Aix*Marseille université

Optimising growth of structure constraints on modified gravity

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colaborators:

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Perenon et al. (2019); *arXiv:190111063*

Centre de Physique Théorique de Marseille

Outline

Effective Field Theory of Dark Energy

Redshift Space Distortions and spectroscopic galaxy survey

Data analysis

Conclusion

2) EFT of DE parameterization

Gravitational action (Horndeski):

$$S_g = \int d^4x \sqrt{-g}\, \frac{M^2(t)}{2} \left[R - 2\lambda(t) - 2\mathcal{C}(t) g^{00} - \mu_2^2(t)(\delta g^{00})^2 - \mu_3(t)\, \delta K \delta g^{00} \right]$$

(Piazza et al. 2014)

$$\mathcal{C} = \frac{1}{2}\left(H\mu_1 - \dot{\mu}_1 - \mu_1^2\right) - \dot{H} - \frac{3}{2}\frac{M_{\rm pl}^2}{M^2} H^2 \Omega_{\rm m} \,,$$

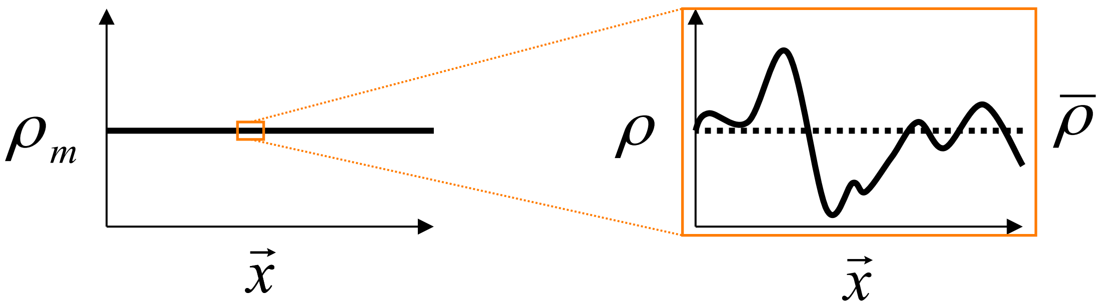
$$\lambda = \frac{1}{2}\left(5H\mu_1 + \dot{\mu}_1 + \mu_1^2\right) + \dot{H} + 3H^2 - \frac{3}{2}\frac{M_{\rm pl}^2}{M^2} H^2 \Omega_{\rm m}$$

$$\frac{\mu_1}{H}(z) = \frac{1-\Omega_{\rm m}(z)}{1-\Omega_{\rm m,0}} \left[p_{10} + p_{11}\left(\Omega_{\rm m}(z) - \Omega_{\rm m,0}\right)\right]$$

$$\frac{\mu_2^2}{H^2}(z) = \frac{1-\Omega_{\rm m}(z)}{1-\Omega_{\rm m,0}} \left[p_{20} + p_{21}\left(\Omega_{\rm m}(z) - \Omega_{\rm m,0}\right)\right]$$

$$\frac{\mu_3}{H}(z) = \frac{1-\Omega_{\rm m}(z)}{1-\Omega_{\rm m,0}} \left[p_{30} + p_{31}\left(\Omega_{\rm m}(z) - \Omega_{\rm m,0}\right)\right]$$

3) EFT of DE dynamics



Homogeneous Background *Deviations on smaller scales*

$$\delta(t,\vec{x}) = \frac{\rho(t,\vec{x}) - \bar{\rho}(t)}{\bar{\rho}(t)}$$

linear growth factor

Density contrast of matter: $\delta(t,\vec{x}) = D(t)\delta(t_0,\vec{x})$ $\quad D(t_0) \equiv 1$

Linear evolution of fluctuations: $\frac{d^2D}{dt^2} + 2H\frac{dD}{dt} - \frac{3}{2}\Omega_m H^2 D\mu = 0$

Velocity fluctuations: $\nabla \cdot \vec{v} = Hf\delta(t,\vec{x})$ Growth rate: $f \equiv \frac{d\ln D}{d\ln a}$

$$z_o = z_c + \frac{\vec{v}\cdot\vec{e}_z}{c}$$

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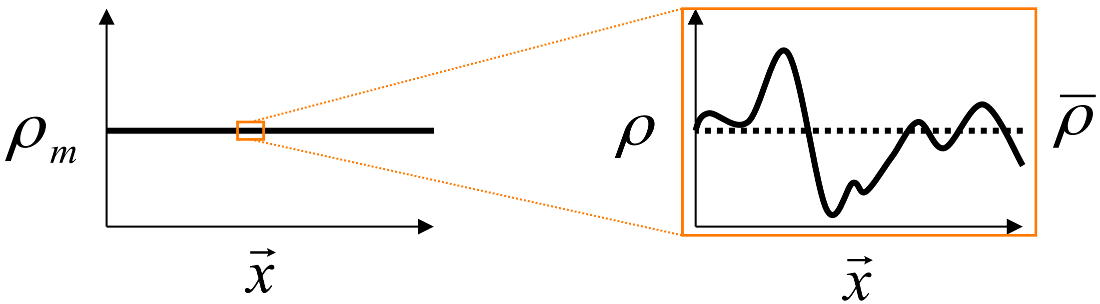

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Effective gravitational coupling

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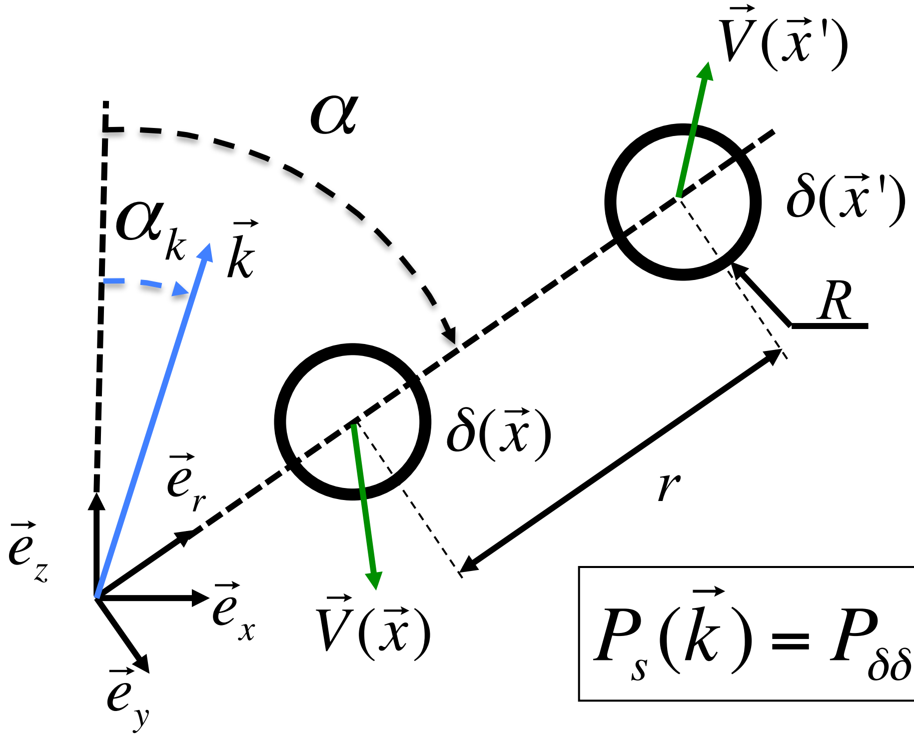


$$v_z \equiv \left[\vec{V}(\vec{x}\,') - \vec{V}(\vec{x})\right] \cdot \vec{e}_z$$

$$\mu_k \equiv \cos(\alpha_k)$$

$$\theta \equiv \frac{1}{H} \vec{\nabla}.\vec{v}$$

$$P_s(\vec{k}) = P_{\delta\delta}(k) + 2 f \mu_k^2 P_{\delta\theta}(k) + f^2 \mu_k^4 P_{\theta\theta}(k)$$

Galaxy-matter bias: $\delta_g \approx b\delta$

no velocity bias: $v_g \approx v$

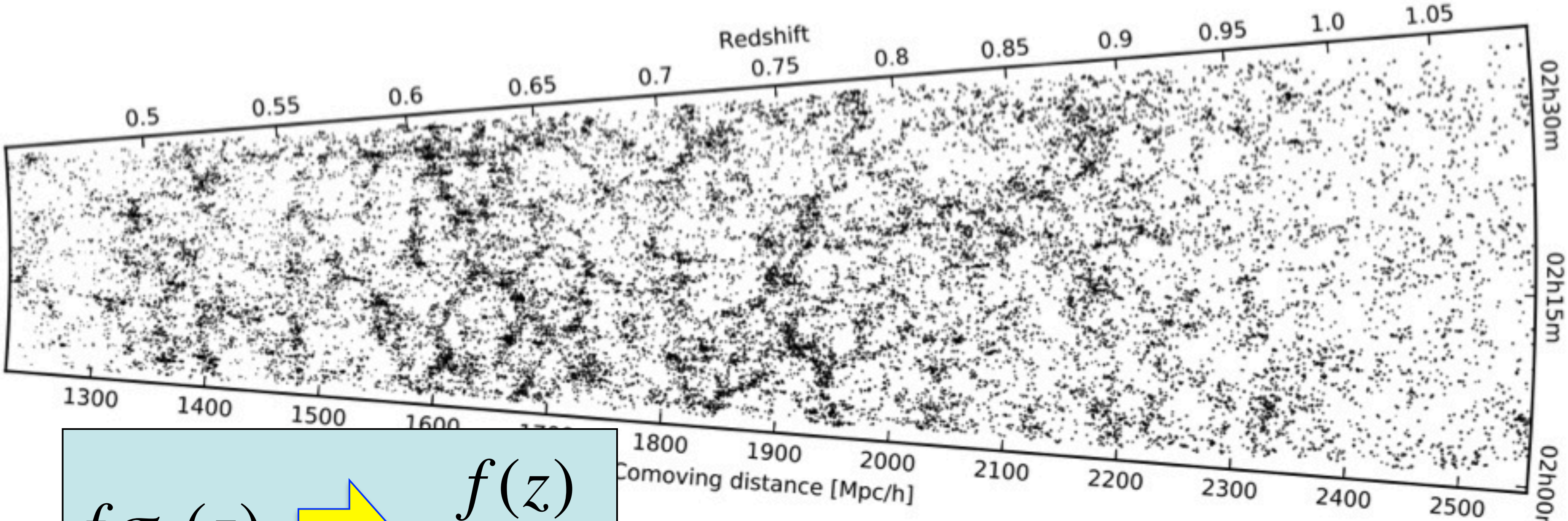
RSD parameter: $f\sigma_8(z)$

Normalisation of the power spectrum:

$$\sigma_8^2(z) \equiv \langle \delta_R^2(z) \rangle$$

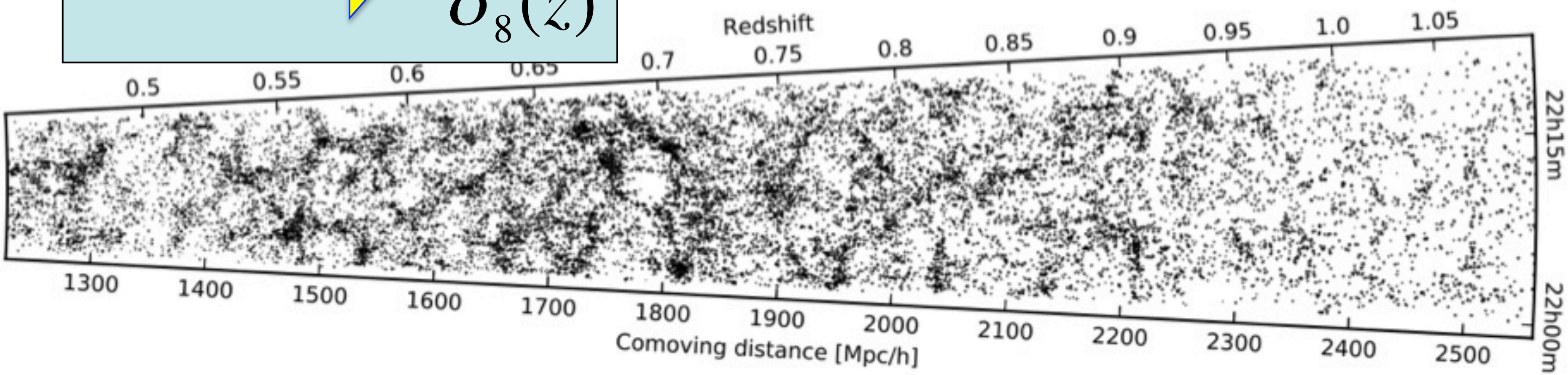
$$\sigma_8(z) = \sigma_8(z_{\rm ini}) \frac{D_+(z)}{D_+(z_{\rm ini})}$$

5) VIPERS



$f\sigma_8(z)$ ⇒ $f(z)$, $\sigma_8(z)$

Galaxy-Galaxy lensing (de la Torre et al. 2017)



VIPERS
VIMOS PUBLIC EXTRAGALACTIC REDSHIFT SURVEY

(Guzzo et al. 2014)

(Scodeggio et al. 2018)

6) Characterizing the Large Scale Structure

Effective gravitational coupling: $\mu = \mu_{\rm sc}\left(1 + \mu_{\rm ff}\right)$ (Perenon et al. 2015)

$$\mu_{\rm sc} = \frac{M^2(z=0)}{M^2(z)}$$

$$\mu_{\rm ff} = \frac{(\mu_1 + \mu_3)^2}{2B}$$

$$\mu_{\rm sc}(z=0) = 1$$

Gravitational slip parameter:

$$\gamma = 1 - \frac{\mu_1(\mu_1 + \mu_3)}{(H + \mu_1)(\mu_1 + \mu_3) - \dot{\mu}_1 + \dot{\mu}_3 - 2\dot{H} - 3(M_{\rm pl}^2/M^2)H^2\Omega_{\rm m}}$$

Light deflection parameter:

$$\Sigma = \mu\,\frac{1+\gamma}{2}$$

7) Stability conditions and CMB prior

No ghost and no gradient instabilities (sharp flat prior):

$$A = 2\mathcal{C} + 4\mu_2^2 + \frac{3}{2}(\mu_1 - \mu_3)^2 > 0 ,$$

$$B = 2\mathcal{C} + \dot{\mu}_3 + H\mu_3 + \frac{1}{2}(3\mu_1^2 - \mu_3^2) > 0$$

Quasi Static Approximation (sharp flat prior):

$$c_s^2 = B/A \geq 0.1$$

Planck covariance matrix (Gaussian prior):

$$\chi^2_{(\Omega_{\mathrm{m},0},\sigma^*_{8,0})} = (\Omega_{\mathrm{m},0} - \Omega^{\mathrm{Planck}}_{\mathrm{m},0}, \sigma^*_{8,0} - \sigma^{\mathrm{Planck}}_{8,0})\, C^{-1}_{\mathrm{Planck}}\, (\Omega_{\mathrm{m},0} - \Omega^{\mathrm{Planck}}_{\mathrm{m},0}, \sigma^*_{8,0} - \sigma^{\mathrm{Planck}}_{8,0})^t$$

where : $\sigma^*_{8,0} = \sigma_{8,0}\dfrac{D_+^{\Lambda\mathrm{CDM}}(z=0)}{D_+(z=0)}$ ⇒ *Ensure that the amplitude of matter perturbation were in agreement with the scalar amplitude measured by Planck*

8) RSD Data

Compilation of 30 measurements of the RSD parameter : $f\sigma_8(z)$

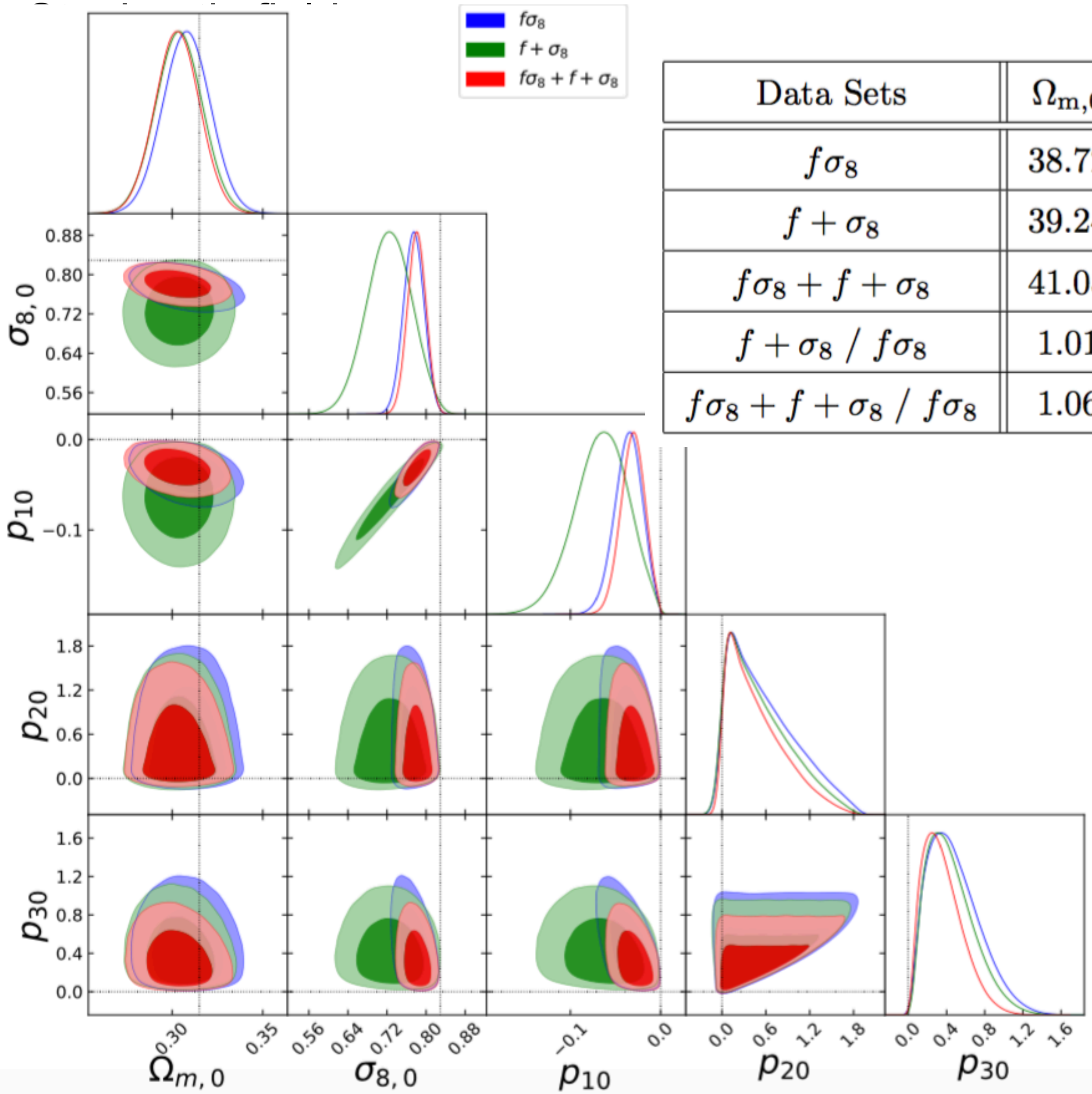
Dataset	z	$f\sigma_8$	f	σ_8	Ref.
2MTF	0.001	0.505 ± 0.085			[93]
6dFGS+SNIa	0.02	0.428 ± 0.0465			[94]
IRAS+SNIa	0.02	0.398 ± 0.065			[95, 96]
2MASS	0.02	0.314 ± 0.048			[95, 97]
SDSS	0.10	0.376 ± 0.038	0.464 ± 0.040	0.769 ± 0.105	[56]
SDSS-MGS	0.15	0.490 ± 0.145			[98]
2dFGRS	0.17	0.510 ± 0.060			[99]
GAMA	0.18	0.360 ± 0.090			[100]
GAMA	0.38	0.440 ± 0.060			[100]
SDSS-LRG-200	0.25	0.3512 ± 0.0583			[101]
SDSS-LRG-200	0.37	0.4602 ± 0.0378			[101]
BOSS DR12	0.31	0.469 ± 0.098			[102]
BOSS DR12	0.36	0.474 ± 0.097			[102]
BOSS DR12	0.40	0.473 ± 0.086			[102]
BOSS DR12	0.44	0.481 ± 0.076			[102]
BOSS DR12	0.48	0.482 ± 0.067			[102]
BOSS DR12	0.52	0.488 ± 0.065			[102]
BOSS DR12	0.56	0.482 ± 0.067			[102]
BOSS DR12	0.59	0.481 ± 0.066			[102]
BOSS DR12	0.64	0.486 ± 0.070			[102]
WiggleZ	0.44	0.413 ± 0.080			[103]
WiggleZ	0.60	0.390 ± 0.063			[103]
WiggleZ	0.73	0.437 ± 0.072			[103]
Vipers PDR-2	0.60	0.550 ± 0.120	0.93 ± 0.22	0.52 ± 0.06	[55, 104]
Vipers PDR-2	0.86	0.400 ± 0.110	0.99 ± 0.19	0.48 ± 0.04	[55, 104]
FastSound	1.40	0.482 ± 0.116			[105]
SDSS-IV	0.978	0.379 ± 0.176			[106]
SDSS-IV	1.23	0.385 ± 0.099			[106]
SDSS-IV	1.526	0.342 ± 0.070			[106]
SDSS-IV	1.944	0.364 ± 0.106			[106]

Shi et al. (2017)

de la Torre at al. (2017)

Table 1. The growth of structure data used in the current analysis. The true uncertainty on the σ_8 measurement of SDSS-veloc is $0.769^{+0.121}_{-0.089}$ but for simplicity we consider the symmetric uncertainty 0.769 ± 0.105.

9) Constraints on EFT parameters (pi0)



Data Sets	$\Omega_{m,0}$	$\sigma_{8,0}$	p_{10}	p_{20}	p_{30}
$f\sigma_8$	38.72	24.16	32.87	1.20	1.95
$f+\sigma_8$	39.24	10.89	17.04	1.31	2.18
$f\sigma_8+f+\sigma_8$	41.05	26.88	37.58	1.49	2.59
$f+\sigma_8\ /\ f\sigma_8$	1.01	0.45	0.52	1.09	1.12
$f\sigma_8+f+\sigma_8\ /\ f\sigma_8$	1.06	1.11	1.15	1.24	1.33

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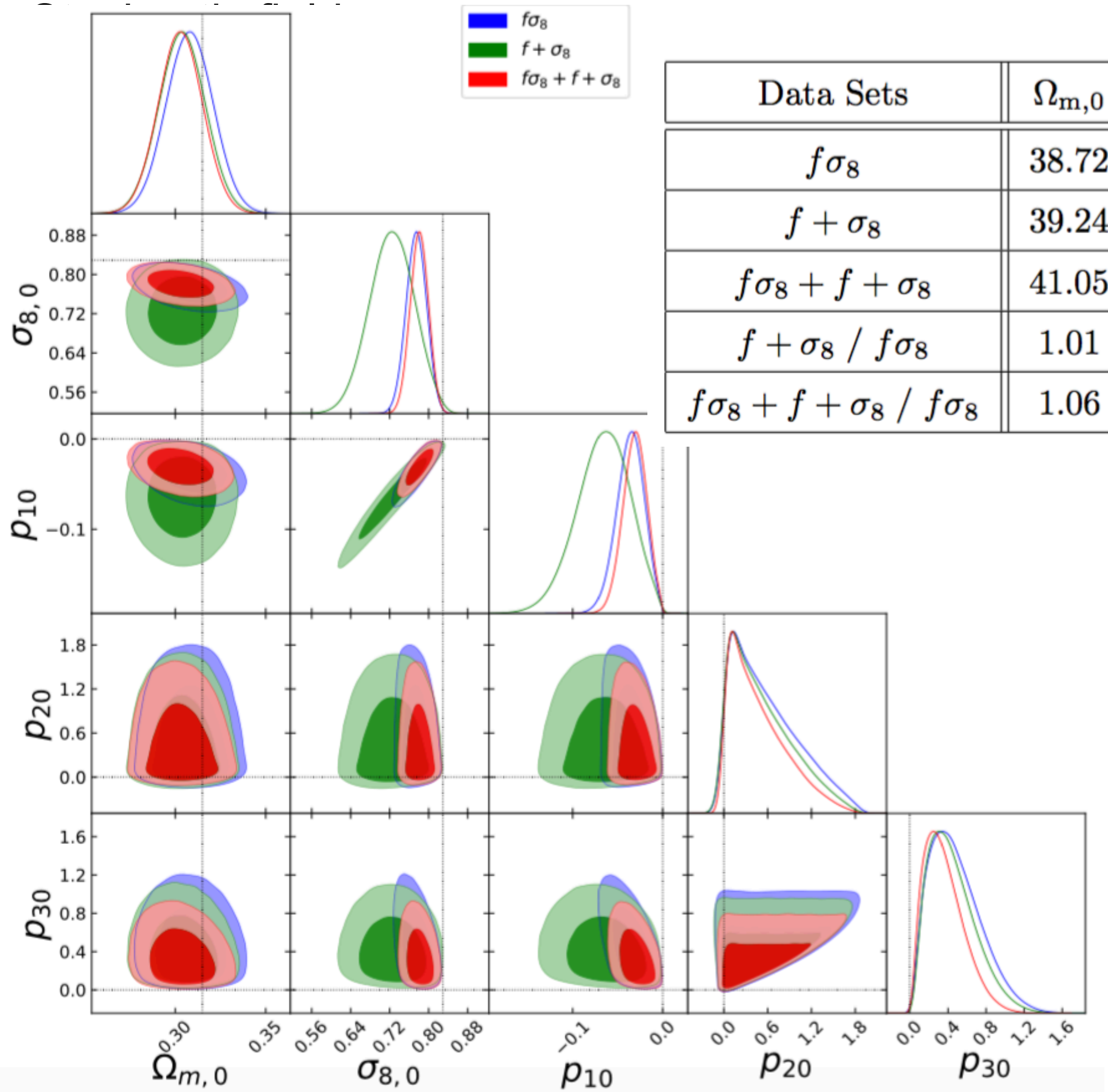

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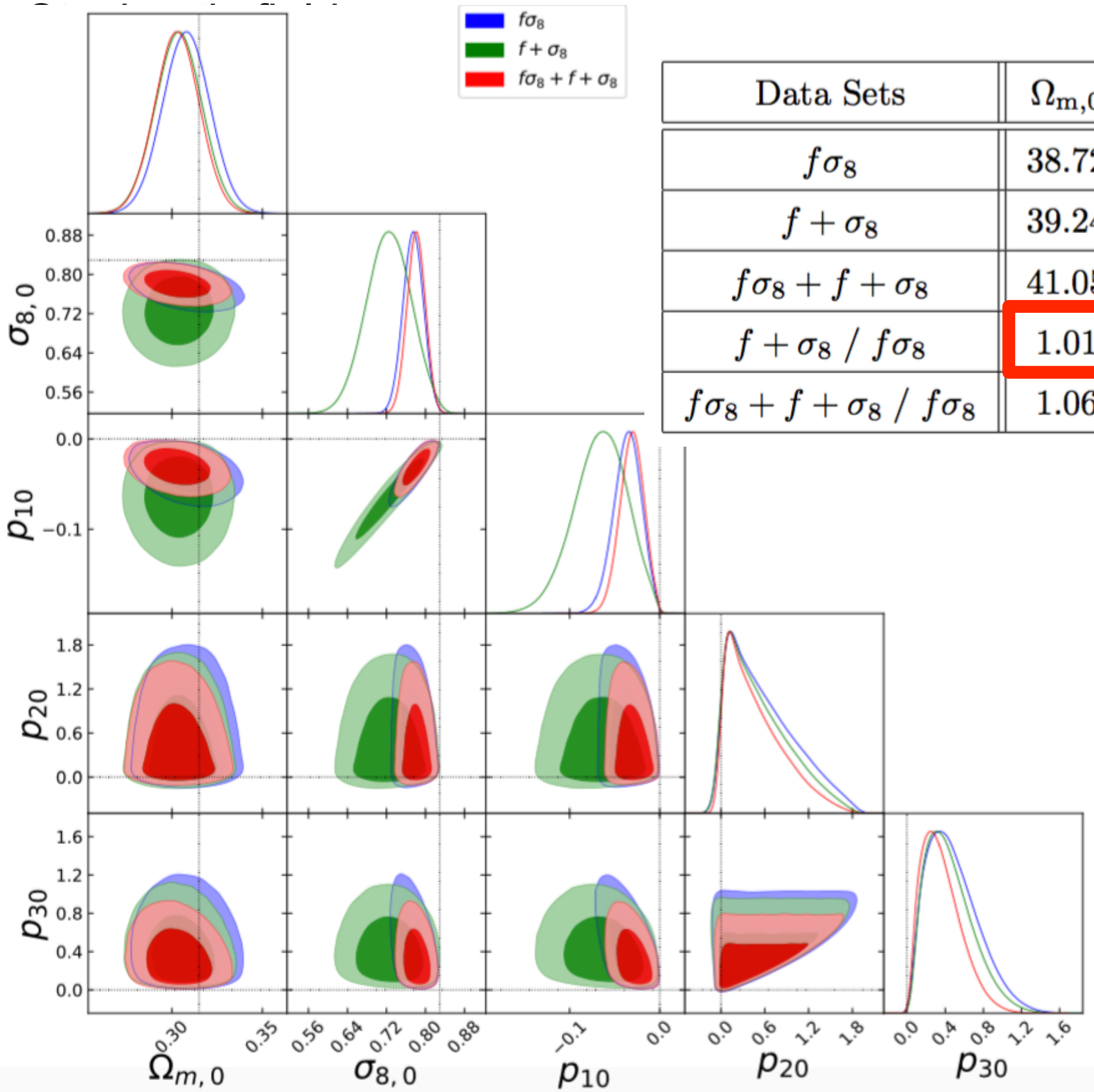

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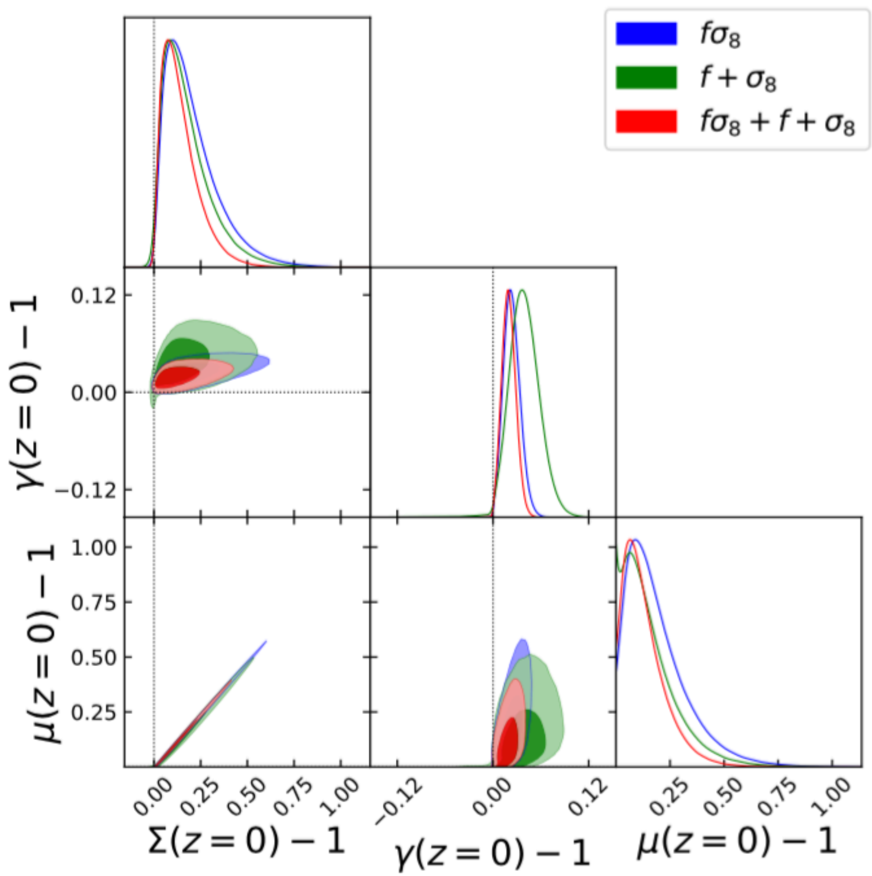
10) Constraints on lensing observables

$$\{\Omega_{m,0},\sigma_8,p_{10},p_{20},p_{30}\}$$



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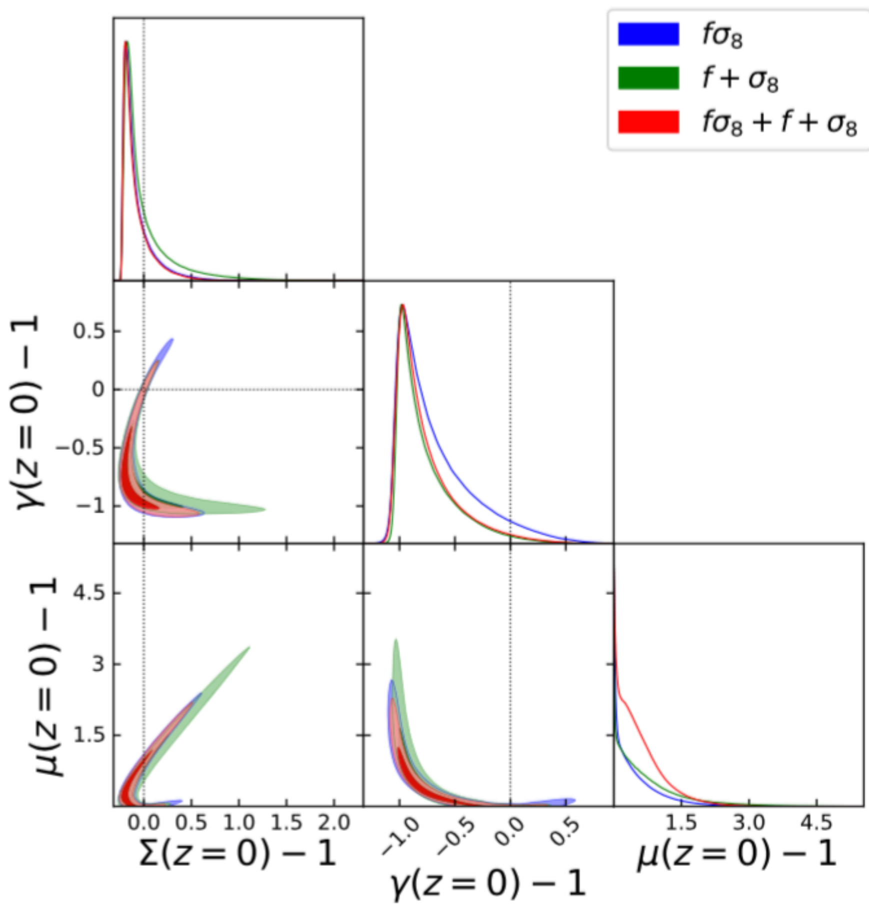


11) Reducing the space of viable models

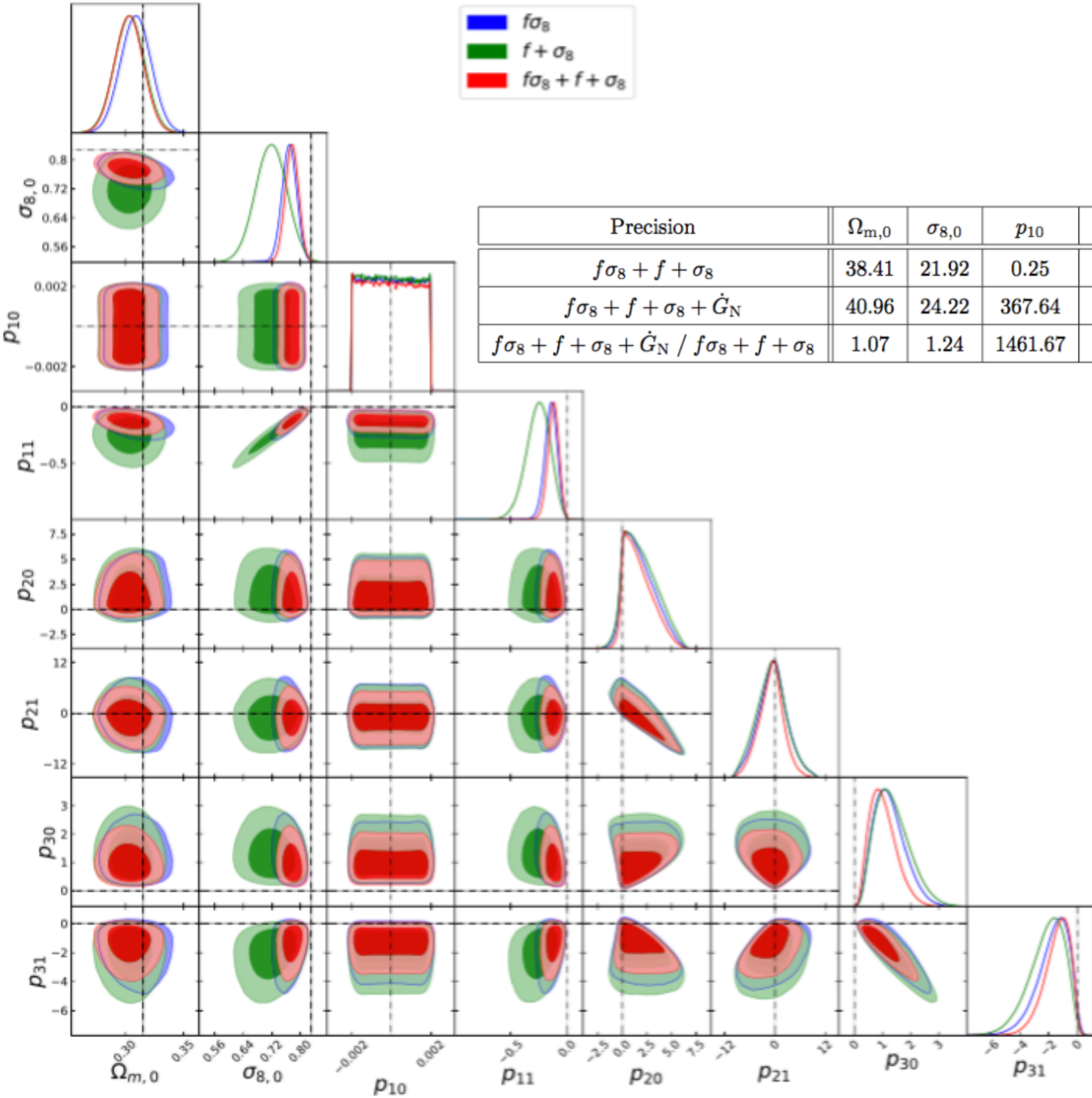
Mars ranging data (Konopliv et al. 2011):

$$|\dot{G}_{\rm N}/G_{\rm N}| \lesssim 1.6 \times 10^{-13}\ {\rm year}^{-1}$$

which can be expressed in terms of the Hubble parameter:

$$|\dot{G}_{\rm N}/G_{\rm N}| < 0.002\ H_0$$

flat sharp prior on coupling: $\big|\mu_1(z=0)\big| = |p_{10}| < 0.002$



Precision	$\Omega_{\rm m,0}$	$\sigma_{8,0}$	p_{10}	p_{11}	p_{20}	p_{21}	p_{30}	p_{31}
$f\sigma_8+f+\sigma_8$	38.41	21.92	0.25	0.07	0.05	0.02	0.25	0.07
$f\sigma_8+f+\sigma_8+\dot{G}_{\rm N}$	40.96	24.22	367.64	10.35	0.38	0.18	1.11	0.59
$f\sigma_8+f+\sigma_8+\dot{G}_{\rm N}$ / $f\sigma_8+f+\sigma_8$	1.07	1.24	1461.67	149.38	7.95	7.66	4.37	8.08

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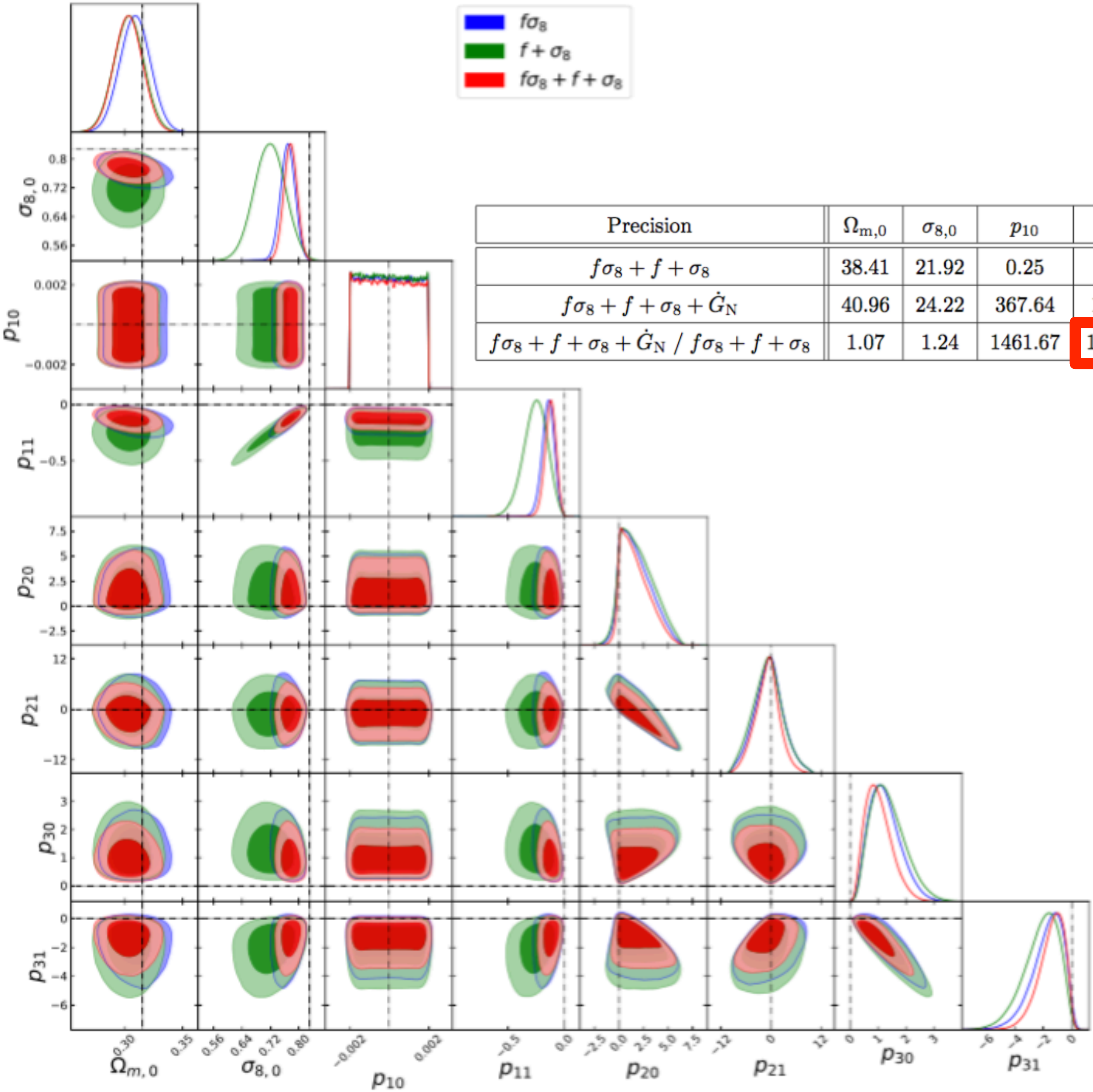

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Final constraints on EFT of DE couplings:

68% limits	p_{10}	p_{11}	p_{20}	p_{21}	p_{30}	p_{31}
$f\sigma_8 + f + \sigma_8$	$-6.643^{+3.686}_{-3.834}$	$23.888^{+13.998}_{-13.403}$	$-4.960^{+18.954}_{-20.924}$	$26.215^{+33.959}_{-37.211}$	$1.746^{3.699}_{-3.655}$	$13.838^{12.946}_{-12.241}$
$f\sigma_8 + f + \sigma_8 + \dot{G}_N$	$-0.000^{+0.002}_{-0.002}$	$-0.127^{+0.095}_{-0.096}$	$1.697^{+2.933}_{-2.157}$	$-0.926^{+5.852}_{-5.990}$	$1.022^{+0.930}_{-0.806}$	$-1.447^{+1.510}_{-1.812}$

Corresponding constraints on lensing observables:

$$\Sigma = \mu \frac{1+\gamma}{2}$$

	$\Omega_{m,0}$	$\sigma_{8,0}$	$\mu\,(z=0)$	$\Sigma\,(z=0)$	$\gamma\,(z=0)$
$f\sigma_8 + f + \sigma_8$	$0.320^{+0.026}_{-0.026}$	$0.789^{+0.042}_{-0.046}$	$1.575^{+1.021}_{-0.575}$	$0.925^{+0.344}_{-0.165}$	$0.240^{+0.615}_{-0.342}$
$f\sigma_8 + f + \sigma_8 + \dot{G}_N$	$0.303^{+0.024}_{-0.024}$	$0.776^{+0.036}_{-0.037}$	$1.321^{+0.370}_{-0.282}$	$1.321^{+0.371}_{-0.280}$	1.00000 ± 0.00093

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$$\mu_{ff} = 1.321^{+0.370}_{-0.284} \quad (95\%\ \text{c.l.})$$

Conclusions

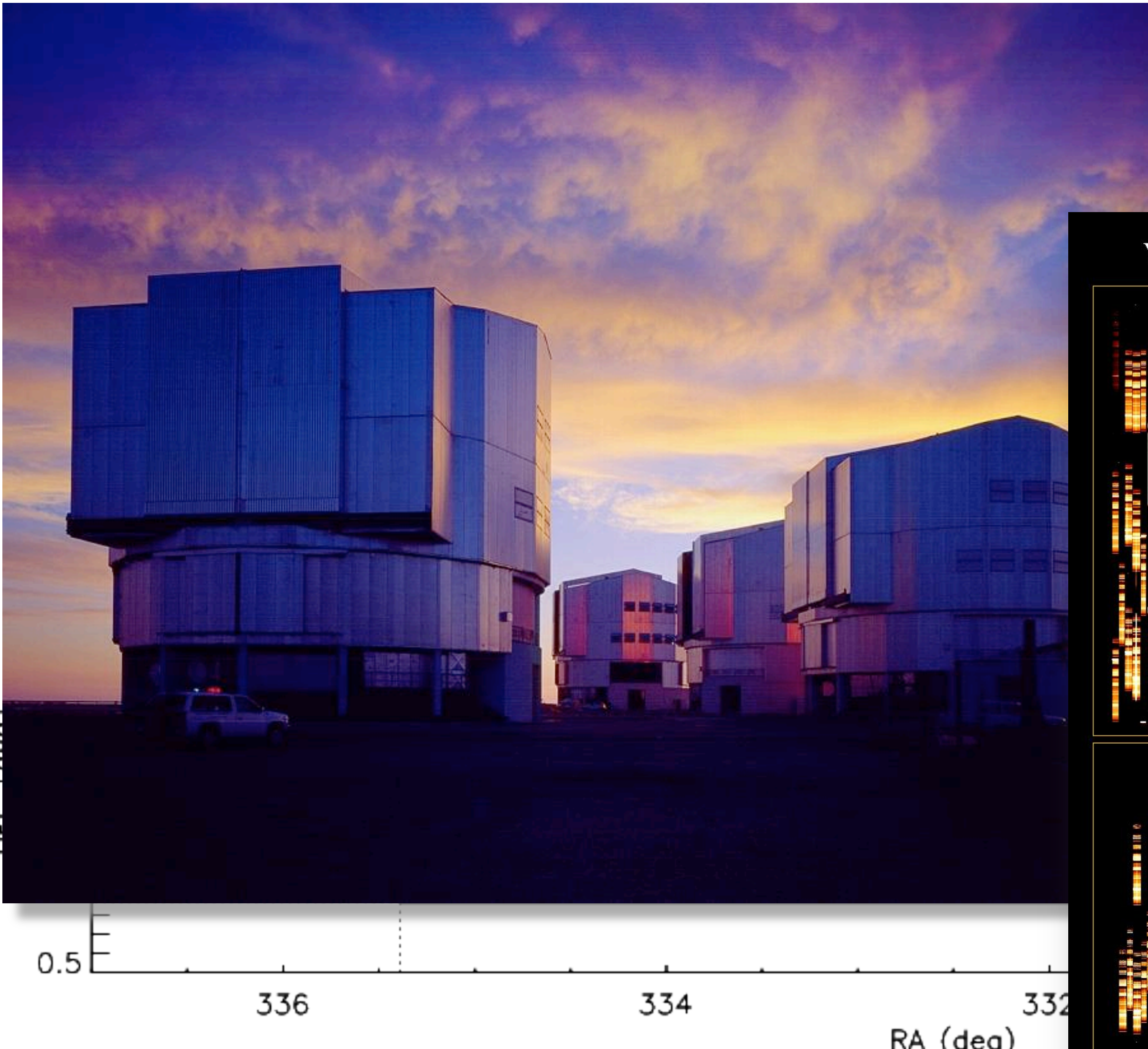
- Separate measurements of f and s8 improve by at least 20% the precision on EFT of DE parameters

- We use the splitting of the gravitational coupling in order to exhibit the strength of gravity across cosmic time

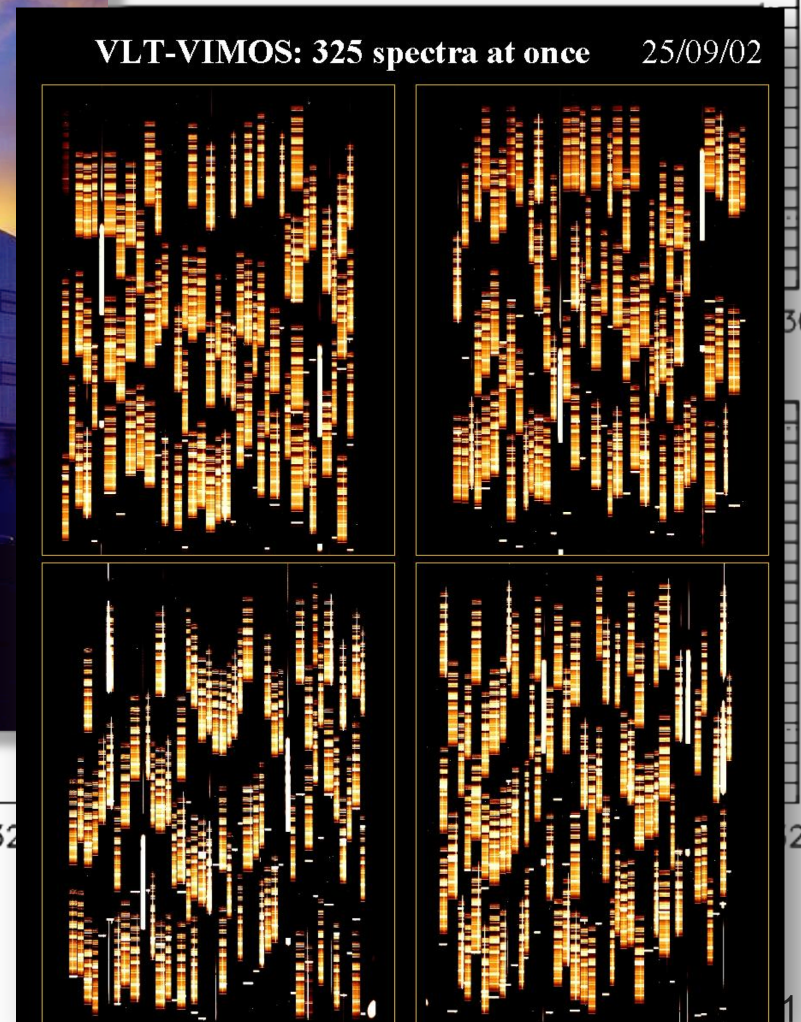
- Using the solar system prior, we showed that
    - The precision obtained from f+s8 increase by a factor of 10
    - The overall precision on the full sample increases by a factor of 4

- Growth of structure data are favouring a fifth force at 95% confidence level

5) VIPERS



Very Large Telescope (Chile)



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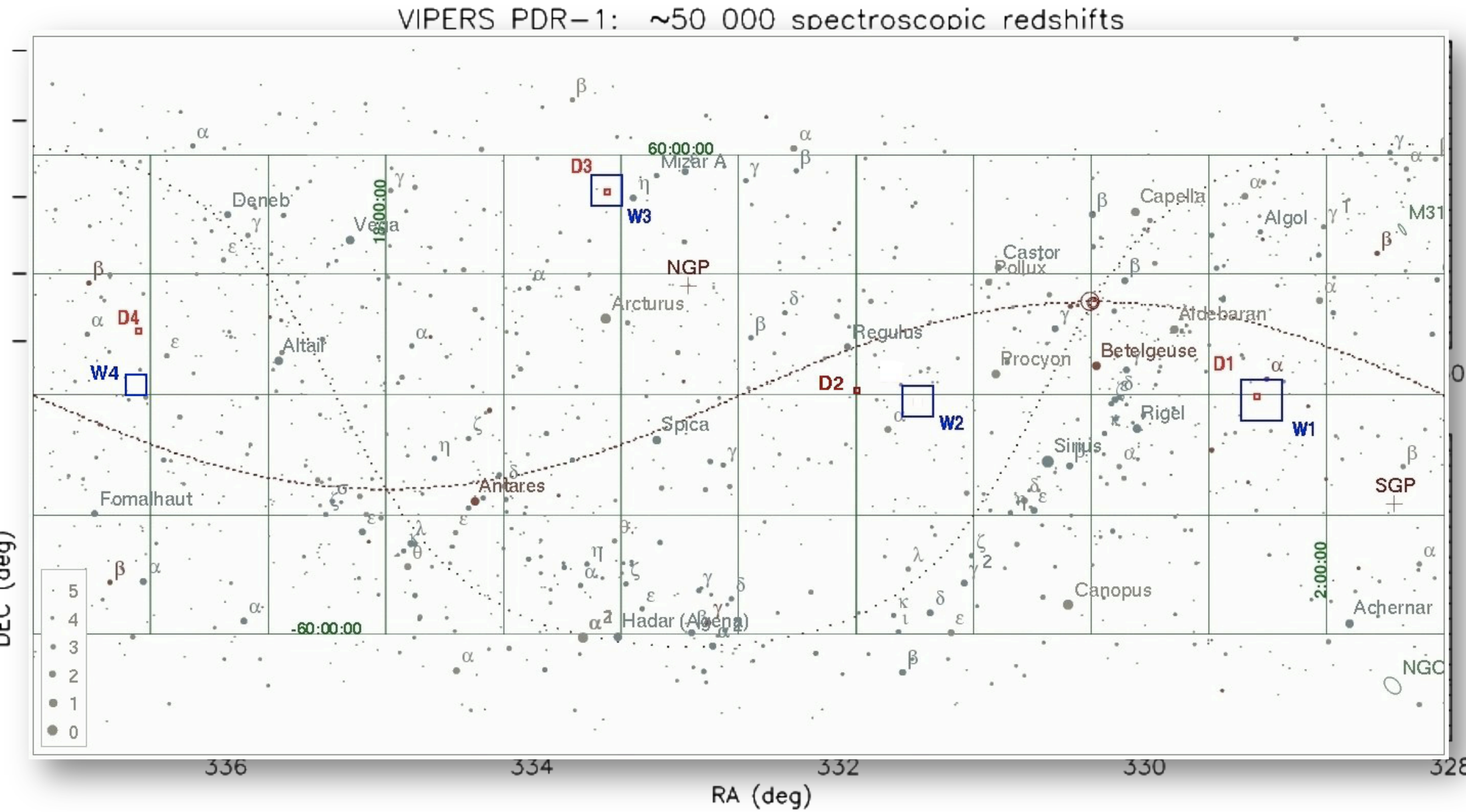

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