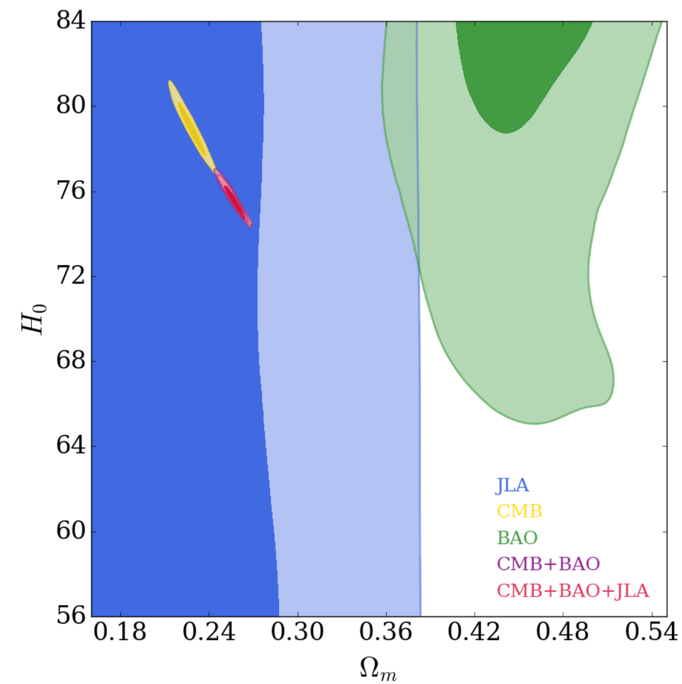

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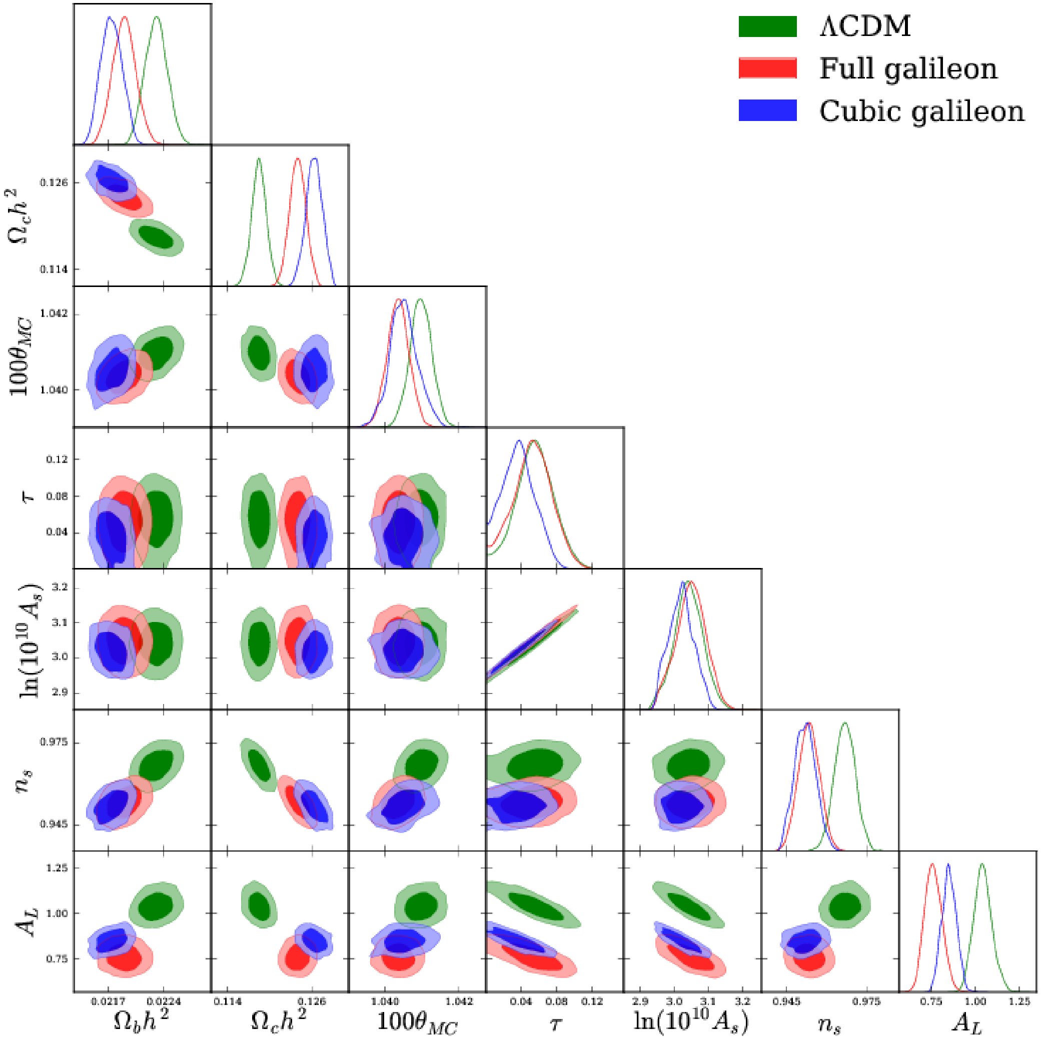

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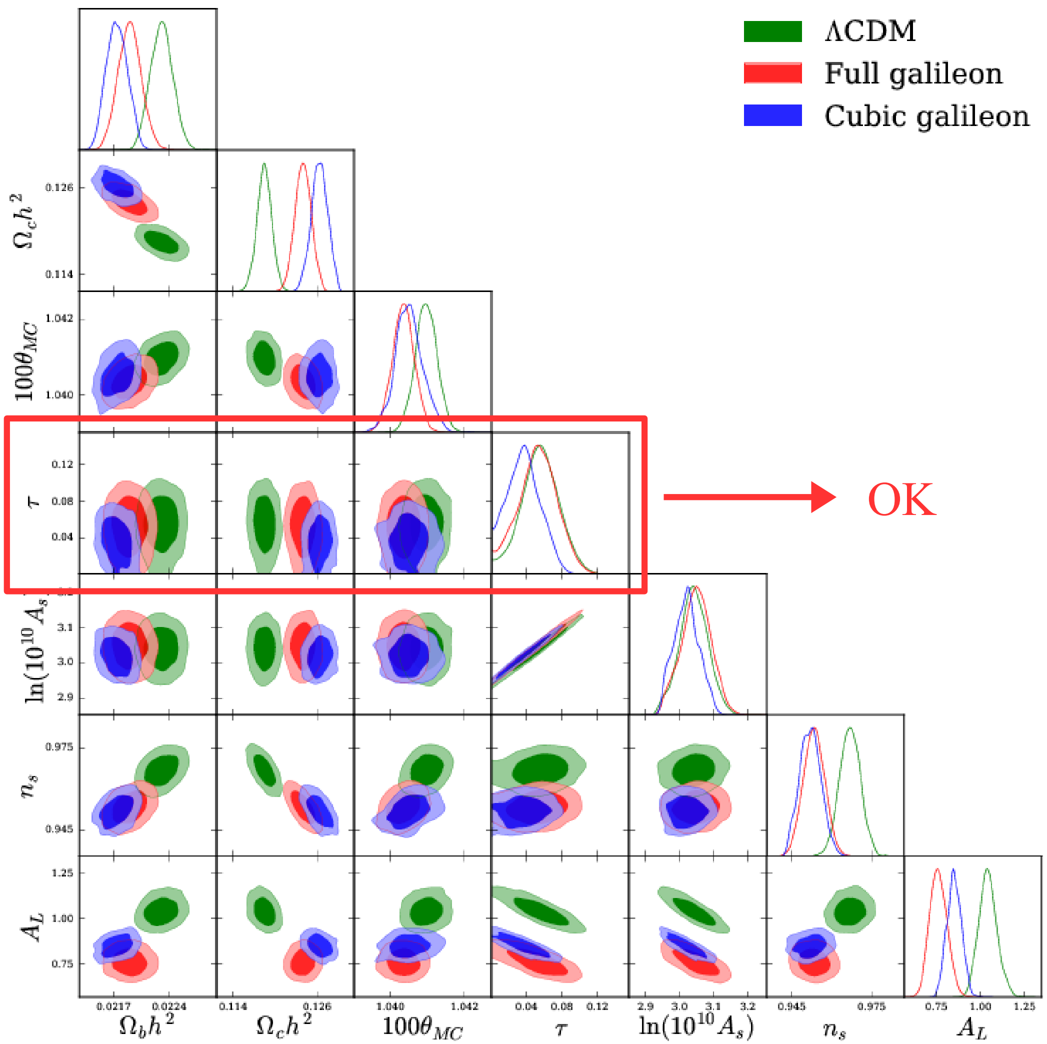

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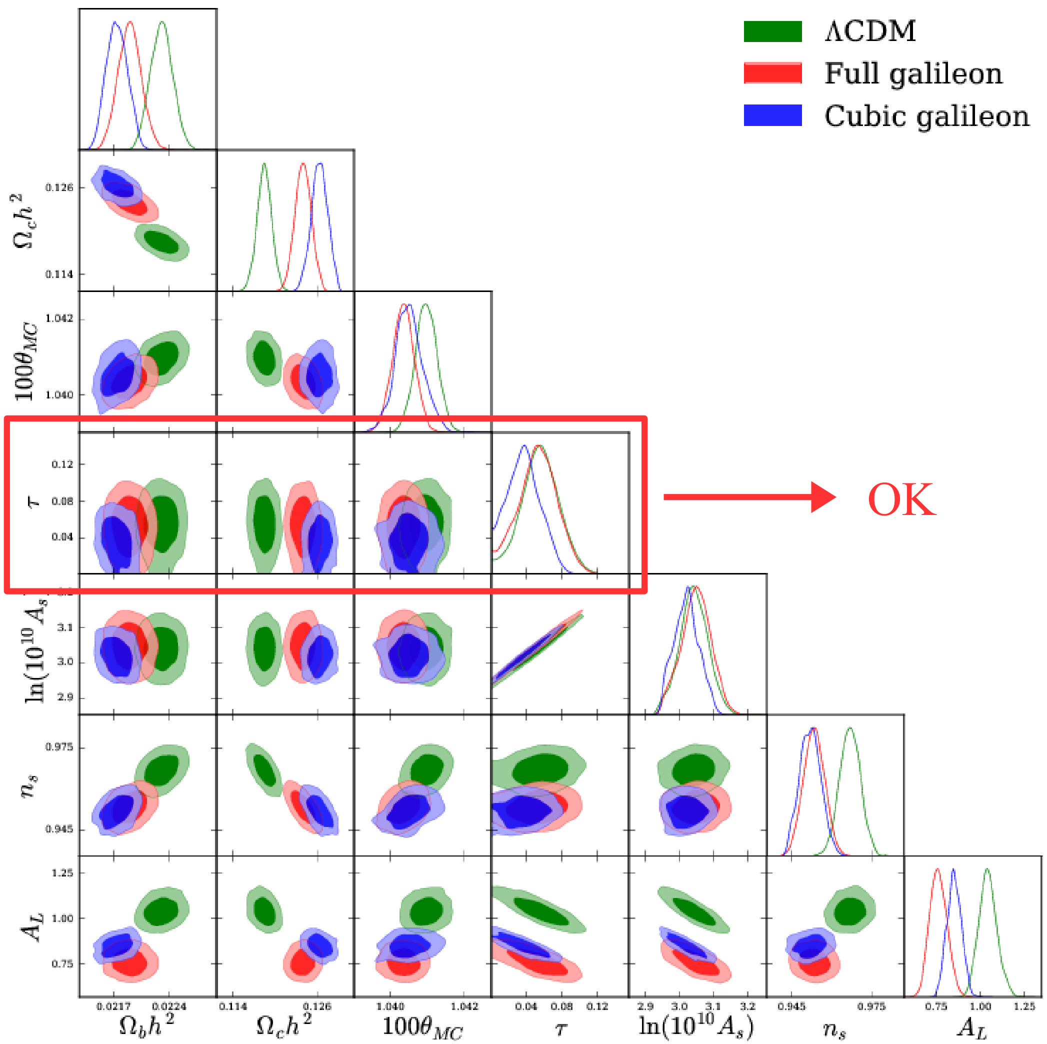
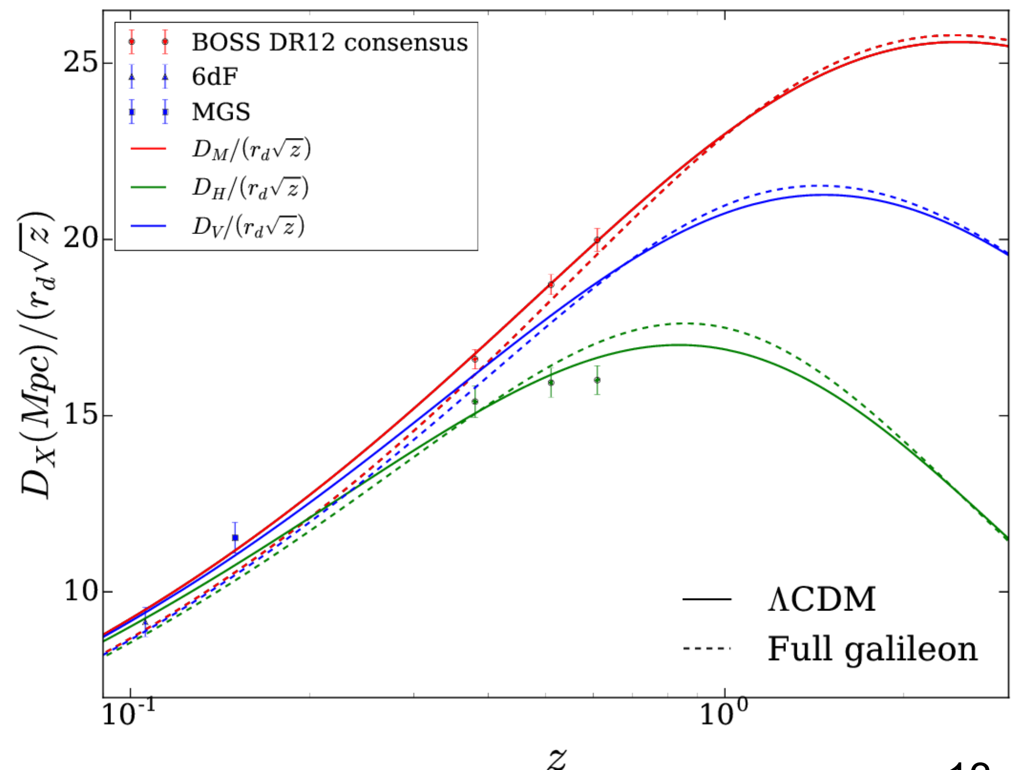
	χ^2(CMB)	χ^2(BAO)	χ^2(JLA)
ΛCDM	12945	5.2	706.6
Full galileon	12960	18.4	718.9
Cubic galileon	12982	25.2	722.4





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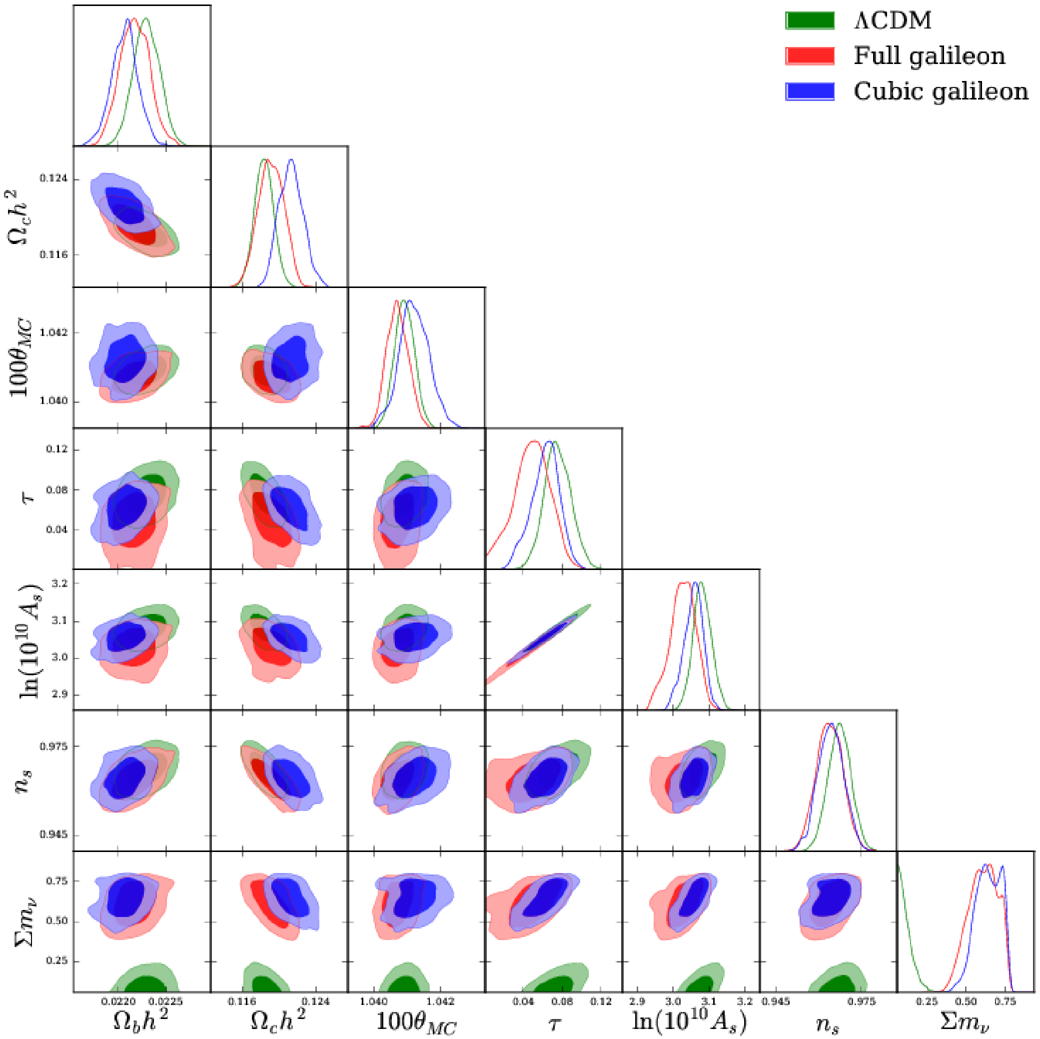

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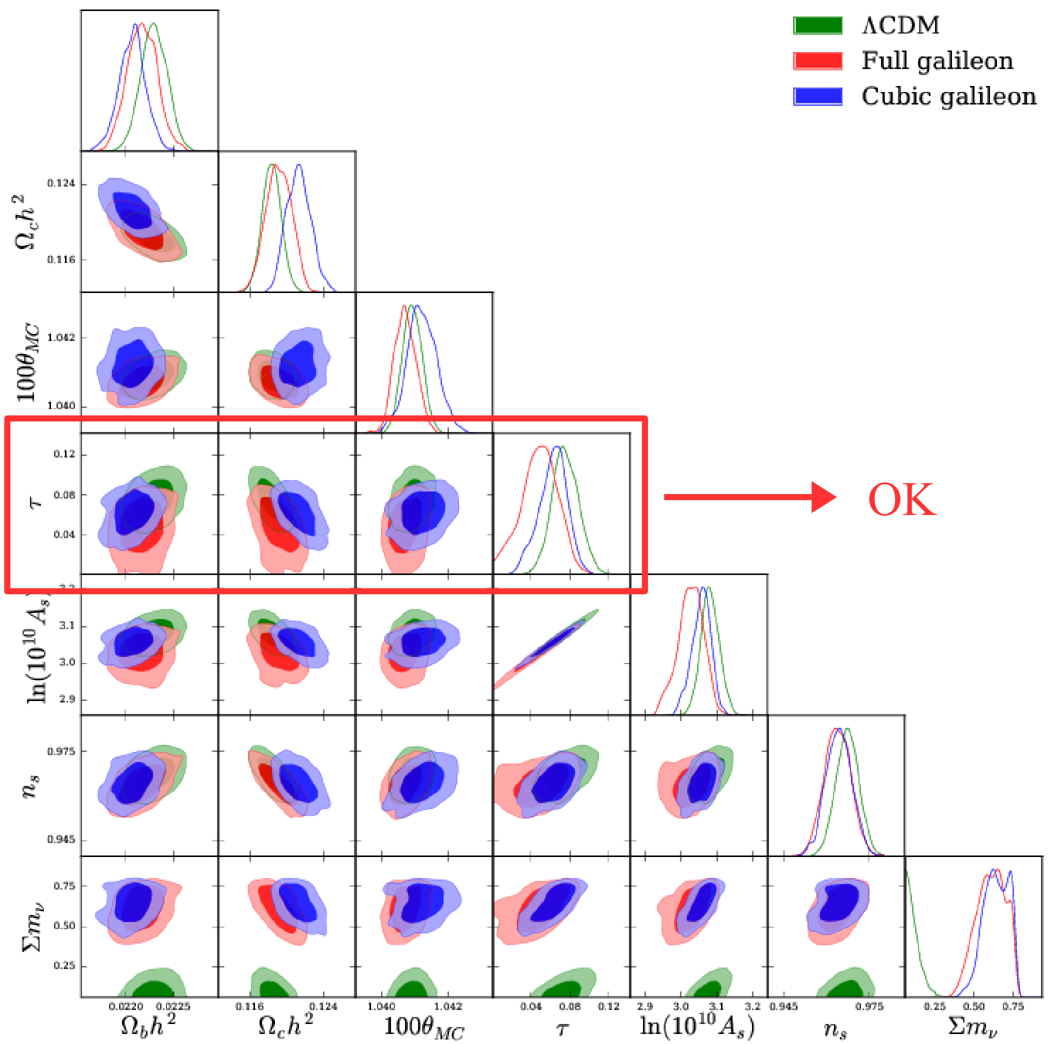

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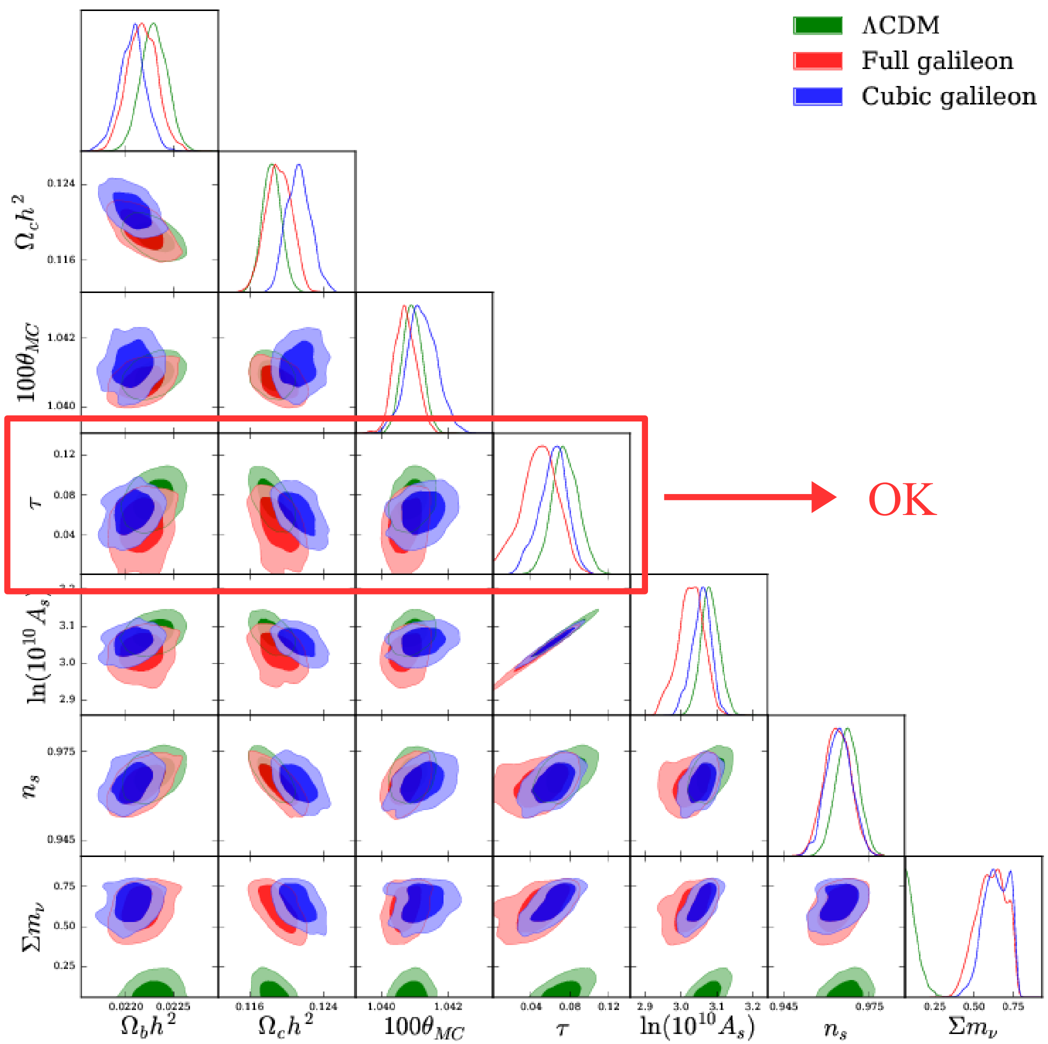
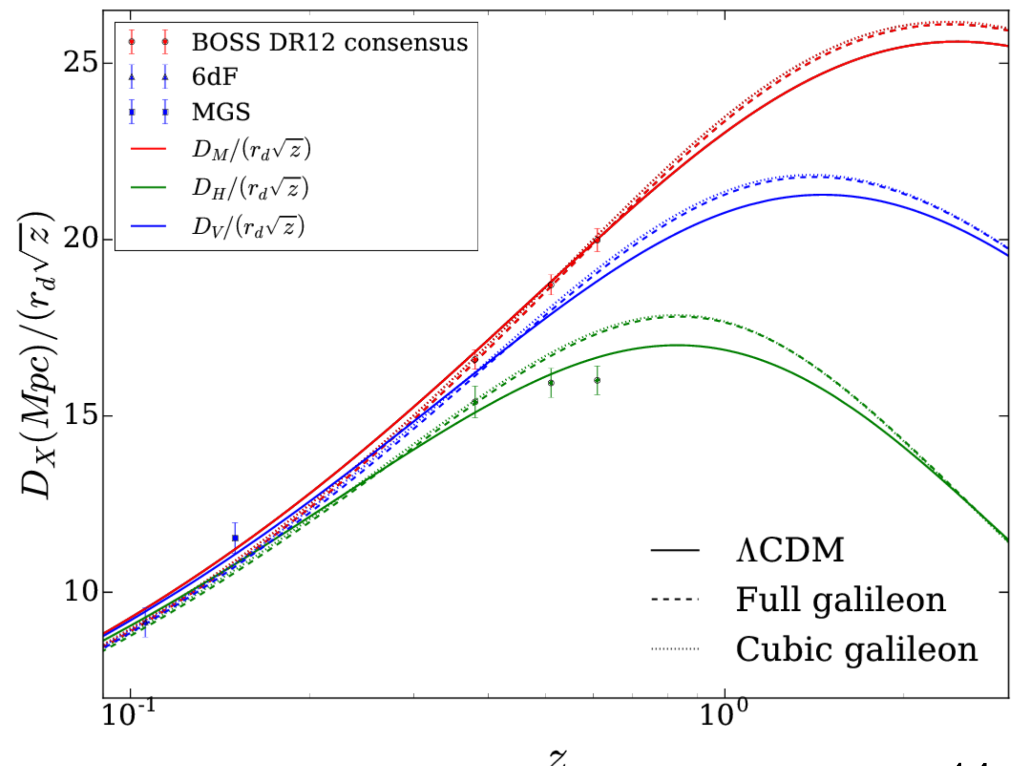
- Model extended to the parameter Σm_ν :

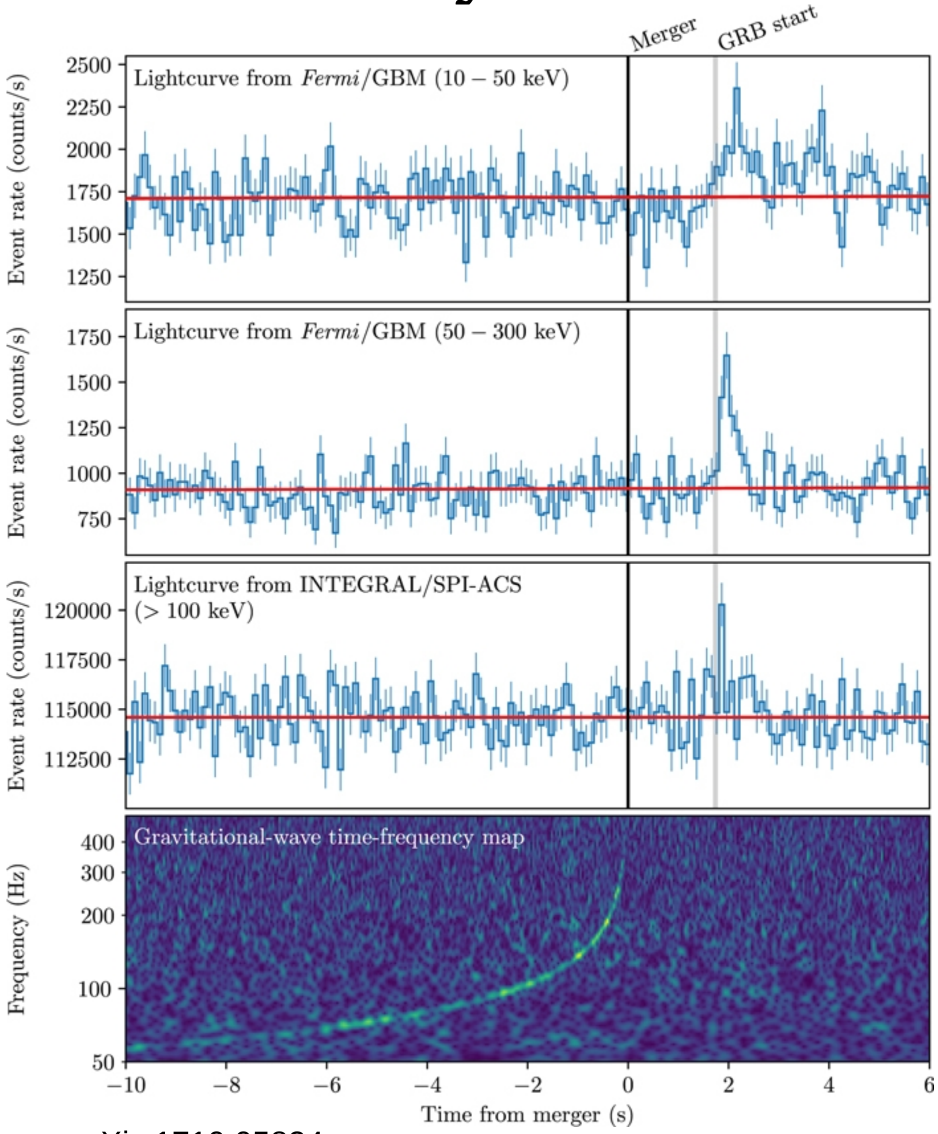


	χ^2(CMB)	χ^2(BAO)	χ^2(JLA)
ΛCDM	12946	5.5	706.7
Full galileon	12950	16.8	717.2
Cubic galileon	12963	18.3	716.5



Results

- Time delay between GW and light from GW170817



arXiv:1710.05834

Results

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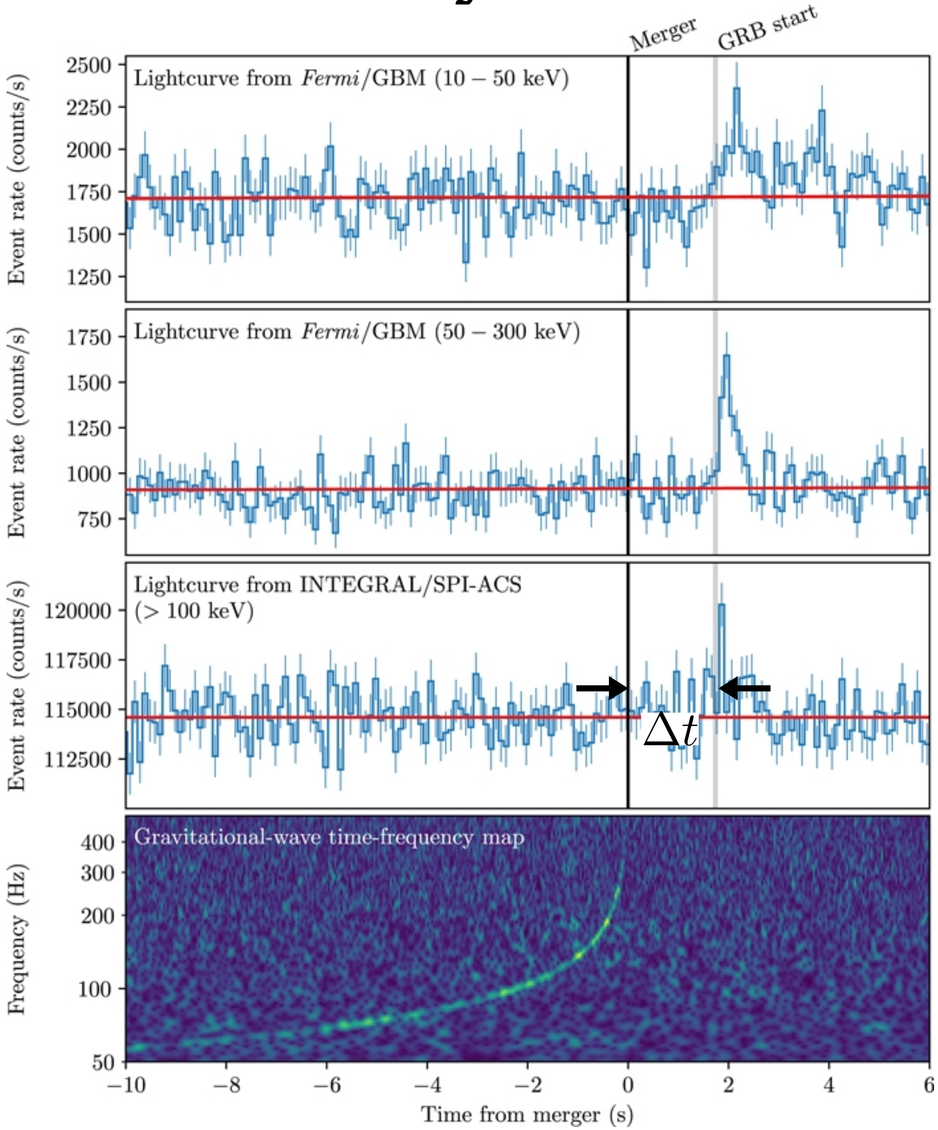

$$\Delta t = \int_{a_e}^{1} \frac{da}{aH}\left(1 - \frac{c}{c_g(a)}\right) + \delta t$$
$$= 1.74 \pm 0.05\mathrm{s}$$

arXiv:1710.05834

Results

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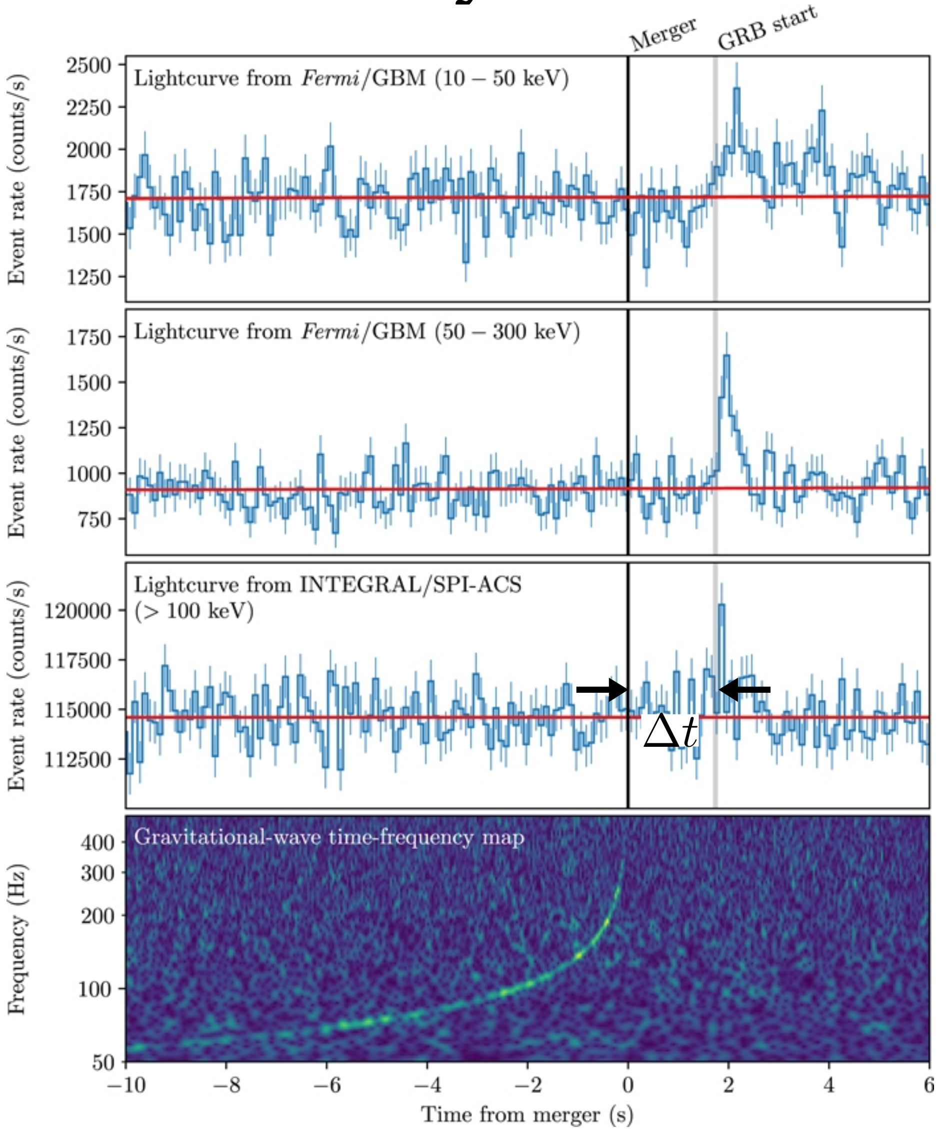

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$$= 1.74 \pm 0.05\text{s}$$

Speed of GW

arXiv:1710.05834

Results

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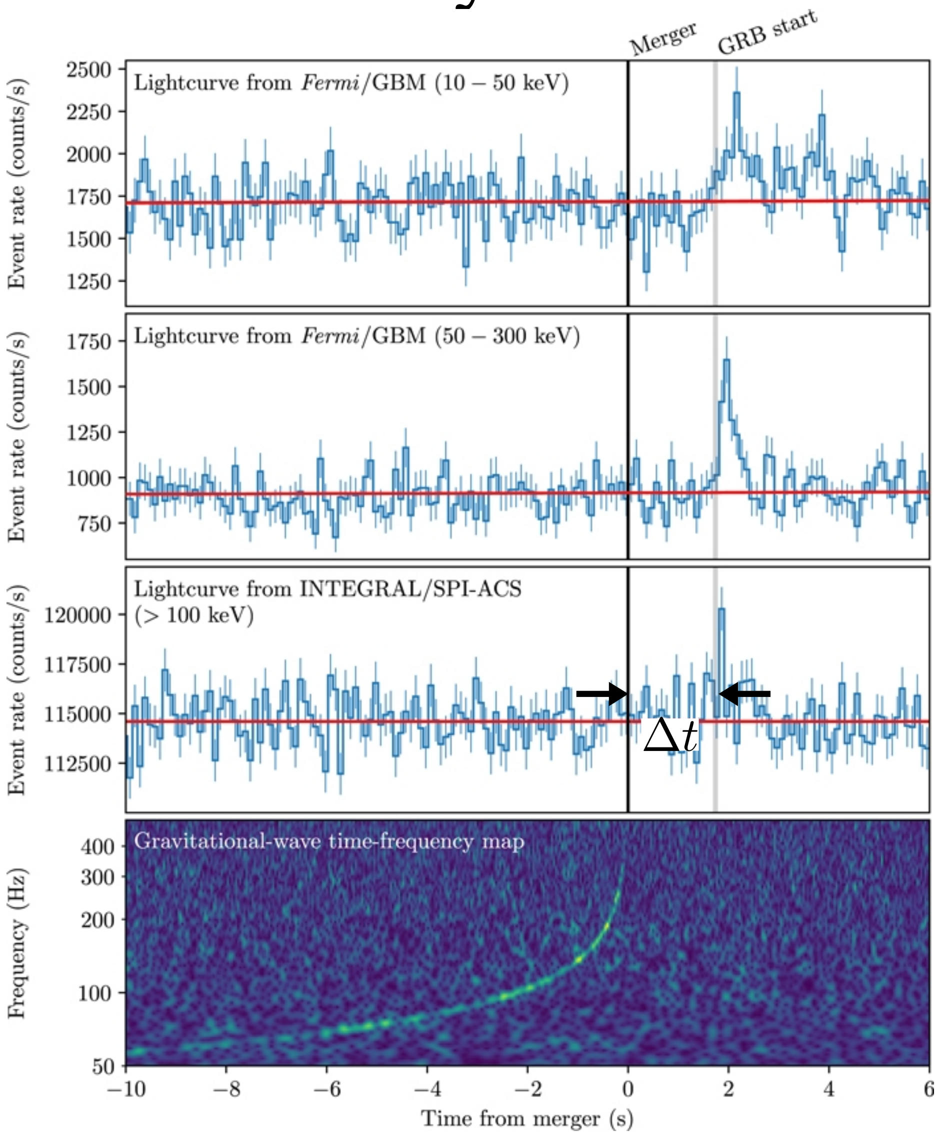


$$\Delta t = \int_{a_e}^{1} \frac{da}{aH}\left(1 - \frac{c}{c_g(a)}\right) + \delta t$$

$$= 1.74 \pm 0.05\text{s}$$

Speed of GW

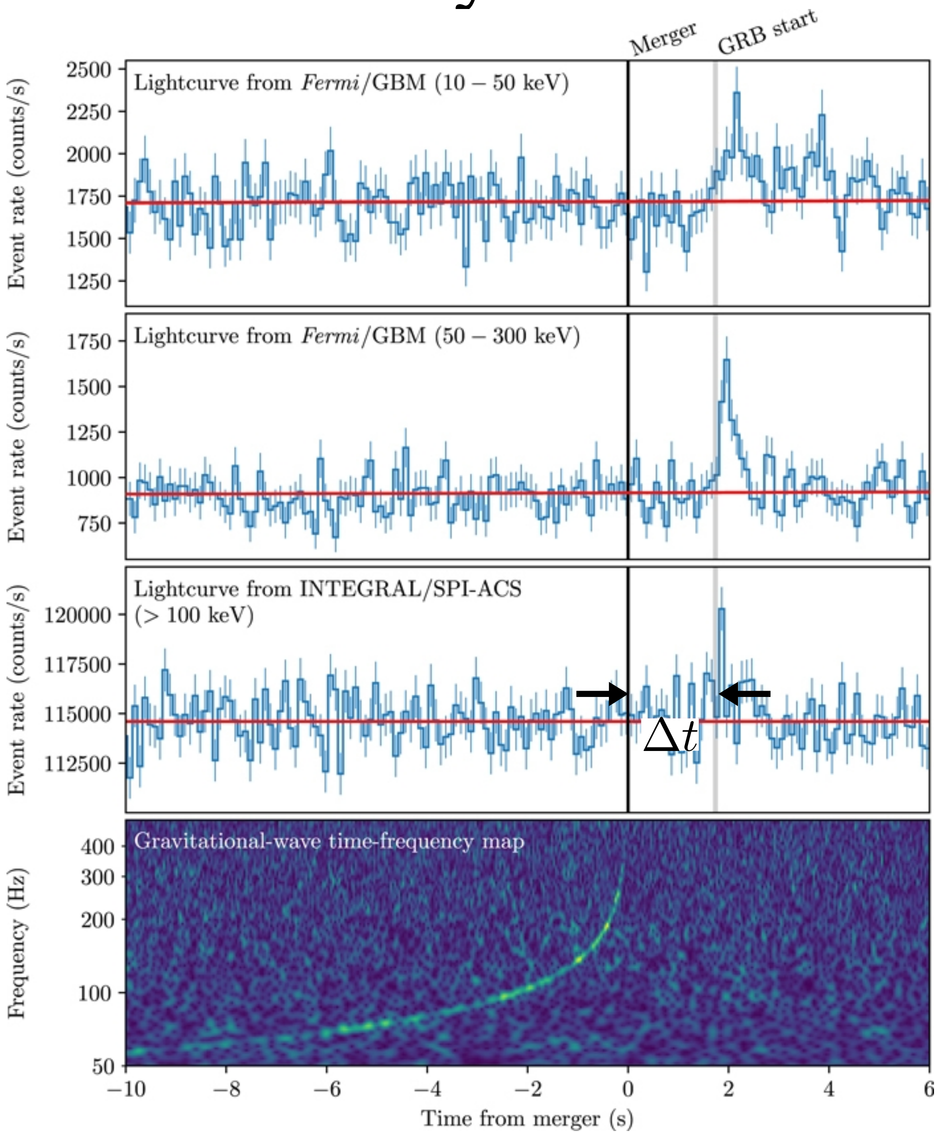
Redshift of host galaxy NGC4993 :

$z_e = 0.009787$

arXiv:1710.05834

Results

➢ Time delay between GW and light from GW170817



$$\Delta t = \int_{a_e}^{1} \frac{da}{aH}\left(1 - \frac{c}{c_g(a)}\right) + \delta t$$
$$= 1.74 \pm 0.05\mathrm{s}$$

Speed of GW

Redshift of host galaxy NGC4993 :
$z_e = 0.009787$

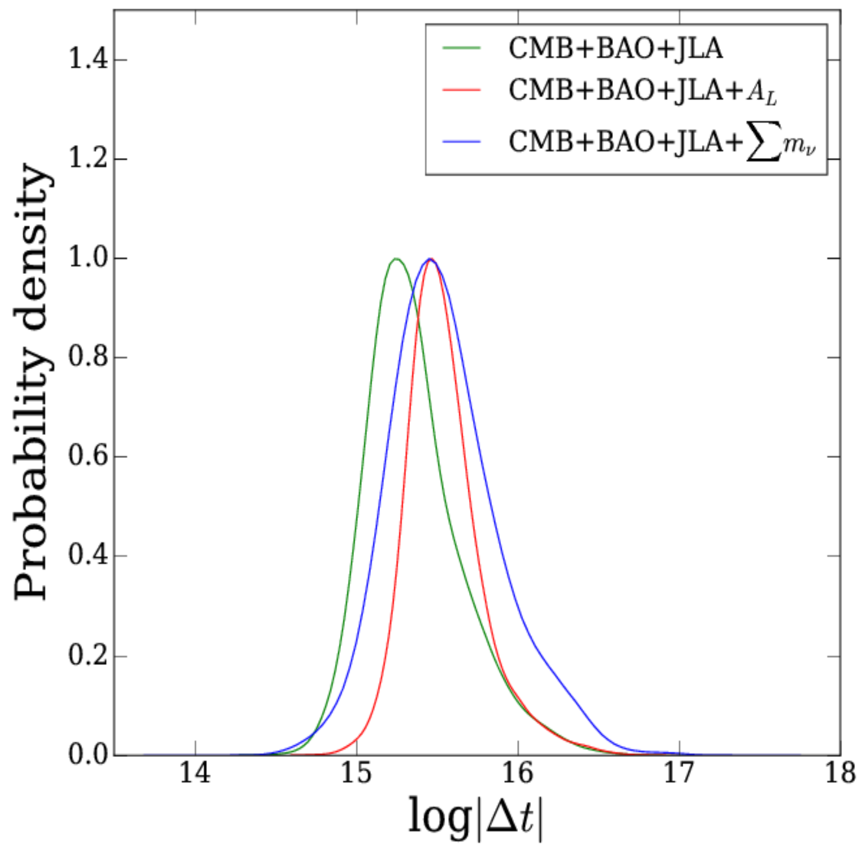
Time delay between GW emission and light emission.
Conservative assumption (arXiv:1710.05834) :
$\delta t \in [-1000\mathrm{s}, 100\mathrm{s}]$

arXiv:1710.05834

Results

- Modification of GW speed only due to c_4, c_5 and c_G

  $\Rightarrow$ affects only the full galileon model



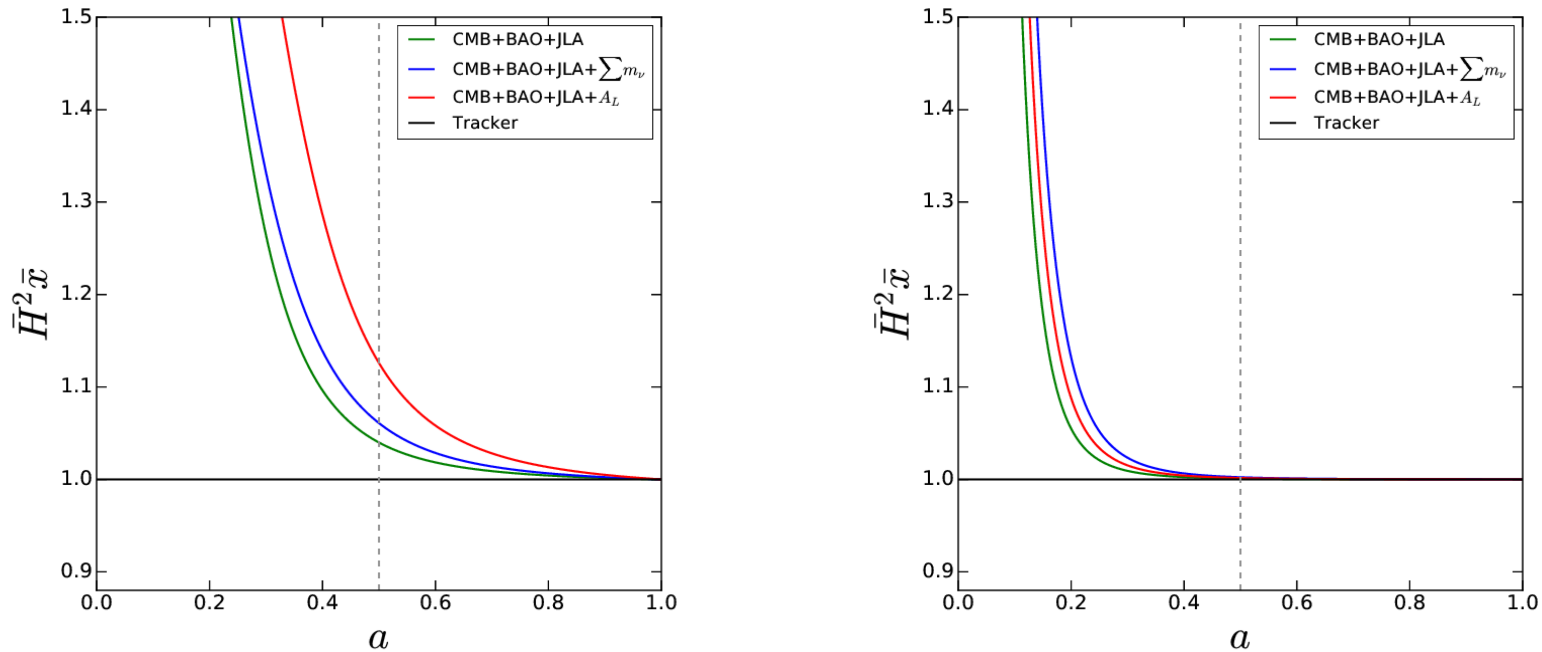
- $\Delta t > 10^{14}$ sec ~ a few million years

Summary

- Study of a theoretically well motivated extension of General Relativity
- Base galileon models in strong tension with BAO data and reionization constraints
- Extended models with A_L and Σm_ν better, but still in tension with BAO
- GW170817 excludes completely the full galileon model
- First full galileon parameter space exploration after Planck

Results

- Was the full exploration useful ?



Full galileon

Cubic galileon

- Best fits of extended full galileon models converge towards tracker later than the beginning of DE dominated era

$\Rightarrow$ risk of missing interesting scenarios if restraining to tracker

Thank you !

$$\tilde{g}_{\mu\nu} = A\left(\pi, X\right) g_{\mu\nu} + B\left(\pi, X\right) \nabla_\mu \pi \nabla_\nu \pi$$

Conformal transformation

$$\pi T^\mu_\mu$$

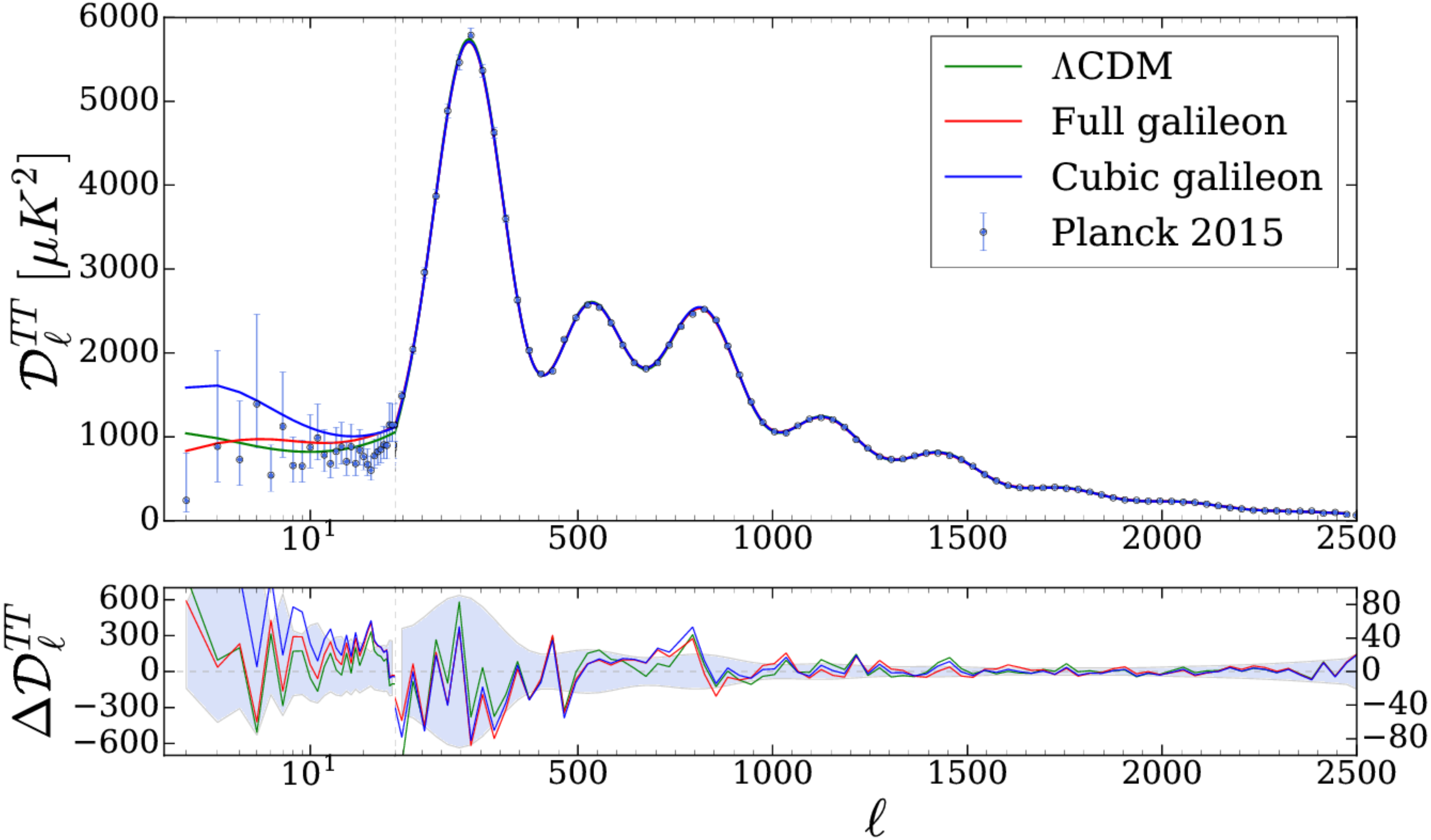
$$M_P c_0 \pi R$$

Disformal transformation

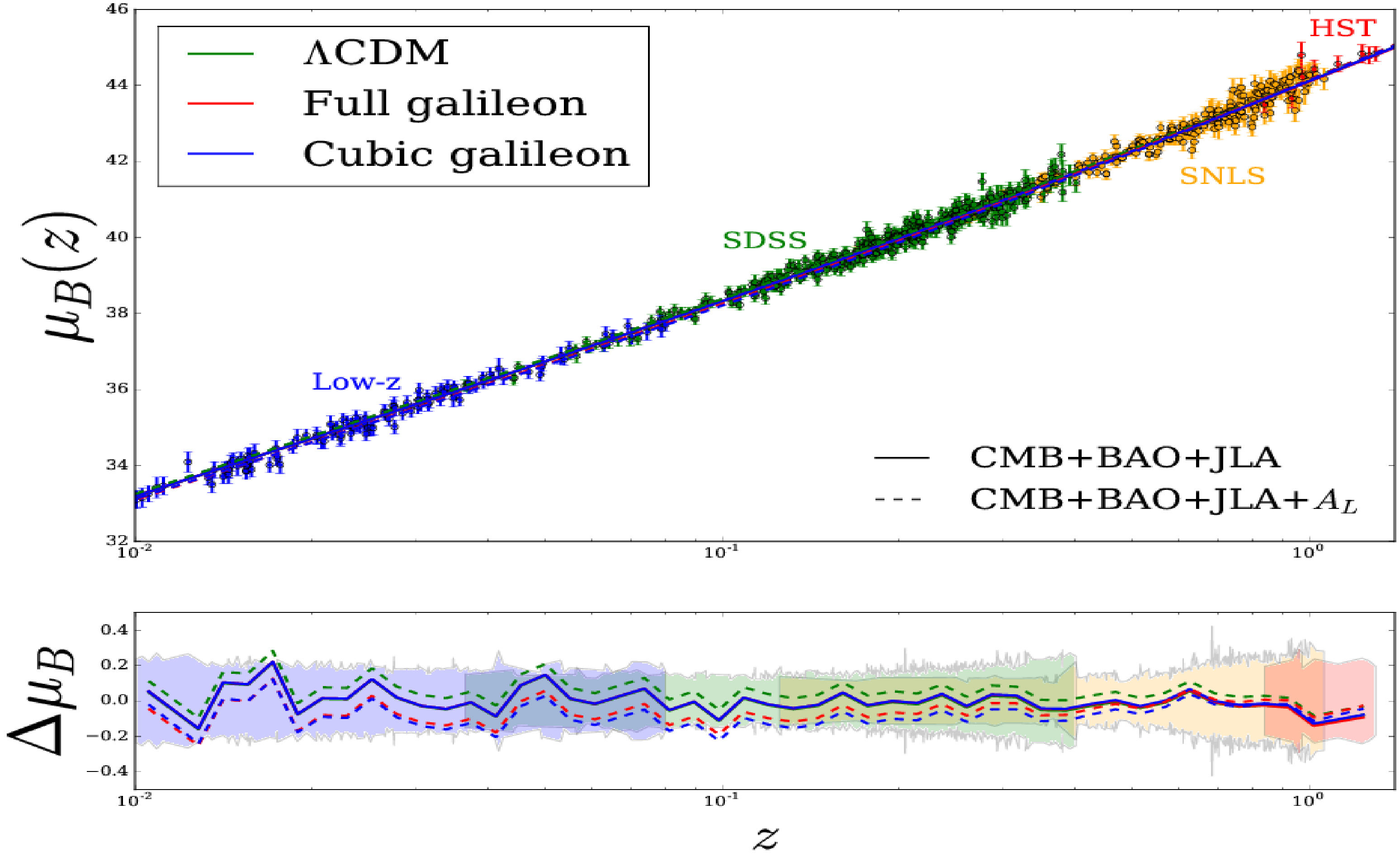
$$\nabla_\mu \pi \nabla_\nu \pi T^{\mu\nu}$$

$$\frac{M_P}{M^3} c_G G^{\mu\nu} \nabla_\mu \pi \nabla_\nu \pi$$

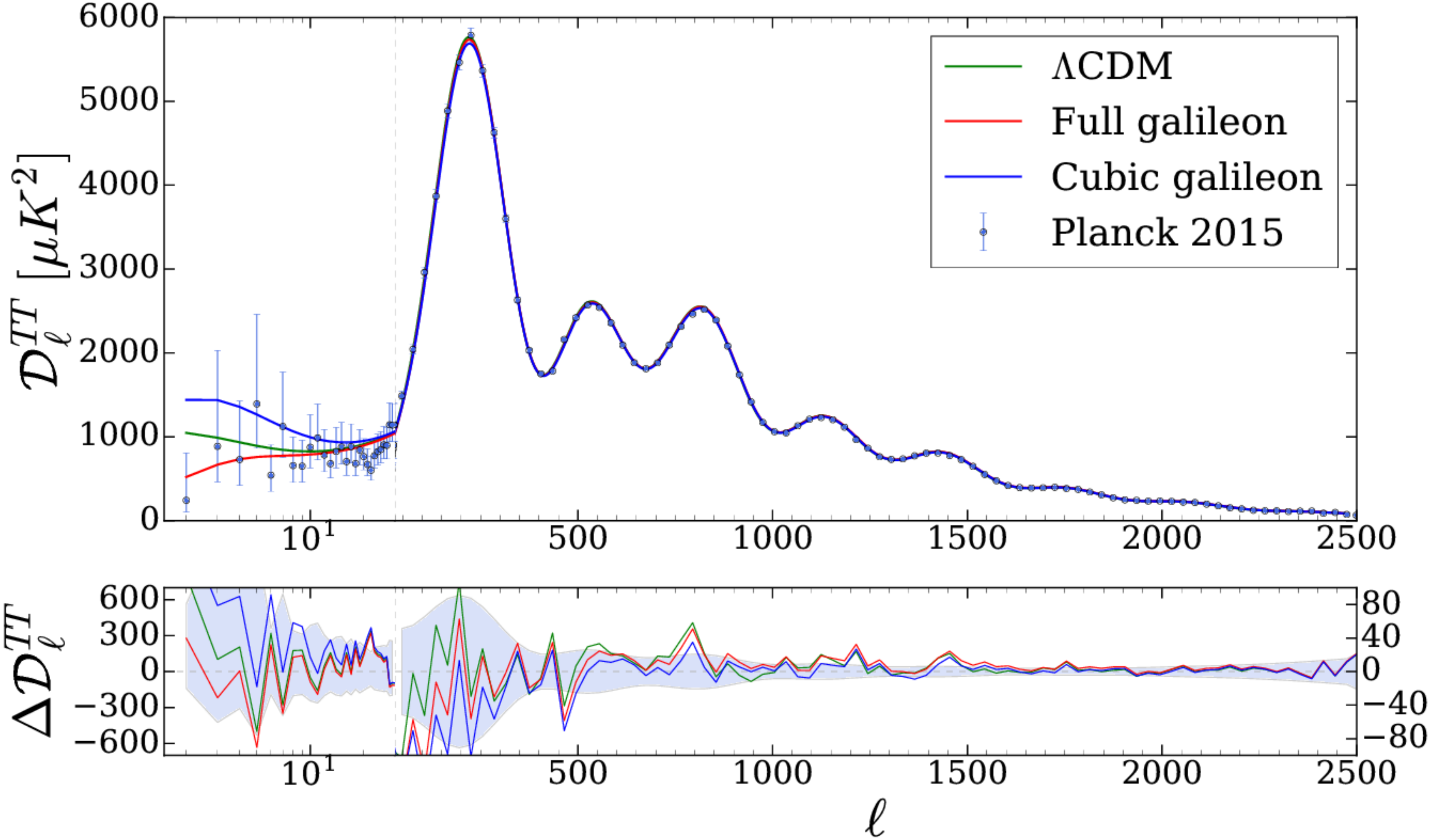
- TT powerspectrum with A_L



- SN hubble diagram with A_L



- TT powerspectrum with Σm_ν



- SN hubble diagram with Σm_ν