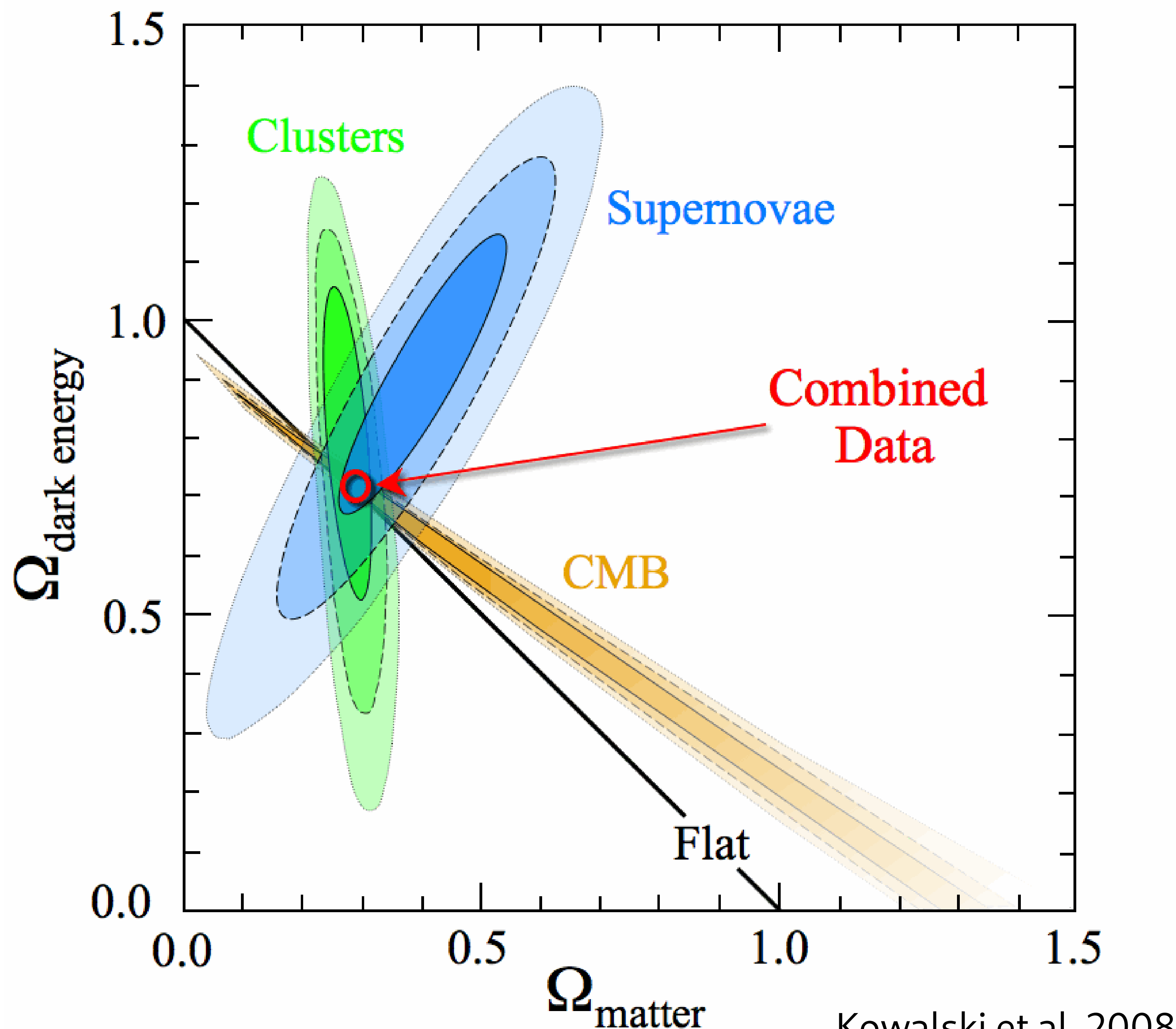
More than the sum of its parts: joint analysis of LSS and CMB experiments

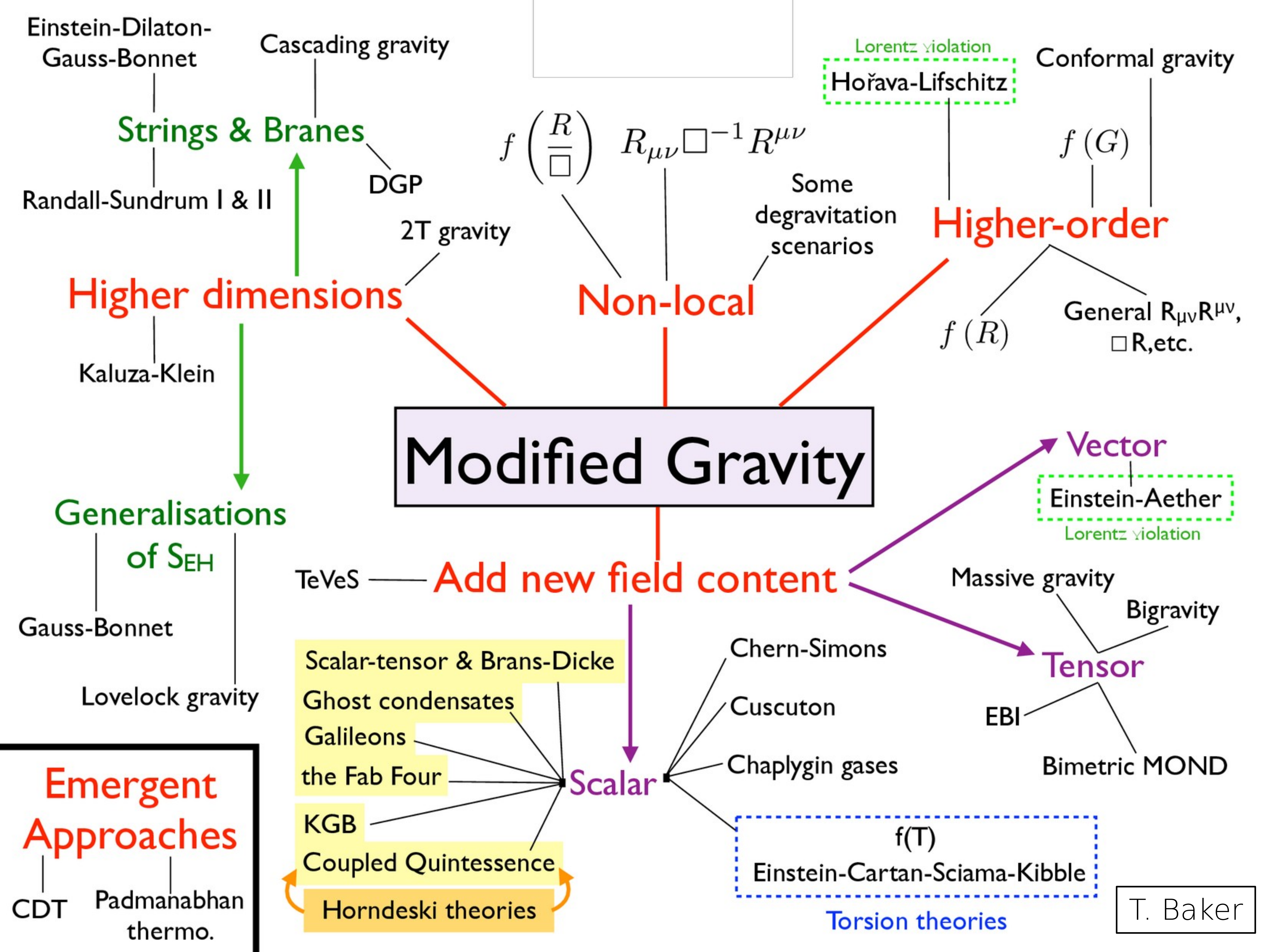
Stéphane Ilić
(IJCLab, France)

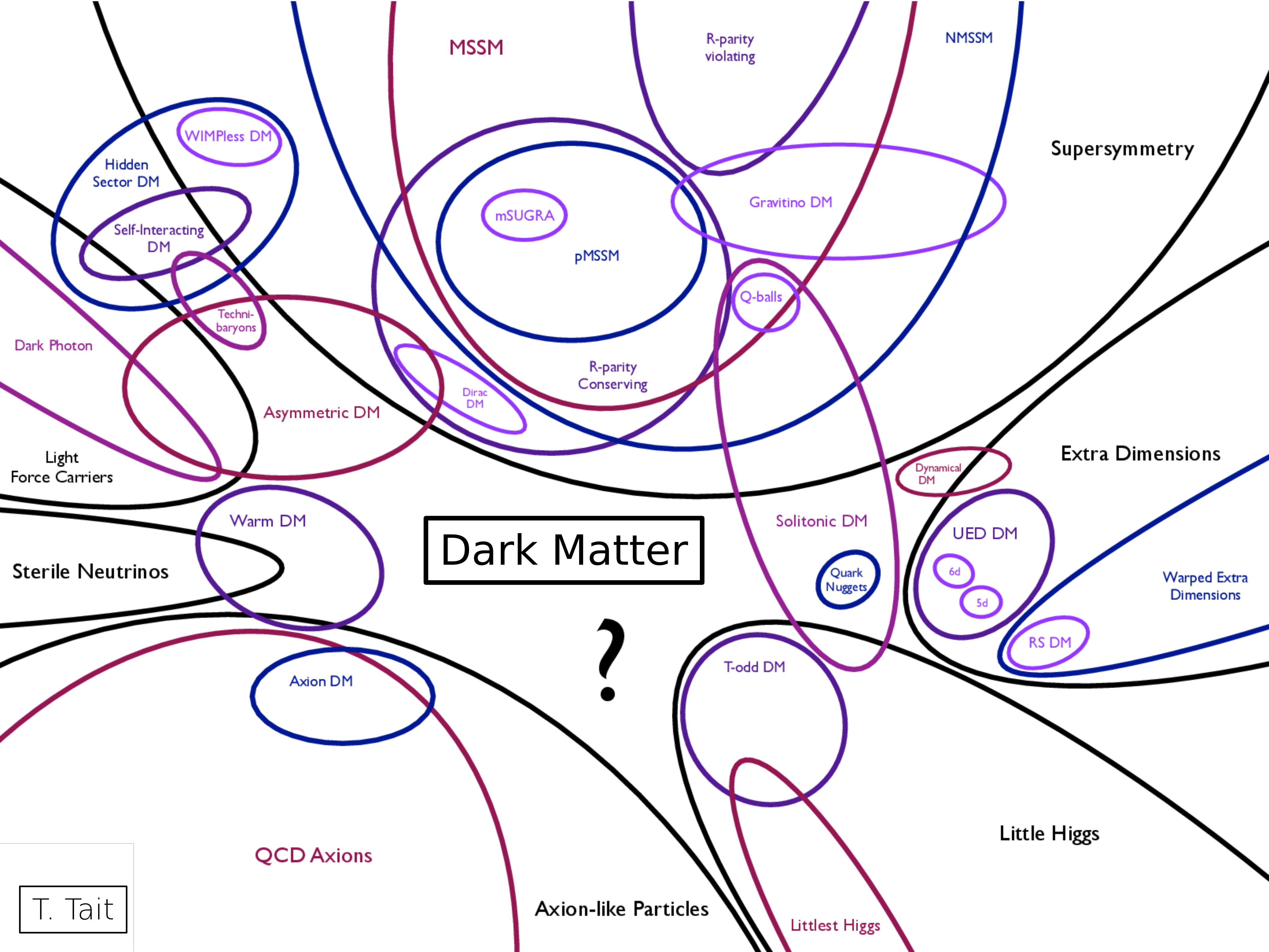
CMB France 2023 @ IAP, Paris, 04/12/2023

Motivating joint analyses



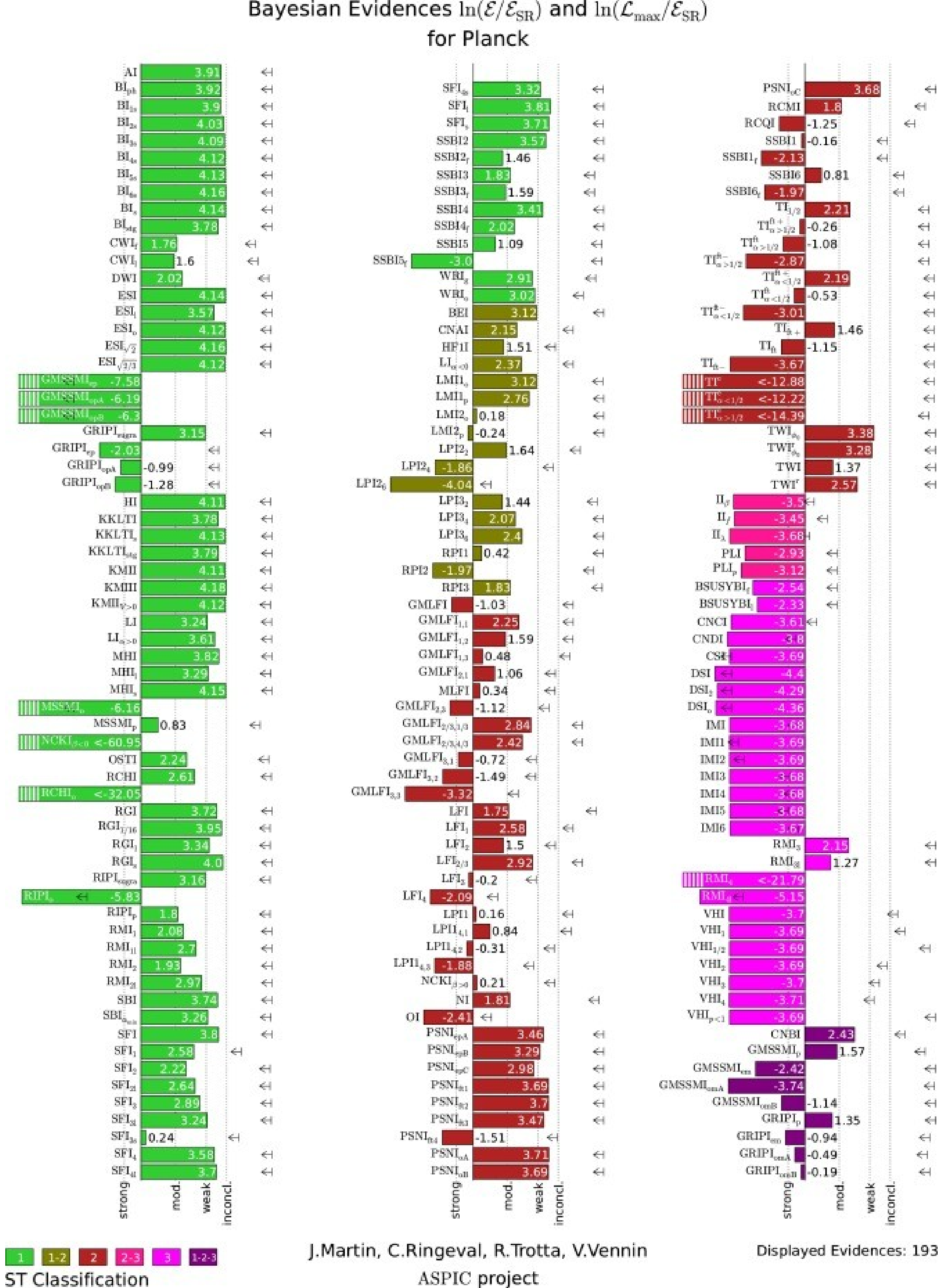
Kowalski et al. 2008

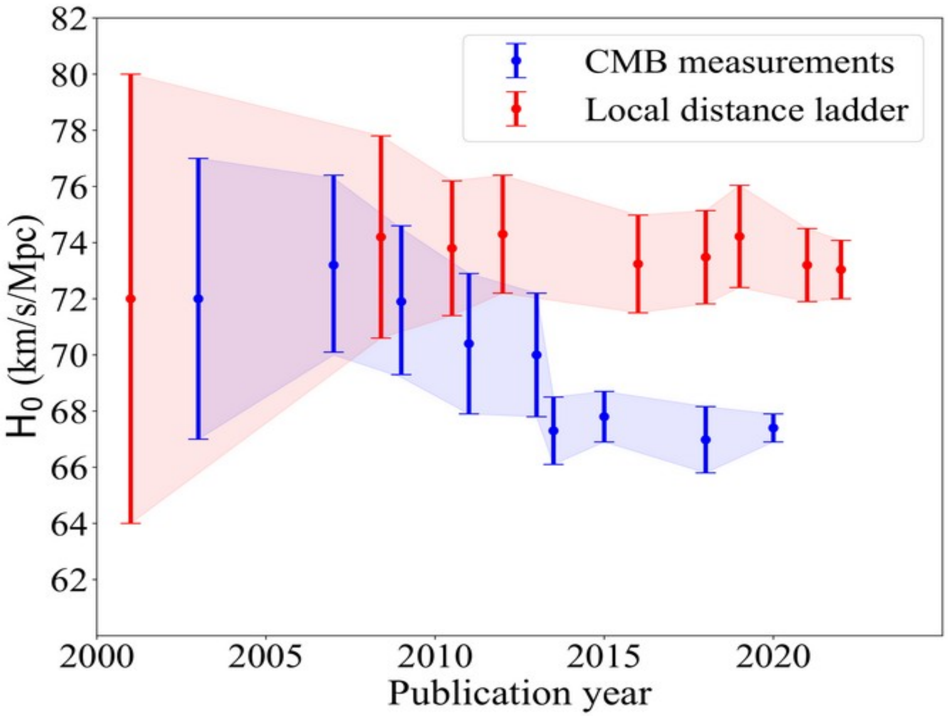

Einstein-Dilaton-Gauss-Bonnet
Cascading gravity
Strings & Branes
DGP
Randall-Sundrum I & II
2T gravity
Higher dimensions
Kaluza-Klein
$f\left(\frac{R}{\Box}\right)$
$R_{\mu\nu}\Box^{-1}R^{\mu\nu}$
Some degravitation scenarios
Non-local
Lorentz violation
Hořava-Lifschitz
Conformal gravity
$f(G)$
Higher-order
$f(R)$
General $R_{\mu\nu}R^{\mu\nu}$, $\Box R$, etc.
Modified Gravity
Vector
Einstein-Aether
Lorentz violation
Generalisations of S_{EH}
Gauss-Bonnet
Lovelock gravity
TeVeS
Add new field content
Massive gravity
Bigravity
Tensor
EBI
Bimetric MOND
Scalar-tensor & Brans-Dicke
Ghost condensates
Galileons
the Fab Four
KGB
Coupled Quintessence
Horndeski theories
Scalar
Chern-Simons
Cuscuton
Chaplygin gases
f(T)
Einstein-Cartan-Sciama-Kibble
Torsion theories
Emergent Approaches
CDT
Padmanabhan thermo.
T. Baker



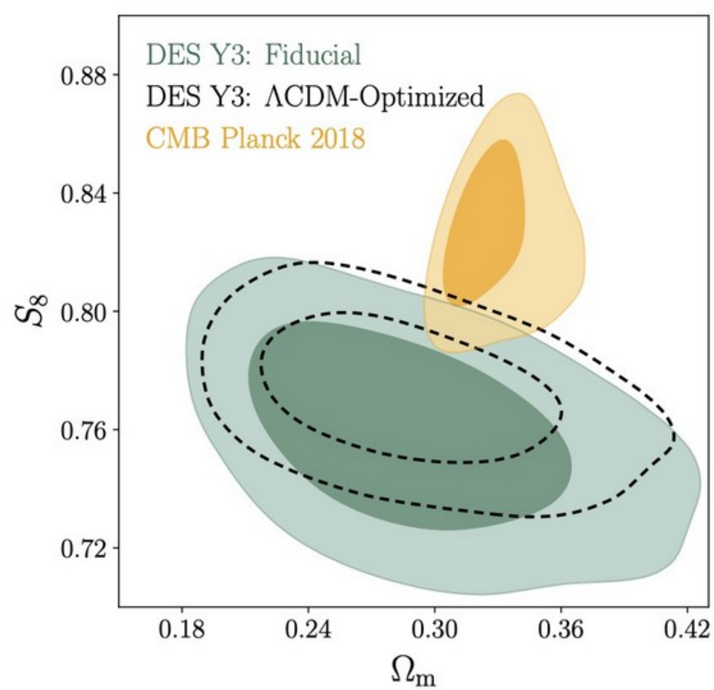
MSSM
R-parity
violating
NMSSM
Supersymmetry
WIMPless DM
Hidden
Sector DM
Self-Interacting
DM
Techni-
baryons
mSUGRA
pMSSM
Gravitino DM
Q-balls
R-parity
Conserving
Dirac
DM
Dark Photon
Asymmetric DM
Light
Force Carriers
Extra Dimensions
Dynamical
DM
Warm DM
Dark Matter
Solitonic DM
UED DM
Sterile Neutrinos
Quark
Nuggets
6d
5d
Warped Extra
Dimensions
RS DM
?
T-odd DM
Axion DM
Little Higgs
QCD Axions
Axion-like Particles
Littlest Higgs
T. Tait

Inflation models

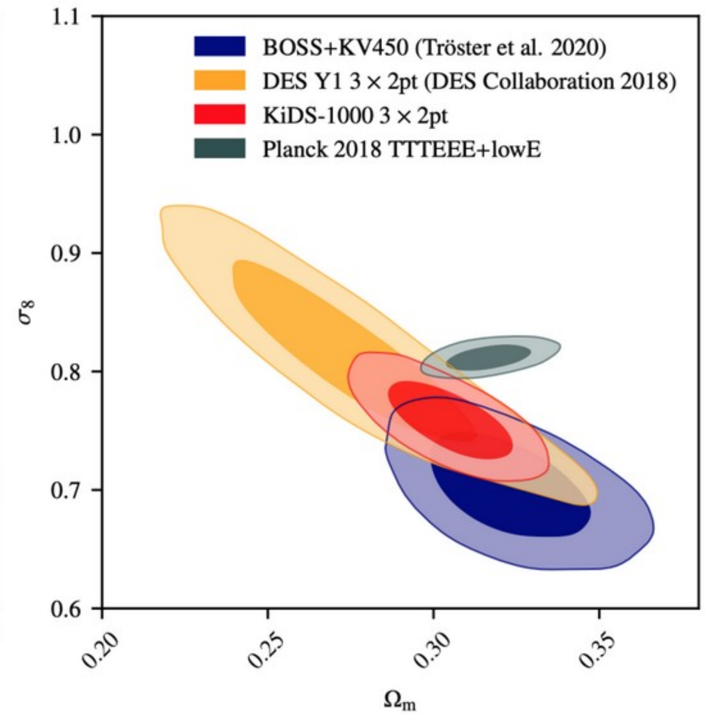




CMB measurements
Local distance ladder
H_0 (km/s/Mpc)
Publication year
82
80
78
76
74
72
70
68
66
64
62
2000
2005
2010
2015
2020



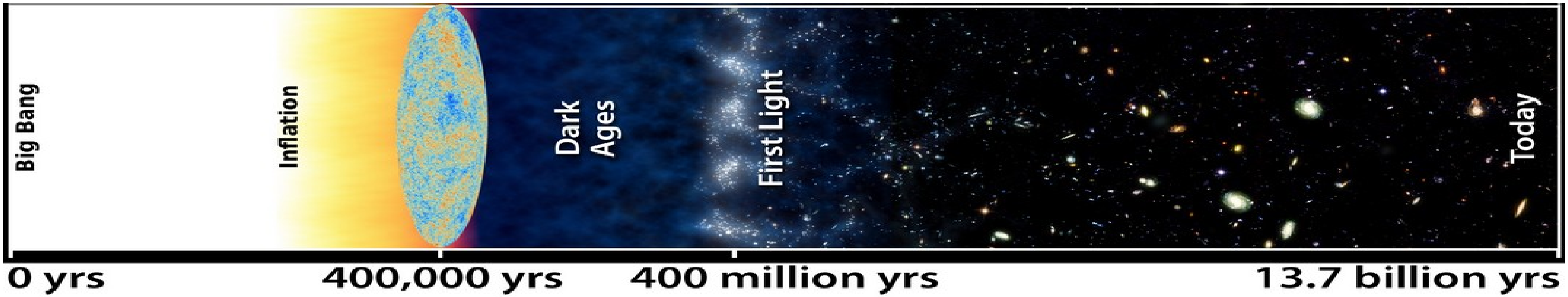
DES Y3: Fiducial
DES Y3: ΛCDM-Optimized
CMB Planck 2018
S_8
Ω_m
0.88
0.84
0.80
0.76
0.72
0.18
0.24
0.30
0.36
0.42



BOSS+KV450 (Tröster et al. 2020)
DES Y1 3 × 2pt (DES Collaboration 2018)
KiDS-1000 3 × 2pt
Planck 2018 TTTEEE+lowE
σ_8
Ω_m
1.1
1.0
0.9
0.8
0.7
0.6
0.20
0.25
0.30
0.35

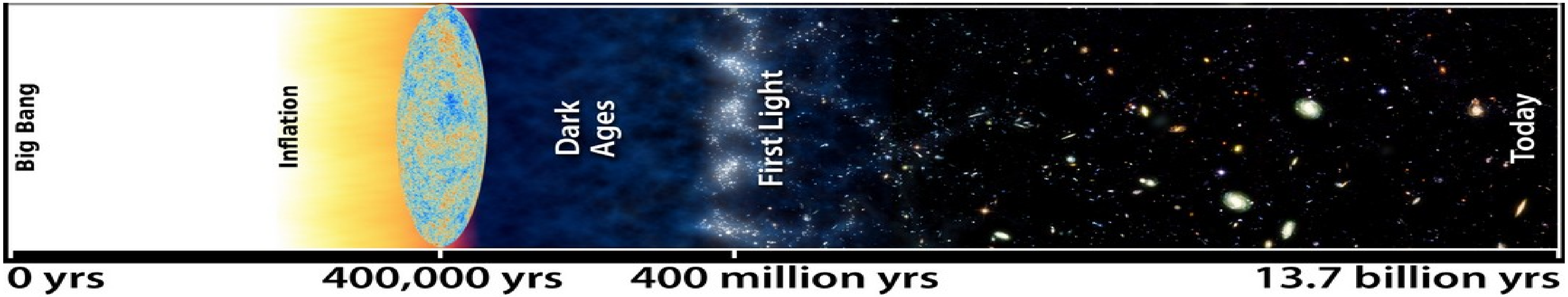
Choosing which observables to combine

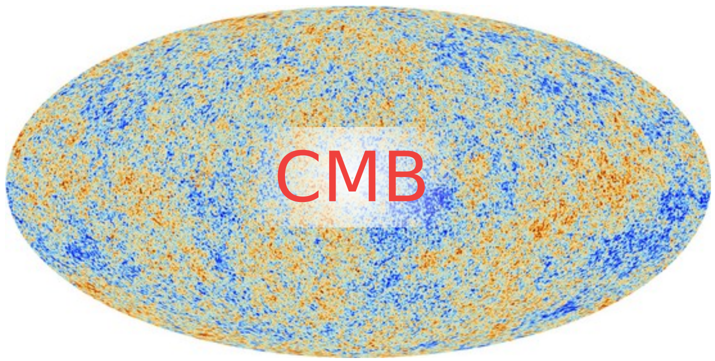
- Probes of different “sectors”:
  - Background evolution: all standard rulers/candles
  - Perturbations: probes of structure growth
- Probes of different epochs:

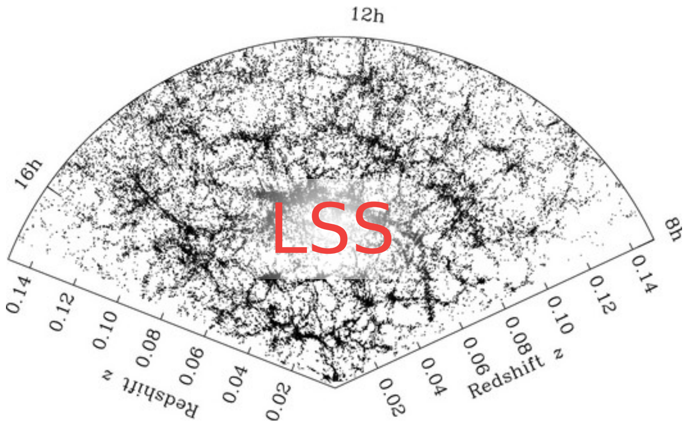


Choosing which observables to combine

- Probes of different "sectors":
  - Background evolution: all standard rulers/candles
  - Perturbations: probes of structure growth
- Probes of different epochs:

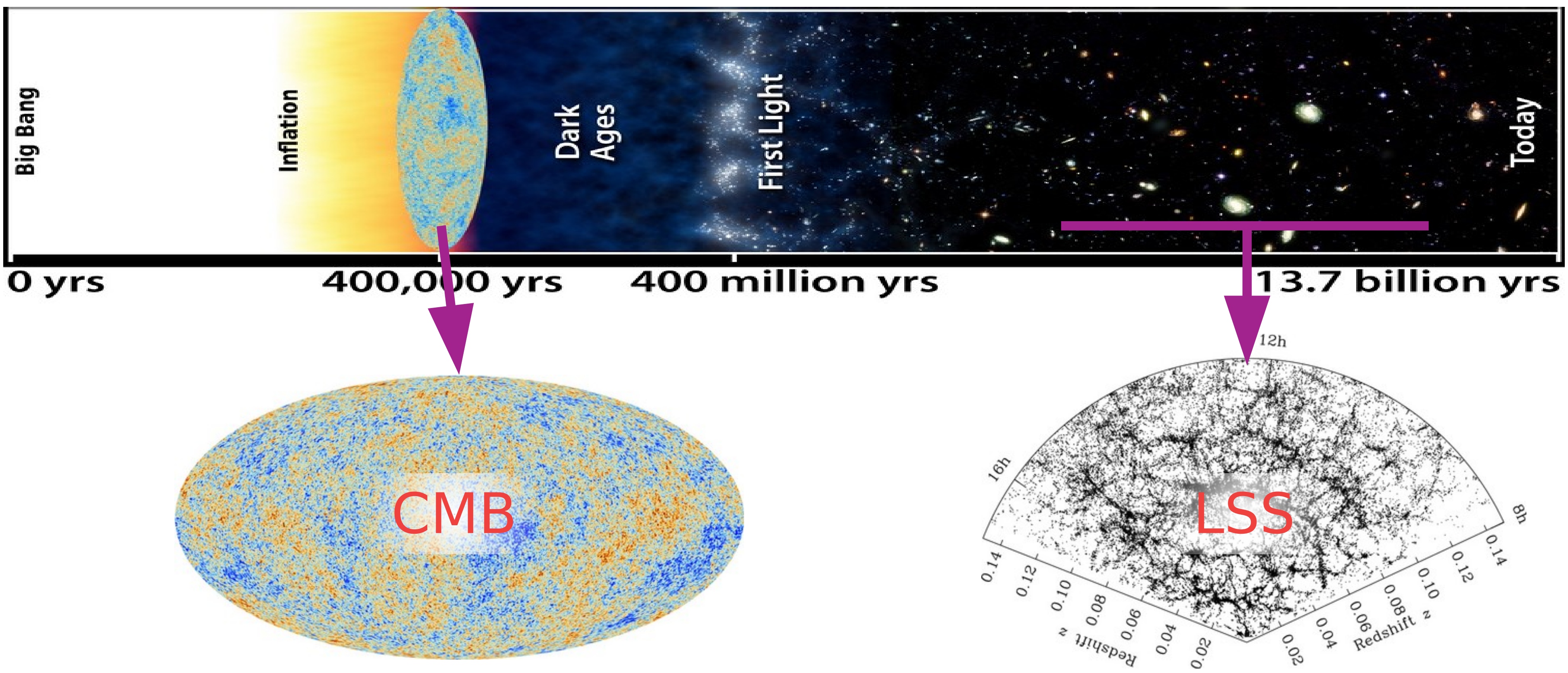






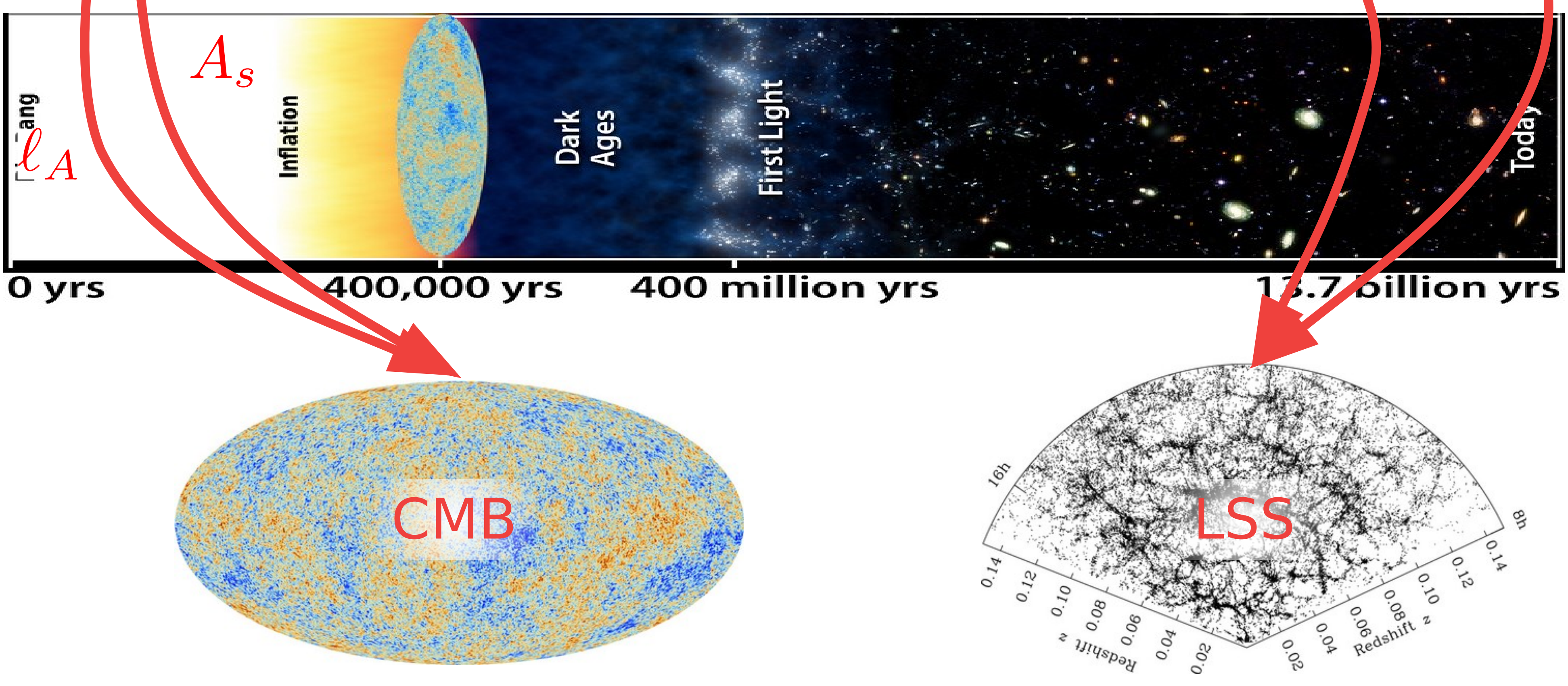
Choosing which observables to combine

- Probes of different "sectors":
  - Background evolution: all standard rulers/candles
  - Perturbations: probes of structure growth
- Probes of different epochs:

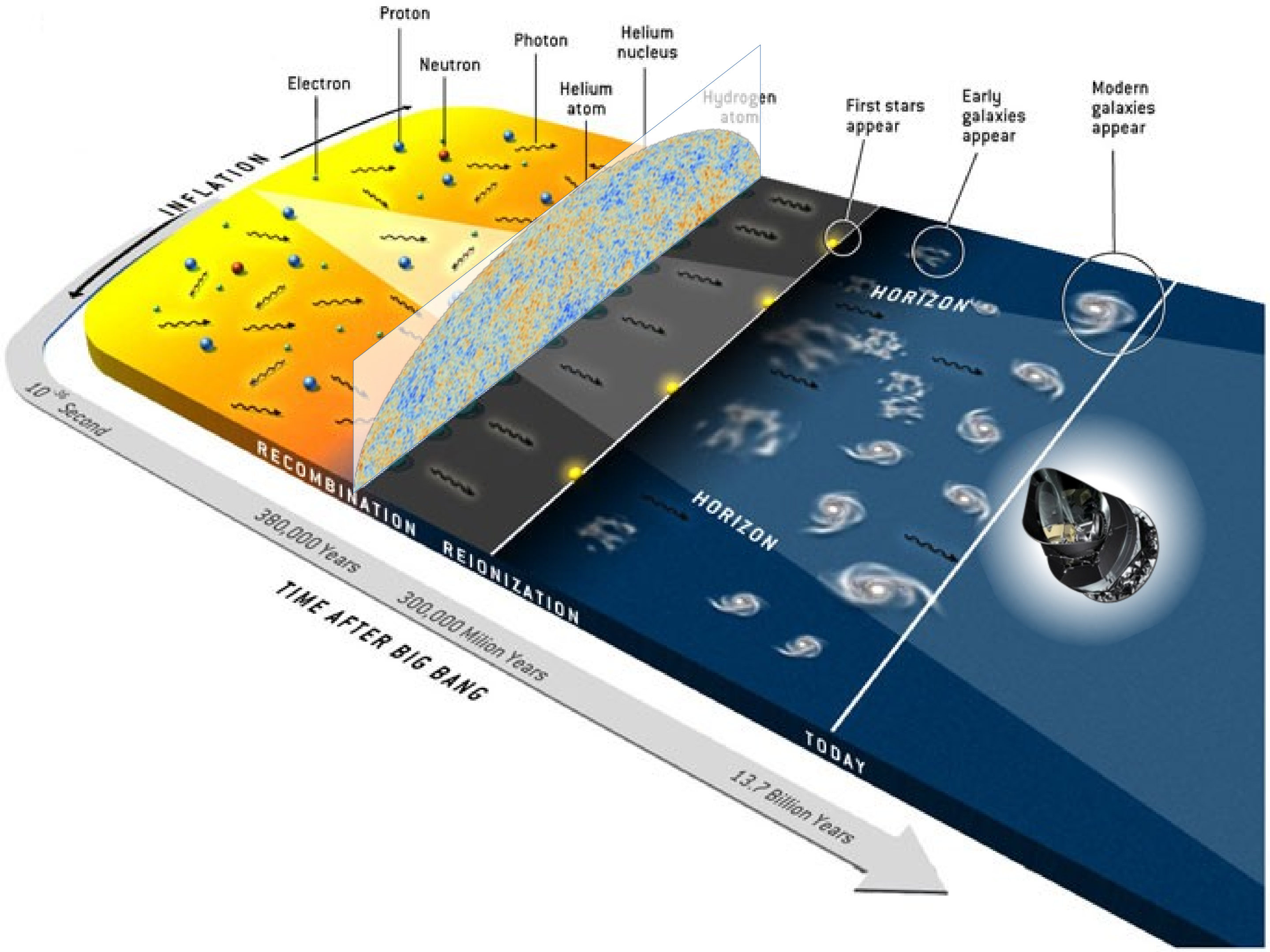


Choosing which observables to combine

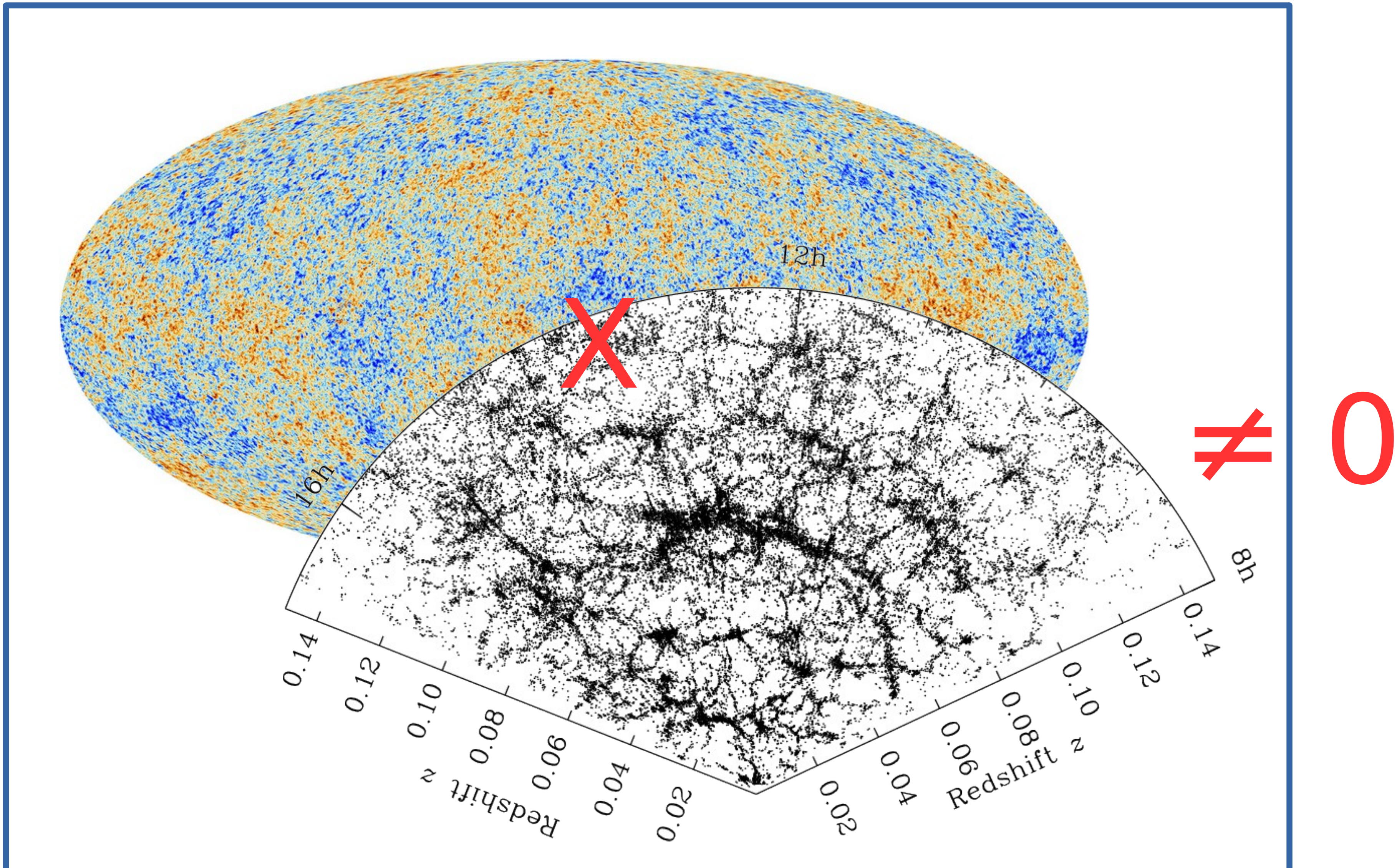
- Probes of different "sectors":
  - Background evolution: all standard rulers/candles
  - Perturbations: probes of structure growth
- Probes of different epochs:



CMB-LSS joint analysis



CMB-LSS joint analysis



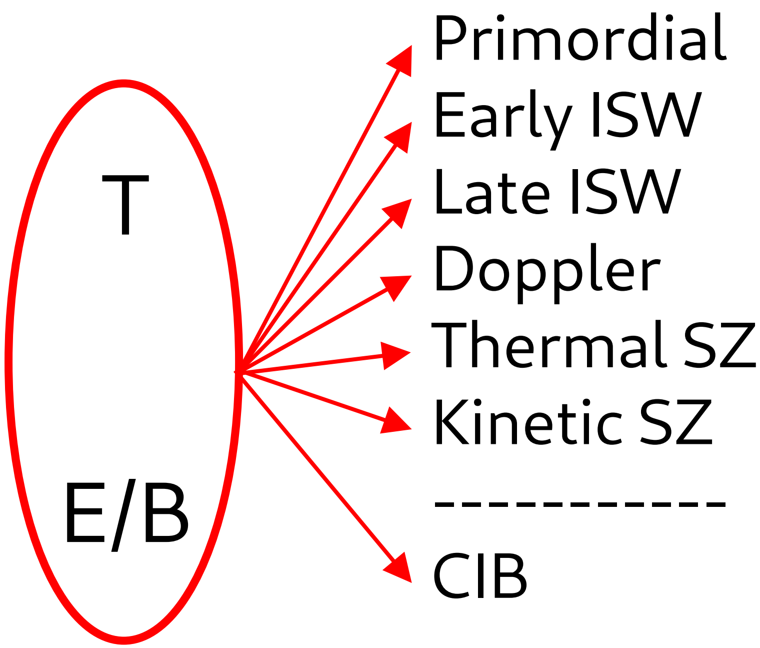
CMB-LSS joint analysis

"CMB"	"LSS"
T	Probes of matter (ρ & v)
E/B	
ϕ	Probes of grav. potential

CMB-LSS joint analysis

"CMB"

"LSS"

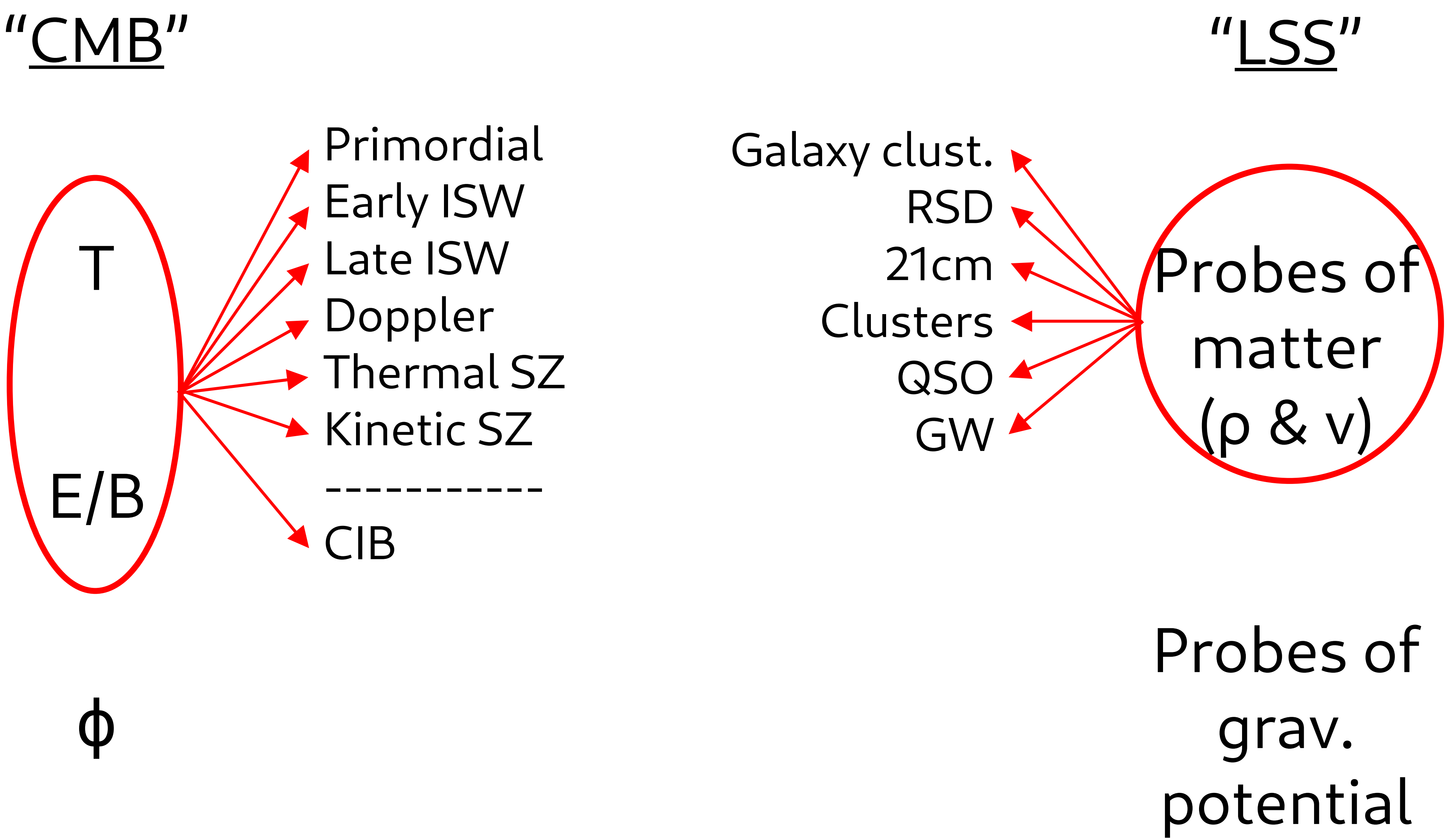


ϕ

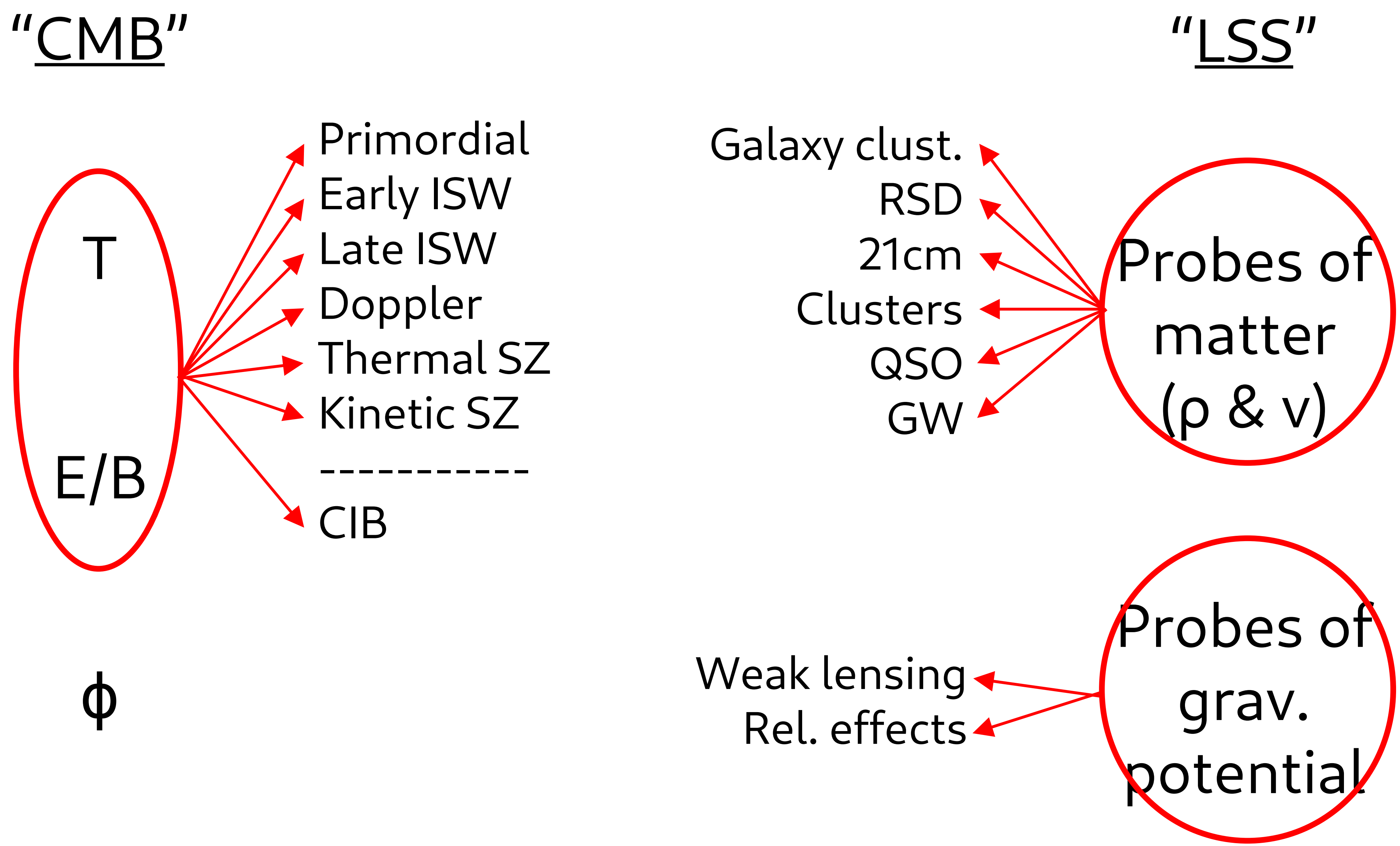
Probes of matter (ρ & v)

Probes of grav. potential

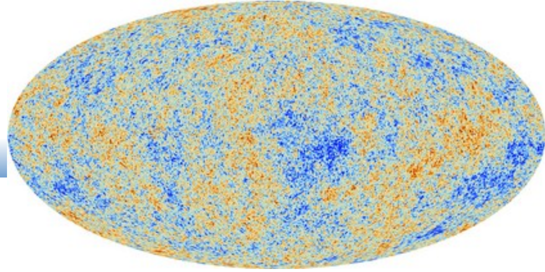
CMB-LSS joint analysis

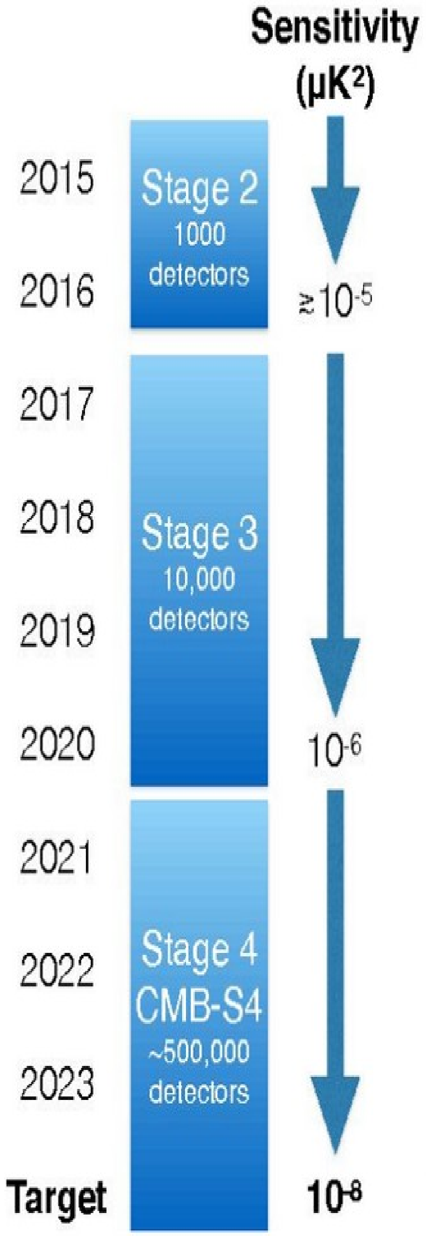


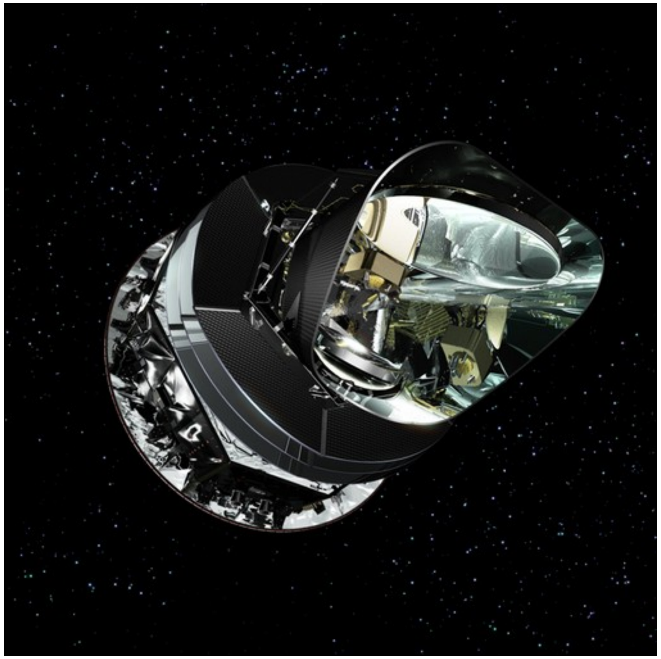
CMB-LSS joint analysis

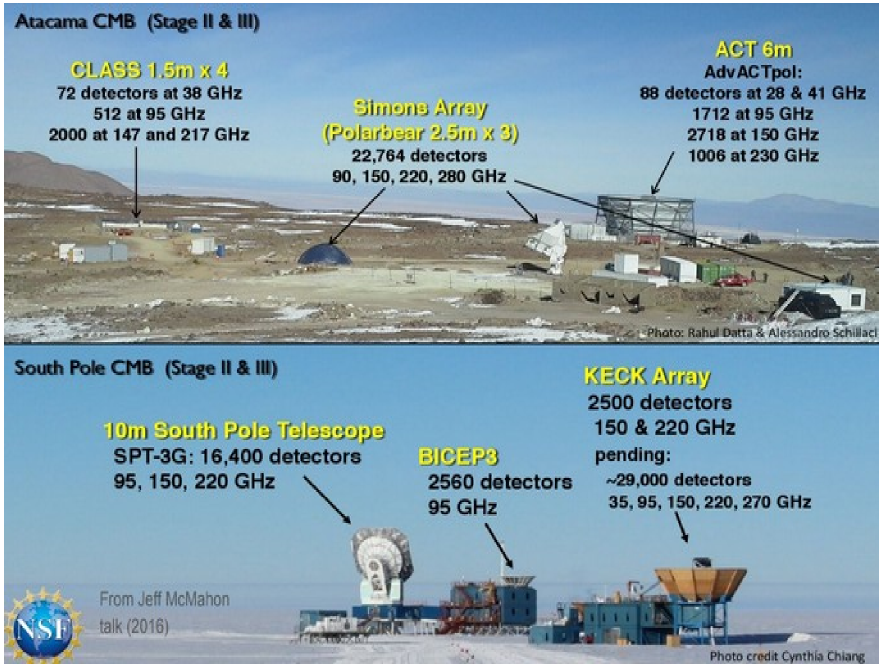


Available & upcoming surveys





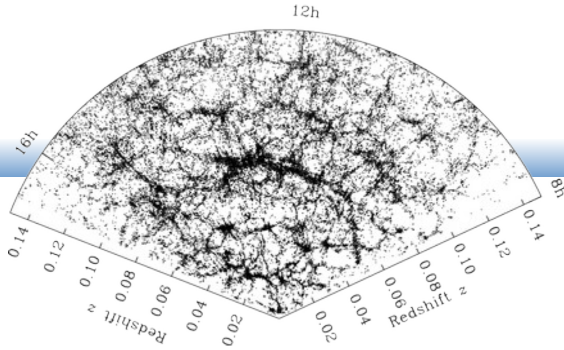




<u>Future:</u>

- Simons Observatory
- CMB Stage-4
- LiteBIRD

Available & upcoming surveys



<u>DETF classification:</u>

- Stage II: SDSS, KiDS, ...
- Stage III: DES, ...
- Stage IV: DESI, LSST, <u>Euclid</u>

+ 21cm, GW, ...

The Euclid CMBX forecasts paper

Ilic et al. 2022, A&A, arXiv:2106.08346

Astronomy & Astrophysics manuscript no. main
September 13, 2021
©ESO 2021

Euclid preparation: XV. Forecasting cosmological constraints for the *Euclid* and CMB joint analysis

Euclid Collaboration: S. Ilić[1,2,3]★, N. Aghanim[4], C. Baccigalupi[5,6,7,8], J.R. Bermejo-Climent[9,10,11], G. Fabbian[12,114], L. Legrand[4,13], D. Paoletti[10,14], M. Ballardini[10,11,15], M. Archidiacono[16,17], M. Douspis[4], F. Finelli[10,11], K. Ganga[18], C. Hernández-Monteagudo[9,19,20], M. Lattanzi[21], D. Marinucci[22], M. Migliaccio[22,23], C. Carbone[24], S. Casas[25], M. Martinelli[26], I. Tutusaus[3,27,28], P. Natoli[21,29], P. Ntelis[30], L. Pagano[29], L. Wenzl[31], A. Gruppuso[10,14], T. Kitching[32], M. Langer[4], N. Mauri[14,33], L. Patrizii[14], A. Renzi[34,35], G. Sirri[14], L. Stanco[34], M. Tenti[14], P. Vielzeuf[5,6], F. Lacasa[4], G. Polenta[36], V. Yankelevich[37], A. Blanchard[3], Z. Sakr[3,38], A. Pourtsidou[39], S. Camera[40,41], V.F. Cardone[42,43], M. Kilbinger[25], M. Kunz[13], K. Markovic[44], V. Pettorino[25], A.G. Sánchez[45], D. Sapone[46], A. Amara[47], N. Auricchio[10], R. Bender[45,48], C. Bodendorf[45], D. Bonino[49], E. Branchini[43,50,51], M. Brescia[52], J. Brinchmann[53,54], V. Capobianco[49], J. Carretero[55], F.J. Castander[27,28], M. Castellano[43], S. Cavuoti[52,56,57], A. Cimatti[58,59], R. Cledassou[60,61], G. Congedo[62], C.J. Conselice[63], L. Conversi[64,65], Y. Copin[66], L. Corcione[49], A. Costille[67], M. Cropper[32], A. Da Silva[68,69], H. Degaudenzi[70], F. Dubath[70], C.A.J. Duncan[71], X. Dupac[65], S. Dusini[34], A. Ealet[66], S. Farrens[25], P. Fosalba[27,28], M. Frailis[8], E. Franceschi[10], P. Franzetti[24], M. Fumana[24], B. Garilli[24], W. Gillard[30], B. Gillis[62], C. Giocoli[72,73], A. Grazian[74], F. Grupp[45,48], L. Guzzo[16,17,75], S.V.H. Haugan[76], H. Hoekstra[77], W. Holmes[44], F. Hormuth[78,79], P. Hudelot[80], K. Jahnke[79], S. Kermiche[30], A. Kiessling[44], R. Kohley[65], B. Kubik[66], M. Kümmel[48], H. Kurki-Suonio[81], R. Laureijs[82], S. Ligori[49], P. B. Lilje[76], I. Lloro[83], O. Mansutti[8], O. Marggraf[84], F. Marulli[10,14,58], R. Massey[85], S. Maurogordato[86], M. Meneghetti[10,14,87], E. Merlin[43], G. Meylan[88], M. Moresco[10,58], B. Morin[25], L. Moscardini[10,11,58], E. Munari[8], S.M. Niemi[82], C. Padilla[55], S. Paltani[70], F. Pasian[8], K. Pedersen[89], W. Percival[90,91,92], S. Pires[25], M. Poncet[61], L. Popa[93], L. Pozzetti[10], F. Raison[45], R. Rebolo[9,19], J. Rhodes[44], M. Roncarelli[10,58], E. Rossetti[58], R. Saglia[45,48], R. Scaramella[42,43], P. Schneider[84], A. Secroun[30], G. Seidel[79], S. Serrano[27,28], C. Sirignano[34,35], J.L. Starck[25], P. Tallada-Crespí[94], A.N. Taylor[62], I. Tereno[68,95], R. Toledo-Moreo[96], F. Torradeflot[55,94], E.A. Valentijn[97], L. Valenziano[10,14], G.A. Verdoes Kleijn[97], Y. Wang[98], N. Welikala[62], J. Weller[45,48], G. Zamorani[10], J. Zoubian[30], E. Medinaceli[72], S. Mei[18], C. Rosset[18], F. Sureau[25], T. Vassallo[48], A. Zacchei[8], S. Andreon[75], A. Balaguera-Antolínez[9,19], M. Baldi[10,14,15], S. Bardelli[10], A. Biviano[5,8], S. Borgani[5,7,8,99], E. Bozzo[70], C. Burigana[11,29,100], R. Cabanac[3], A. Cappi[10,86], C.S. Carvalho[95], G. Castignani[58], C. Colodro-Conde[19], J. Coupon[70], H.M. Courtois[101], J. Cuby[67], S. de la Torre[67], D. Di Ferdinando[14], H. Dole[4], M. Farina[102], P.G. Ferreira[71], P. Flose-Reimberg[80], S. Galeotta[8], G. Gozaliasl[103,104], J. Graciá-Carpio[45], E. Keihanen[104], C.C. Kirkpatrick[81], V. Lindholm[104,105], G. Mainetti[106], D. Maino[16,17,24], N. Martinet[67], M. Maturi[107,108], R.B. Metcalf[10,15], G. Morgante[10], C. Neissner[55], J. Nightingale[85], A.A. Nucita[109,110], D. Potter[111], G. Riccio[52], E. Romelli[8], M. Schirmer[79], M. Schultheis[86], V. Scottez[80], R. Teyssier[111], A. Tramacere[70], J. Valiviita[105,112], M. Viel[5,6,7,8], L. Whittaker[63,113], E. Zucca[10]

(Affiliations can be found after the references)

ABSTRACT

The combination and cross-correlation of the upcoming *Euclid* data with cosmic microwave background (CMB) measurements is a source of great expectation since it will provide the largest lever arm of epochs, ranging from recombination to structure formation across the entire past light cone. In this work, we present forecasts for the joint analysis of *Euclid* and CMB data on the cosmological parameters of the standard cosmological model and some of its extensions. This work expands and complements the recently published forecasts based on *Euclid*-specific probes, namely galaxy clustering, weak lensing, and their cross-correlation. With some assumptions on the specifications of current and future CMB experiments, the predicted constraints are obtained from both a standard Fisher formalism and a posterior-fitting approach based on actual CMB data. Compared to a *Euclid*-only analysis, the addition of CMB data leads to a substantial impact on constraints for all cosmological parameters of the standard Λ-cold-dark-matter model, with improvements reaching up to a factor of ten. For the parameters of extended models, which include a redshift-dependent dark energy equation of state, non-zero curvature, and a phenomenological modification of gravity, improvements can be of the order of two to three, reaching higher than ten in some cases. The results highlight the crucial importance for cosmological constraints of the combination and cross-correlation of *Euclid* probes with CMB data.

Key words. Cosmology:large-scale structure of Universe, cosmic background radiation, Surveys, Methods: statistical

The Euclid CMBX forecasts paper

Ilic et al. 2022, A&A, arXiv:2106.08346

Astronomy & Astrophysics manuscript no. main
September 13, 2021

©ESO 2021

Objectives:

- Forecast the cosmological potential of the Euclid x CMB combined analysis
- Basis for the future of forecasts in Euclid and the development of the cosmological pipeline

ABSTRACT

The combination and cross-correlation of the upcoming *Euclid* data with cosmic microwave background (CMB) measurements is a source of great expectation since it will provide the largest lever arm of epochs, ranging from recombination to structure formation across the entire past light cone. In this work, we present forecasts for the joint analysis of *Euclid* and CMB data on the cosmological parameters of the standard cosmological model and some of its extensions. This work expands and complements the recently published forecasts based on *Euclid*-specific probes, namely galaxy clustering, weak lensing, and their cross-correlation. With some assumptions on the specifications of current and future CMB experiments, the predicted constraints are obtained from both a standard Fisher formalism and a posterior-fitting approach based on actual CMB data. Compared to a *Euclid*-only analysis, the addition of CMB data leads to a substantial impact on constraints for all cosmological parameters of the standard Λ-cold-dark-matter model, with improvements reaching up to a factor of ten. For the parameters of extended models, which include a redshift-dependent dark energy equation of state, non-zero curvature, and a phenomenological modification of gravity, improvements can be of the order of two to three, reaching higher than ten in some cases. The results highlight the crucial importance for cosmological constraints of the combination and cross-correlation of *Euclid* probes with CMB data.

Key words. Cosmology:large-scale structure of Universe, cosmic background radiation, Surveys, Methods: statistical

Summary of content

- Fisher matrix-based forecasts
- 2 “scientific cases”

Observables considered

Case n°0 (“3x2 pt”)

	T	E	B	P	D	L
T	tt	te	tb	tp	td	tl
	✗	✗	✗✗	✗	✗	✗
E		ee	eb	ep	ed	el
		✗	✗✗	✗	✗	✗
B			bb	bp	bd	bl
			✗✗	✗✗	✗✗	✗✗
P				pp	pd	pl
(CMB lens.)				✗	✗	✗
D					dd	dl
(Gal. Clus.)					✓	✓
L						ll
(Weak Lens.)						✓

+ Gal. Clus. Spec.

Euclid only (=IST:F)

Observables considered

Case n°1 (“6x2 pt”)

	T	E	B	P	D	L
T	tt	te	tb	tp	td	tl
	✗	✗	✗✗	✗	✗	✗
E		ee	eb	ep	ed	el
		✗	✗✗	✗	✗	✗
B			bb	bp	bd	bl
			✗✗	✗✗	✗✗	✗✗
P				pp	pd	pl
(CMB lens.)				✓	✓	✓
D					dd	dl
(Gal. Clus.)					✓	✓
L						ll
(Weak Lens.)						✓

+ Gal. Clus. Spec.

All “matter” probes and
their cross-correlations

Observables considered

Case n°2 ("15x2 pt")

	T	E	B	P	D	L
T	tt	te	tb	tp	td	tl
	✔✔	✔✔	✖✖	✔✔	✔✔	✔✔
E		ee	eb	ep	ed	el
		✔✔	✖✖	✔✔	✔✔	✔✔
B			bb	bp	bd	bl
			✖✖	✖✖	✖✖	✖✖
P				pp	pd	pl
(CMB lens.)				✔	✔	✔
D					dd	dl
(Gal. Clus.)					✔	✔
L						ll
(Weak Lens.)						✔

+ Gal. Clus. Spec.

All CMB x Euclid probes & correlations

Summary of content

- Fisher matrix-based forecasts
- 2 “scientific cases” (Euclid×CMB ϕ, Euclid×CMB T/E/ϕ)

Summary of content

- Fisher matrix-based forecasts
- 2 “scientific cases” (Euclid×CMB ϕ, Euclid×CMB T/E/ϕ)
- 6 cosmological models (flat/non-flat, Λ/$\{w_0,w_a\}$, gamma)
- 10 cosmological parameters + 8/13 nuisance parameters
- 2 sets of Euclid specifications (pessimistic, optimistic)
- 3 scenarios for CMB experiments (Planck, SO, CMB-S4)

Companion to InterScience Taskforce (IST:F) forecasts paper (arXiv:1910.09273), identical recipes for Euclid observables

Results: focus on pessimistic Euclid + SO

From Euclid only to Euclid×CMB ϕ

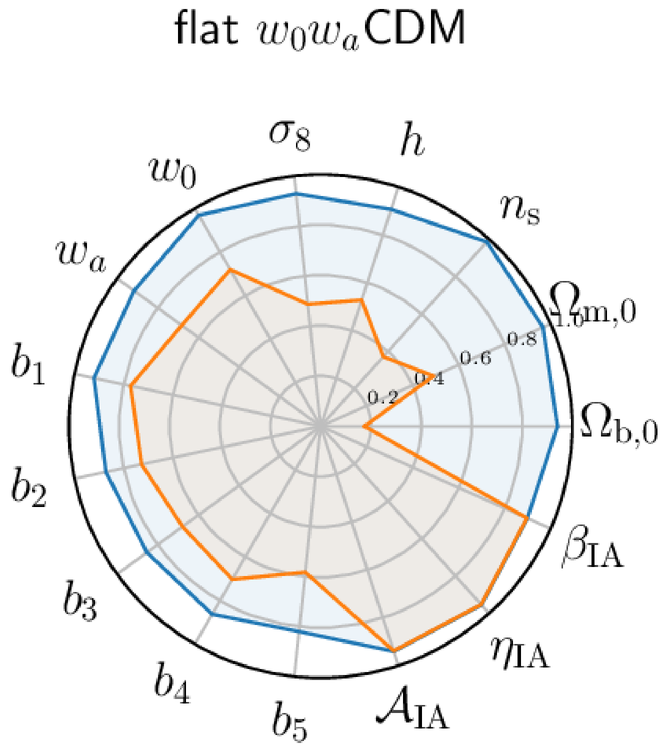
	$\Omega_{b,0}$	$\Omega_{m,0}$	n_s	h	σ_8	τ	w_0	w_a	$\Omega_{DE,0}$	γ	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	A_{IA}	η_{IA}	β_{IA}
Pessimistic Euclid + SO, flat ΛCDM	1.0	1.0	1.0	1.0	1.1						1.0	1.1	1.0	1.0	1.1						1.1	1.0	1.1
non-flat ΛCDM	1.0	1.0	1.0	1.0	1.0				1.2		1.0	1.0	1.0	1.0	1.0						1.1	1.0	1.1
flat $w_0 w_a$CDM	1.1	1.0	1.0	1.1	1.1		1.0	1.1			1.1	1.1	1.2	1.2	1.2						1.1	1.0	1.1
non-flat $w_0 w_a$CDM	1.0	1.0	1.0	1.1	1.0		1.1	1.7	2.6		1.1	1.1	1.0	1.0	1.0						1.1	1.0	1.1
flat $w_0 w_a \gamma$CDM	1.0	1.0	1.0	1.0	1.0		1.0	1.1		1.2	1.1	1.2	1.3	1.2	1.3						1.1	1.0	1.1
non-flat $w_0 w_a \gamma$CDM	1.0	1.1	1.0	1.0	1.1		1.0	1.7	2.0	1.2	1.1	1.0	1.0	1.0	1.0						1.1	1.0	1.1

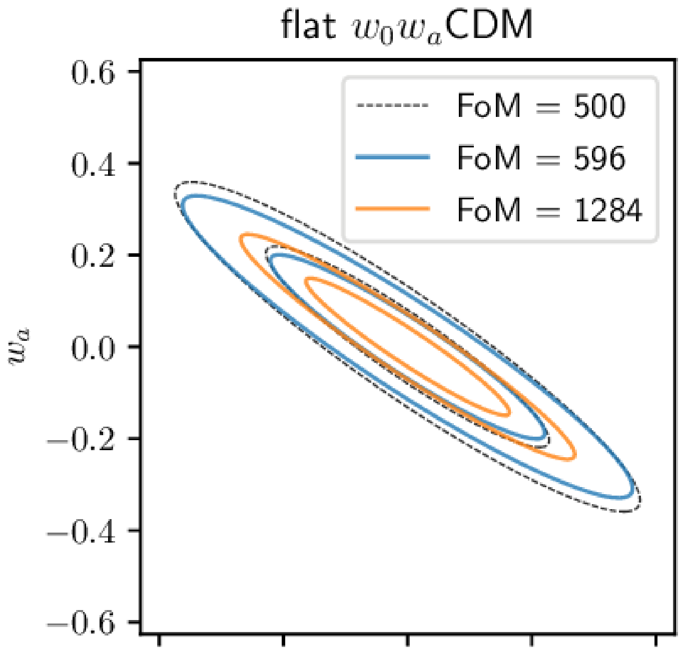
From Euclid only to Euclid×Euclid×CMB T/E/ϕ

	$\Omega_{b,0}$	$\Omega_{m,0}$	n_s	h	σ_8	τ	w_0	w_a	$\Omega_{DE,0}$	γ	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	A_{IA}	η_{IA}	β_{IA}
Pessimistic Euclid + SO, flat ΛCDM	7.8	1.6	2.7	2.9	1.6	2.3					1.5	1.4	1.3	1.2	1.3						1.1	1.0	1.1
non-flat ΛCDM	6.1	1.7	2.3	2.3	1.8	1.2			4.6		1.9	2.0	2.0	1.8	2.3						1.1	1.0	1.1
flat $w_0 w_a$CDM	5.7	2.0	2.7	1.9	2.1	1.6	1.4	1.5			1.3	1.4	1.5	1.4	1.7						1.1	1.0	1.1
non-flat $w_0 w_a$CDM	6.1	2.2	2.4	2.0	2.4	1.7	1.5	2.3	8.7		1.6	1.5	1.5	1.5	1.6						1.1	1.1	1.1
flat $w_0 w_a \gamma$CDM	7.0	2.7	2.8	1.9	2.3	1.6	1.4	1.4		1.7	1.3	1.4	1.5	1.5	1.8						1.1	1.0	1.1
non-flat $w_0 w_a \gamma$CDM	7.6	2.9	2.4	2.0	2.8	1.7	1.4	2.3	8.3	1.8	1.6	1.5	1.5	1.5	1.6						1.1	1.0	1.1

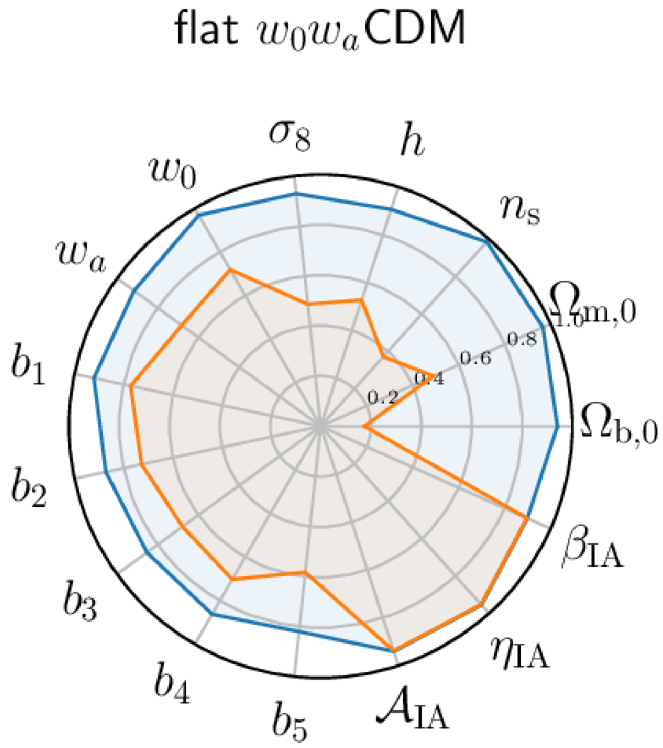
Improvement factors = $\sigma_{before} / \sigma_{after}$

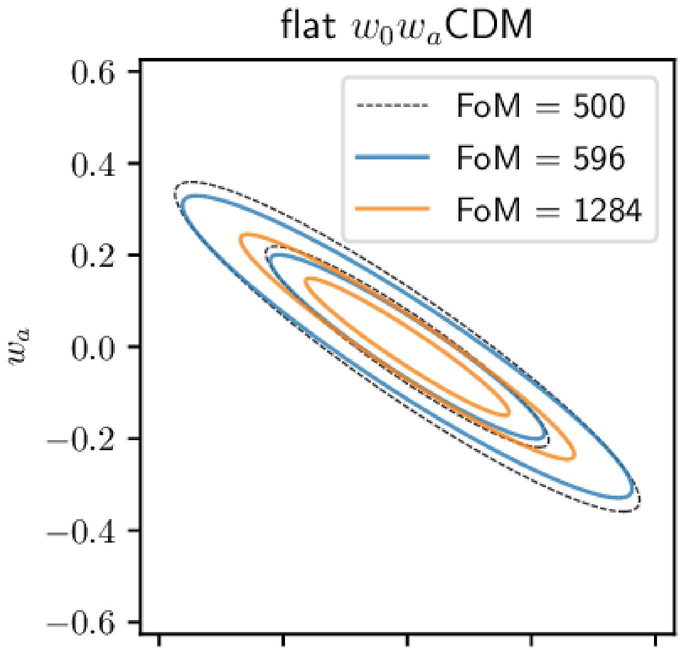
Results: focus on pessimistic Euclid + SO





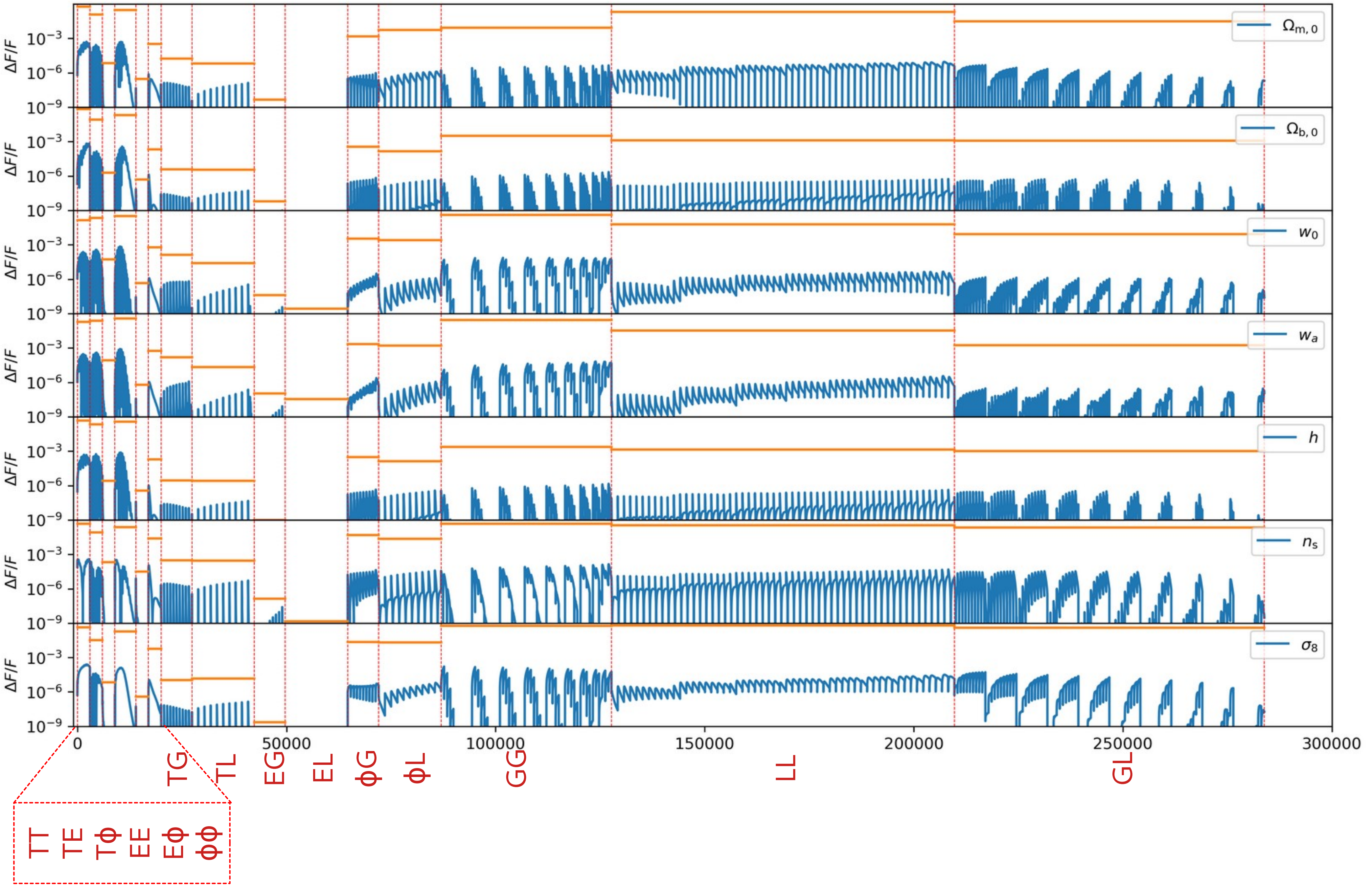
Results: focus on pessimistic Euclid + SO



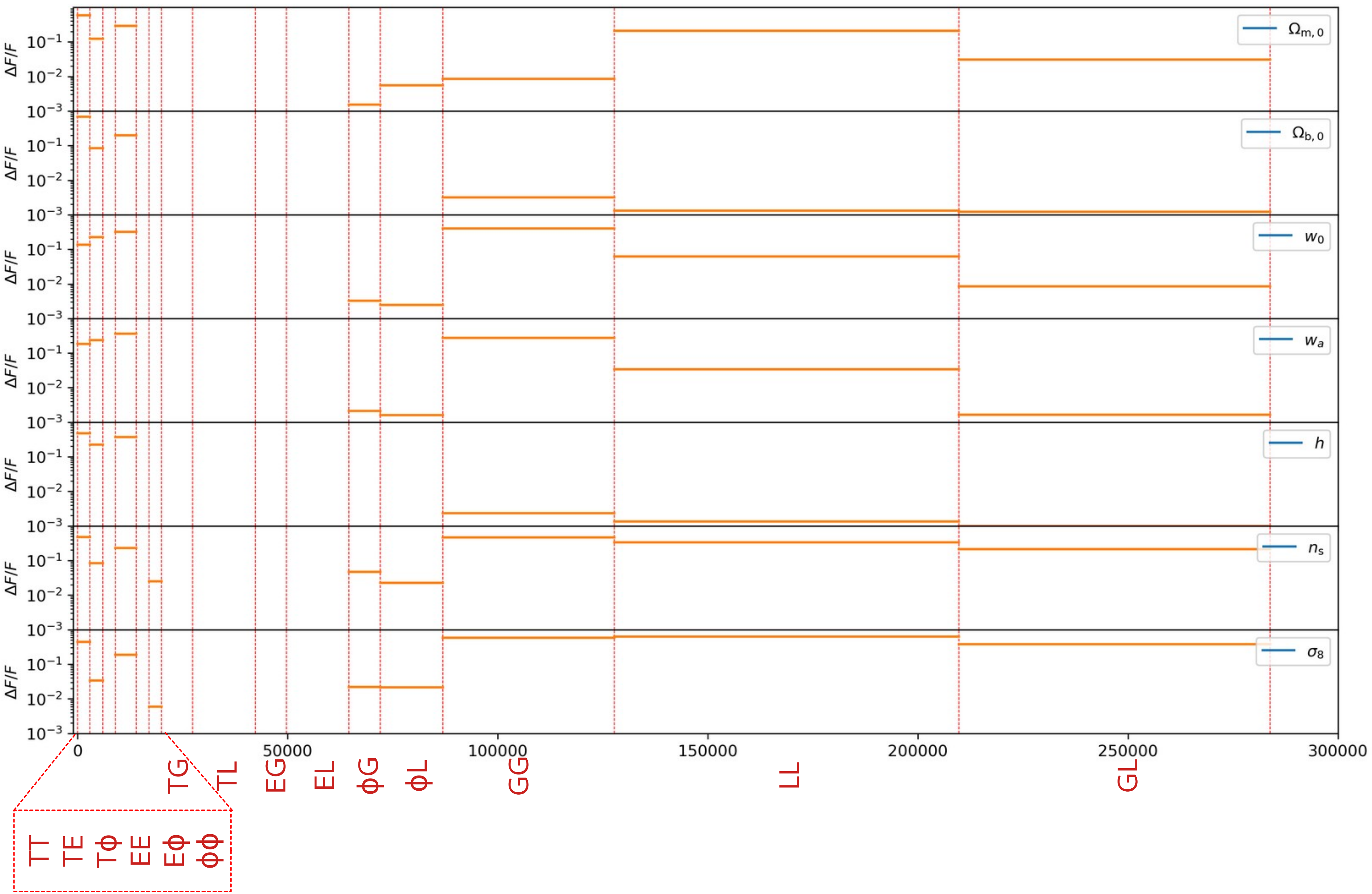


Where do the constraints come from?

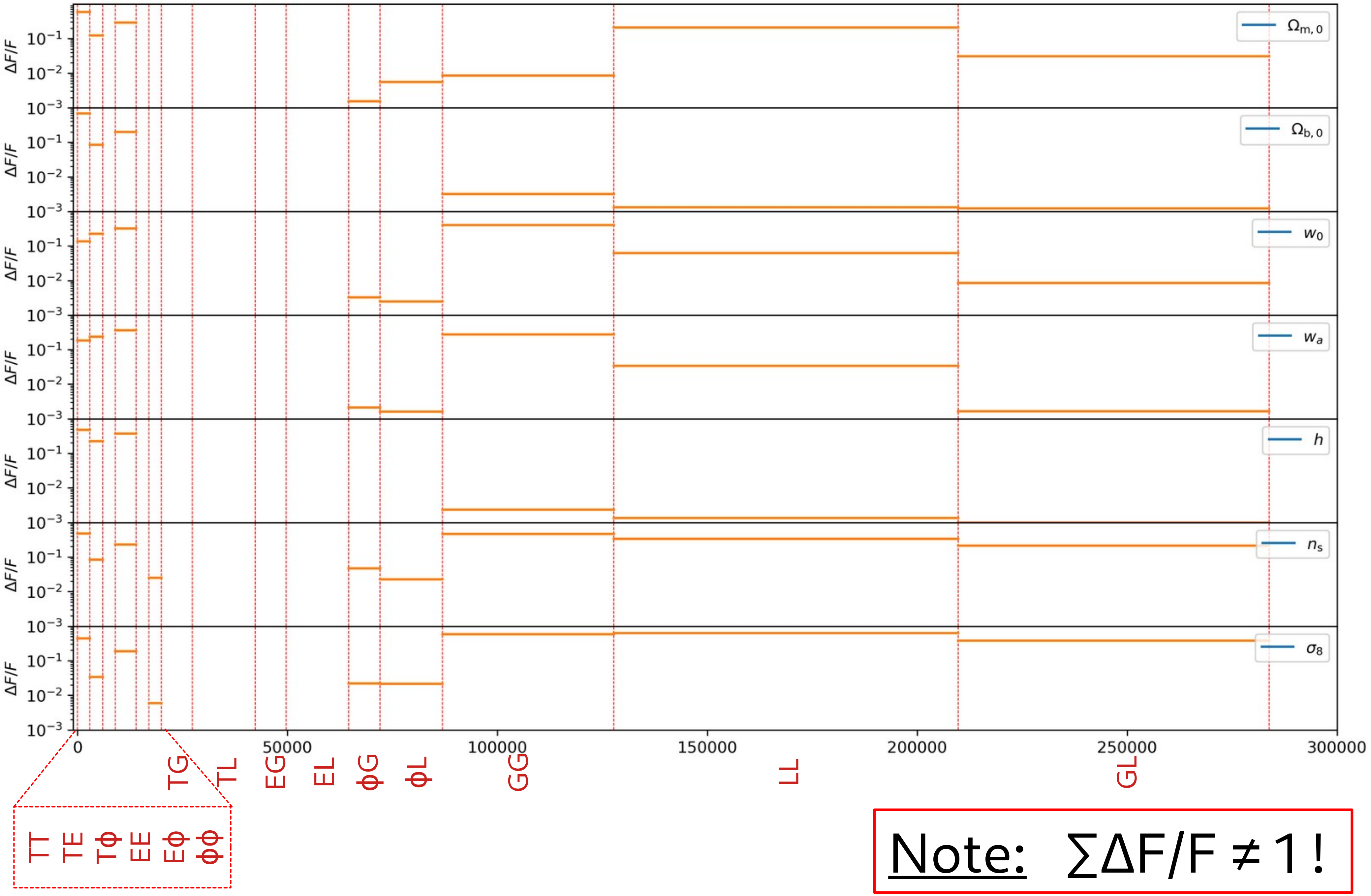
Results: focus on pessimistic Euclid + SO



Results: focus on pessimistic Euclid + SO

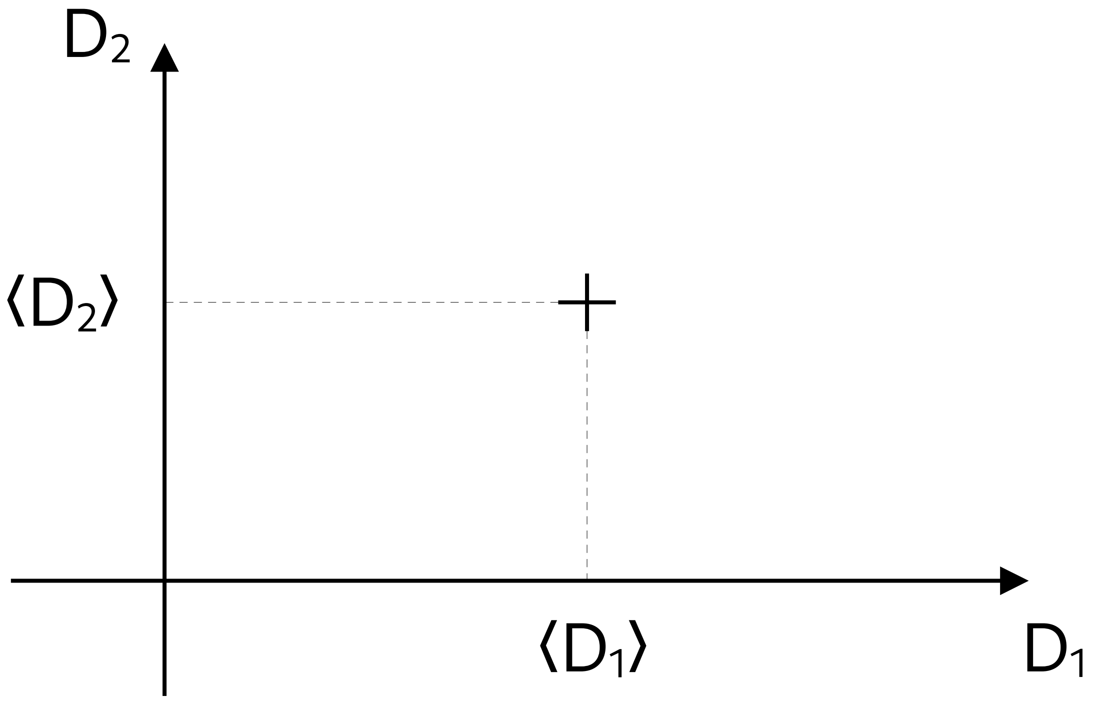


Results: focus on pessimistic Euclid + SO

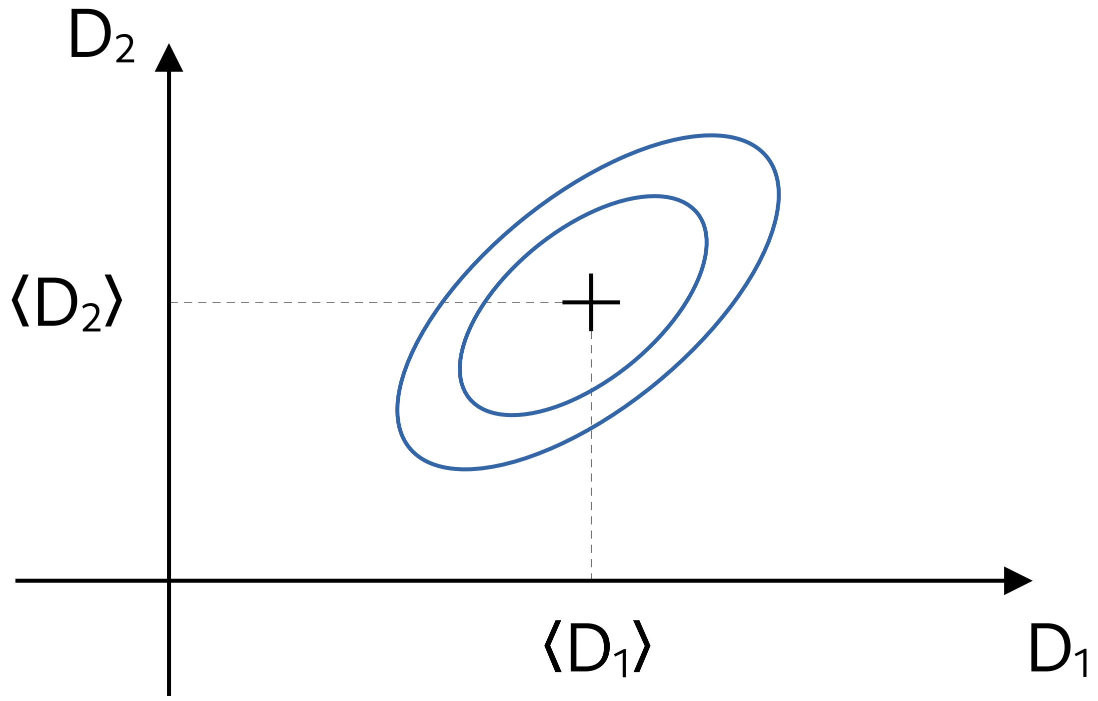


Note: $\sum \Delta F/F \neq 1$!

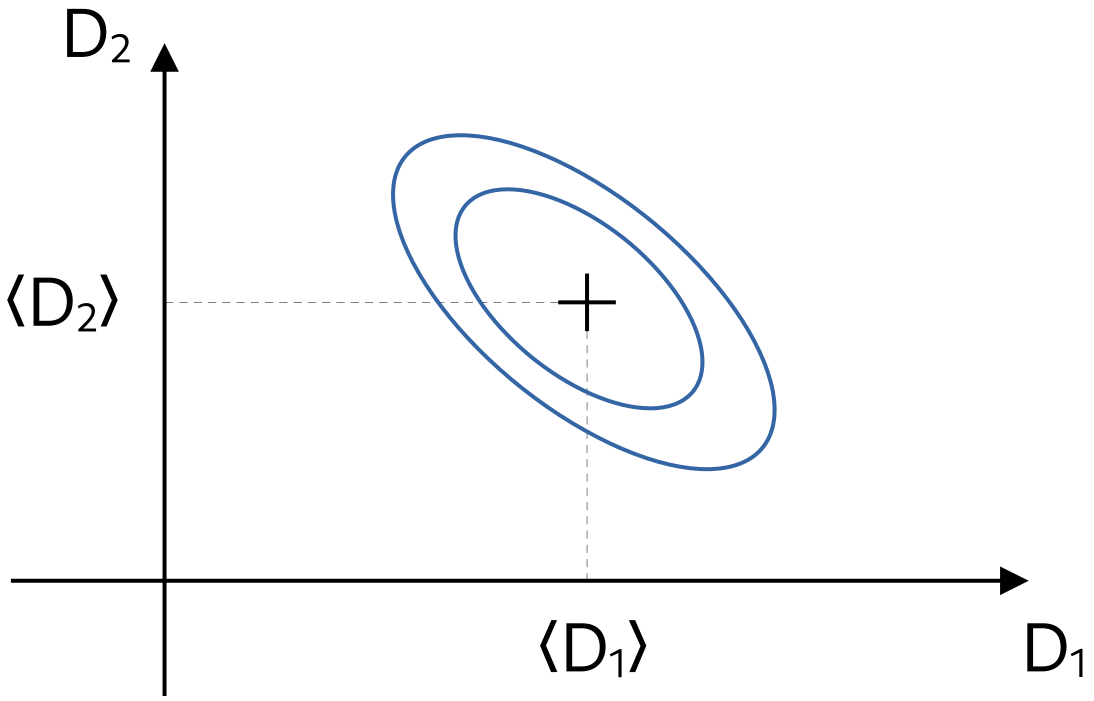
Origin of constraints



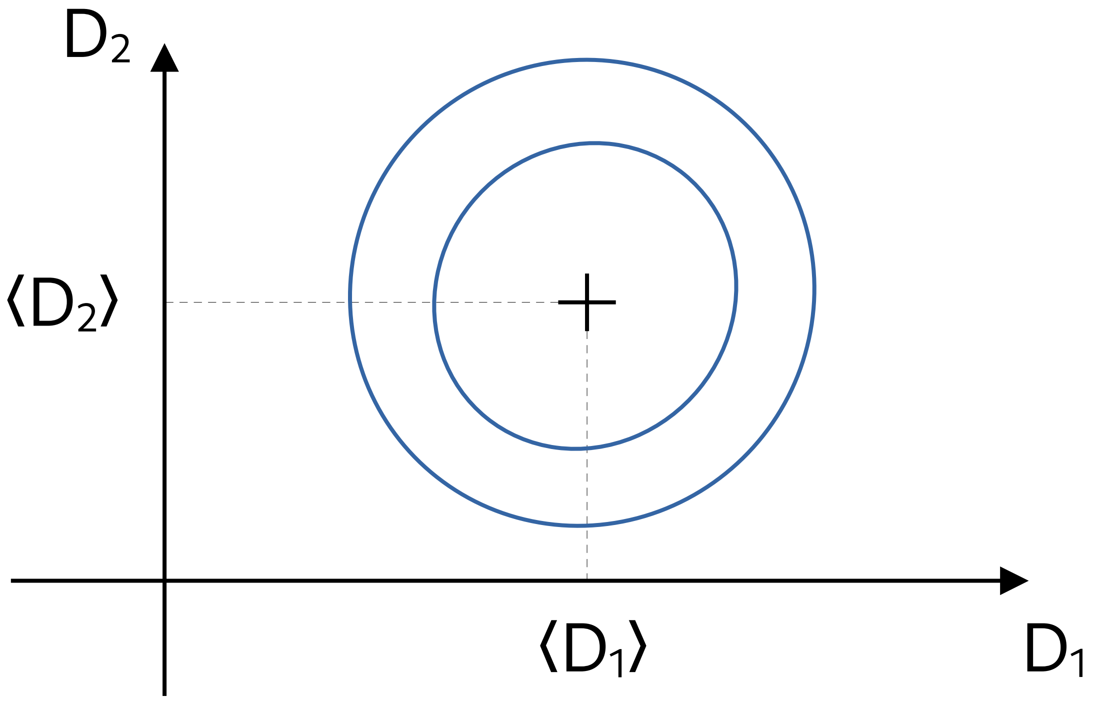
Origin of constraints



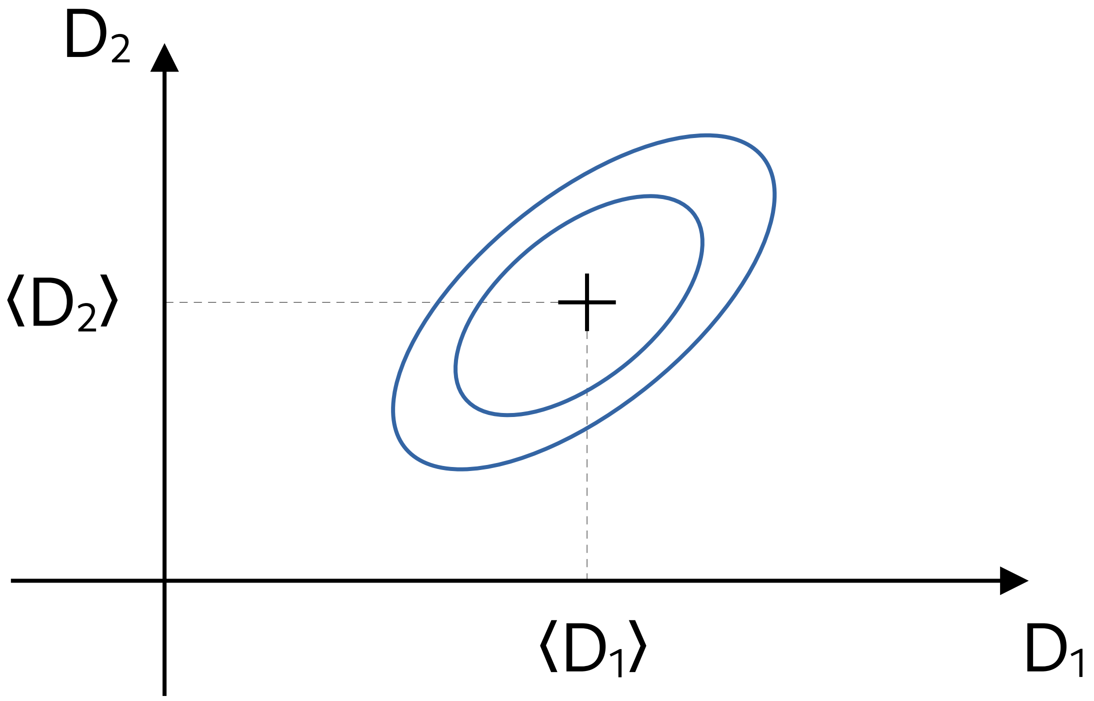
Origin of constraints



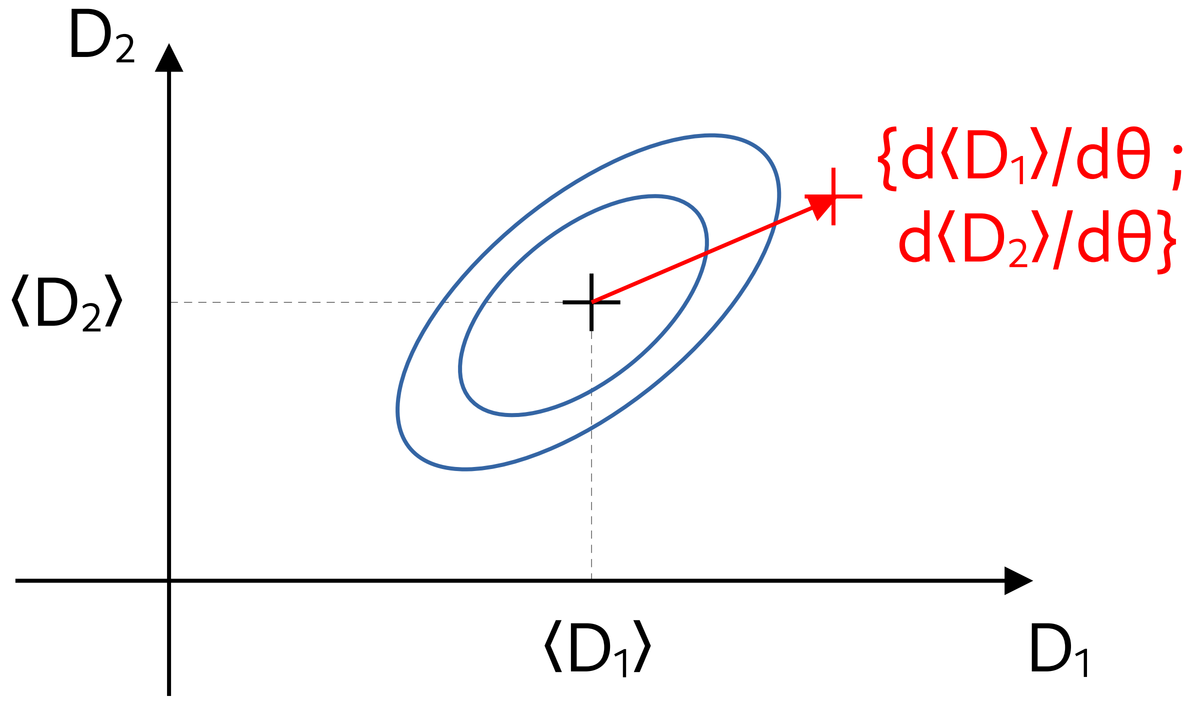
Origin of constraints



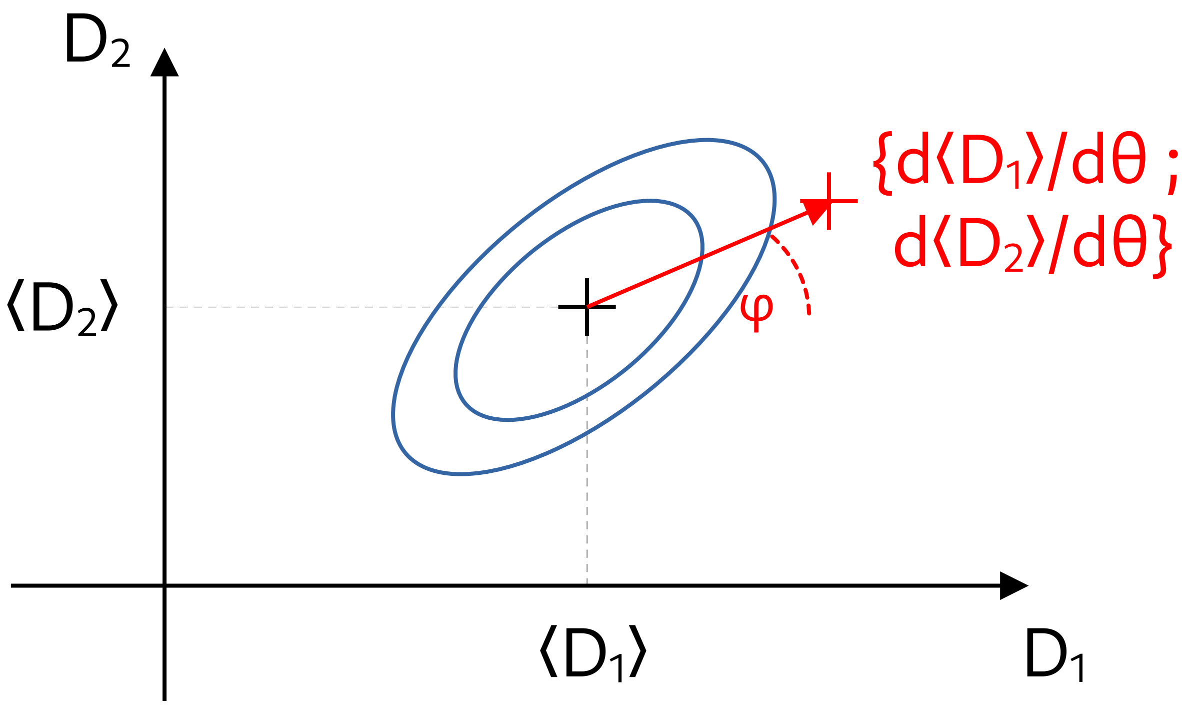
Origin of constraints



Origin of constraints



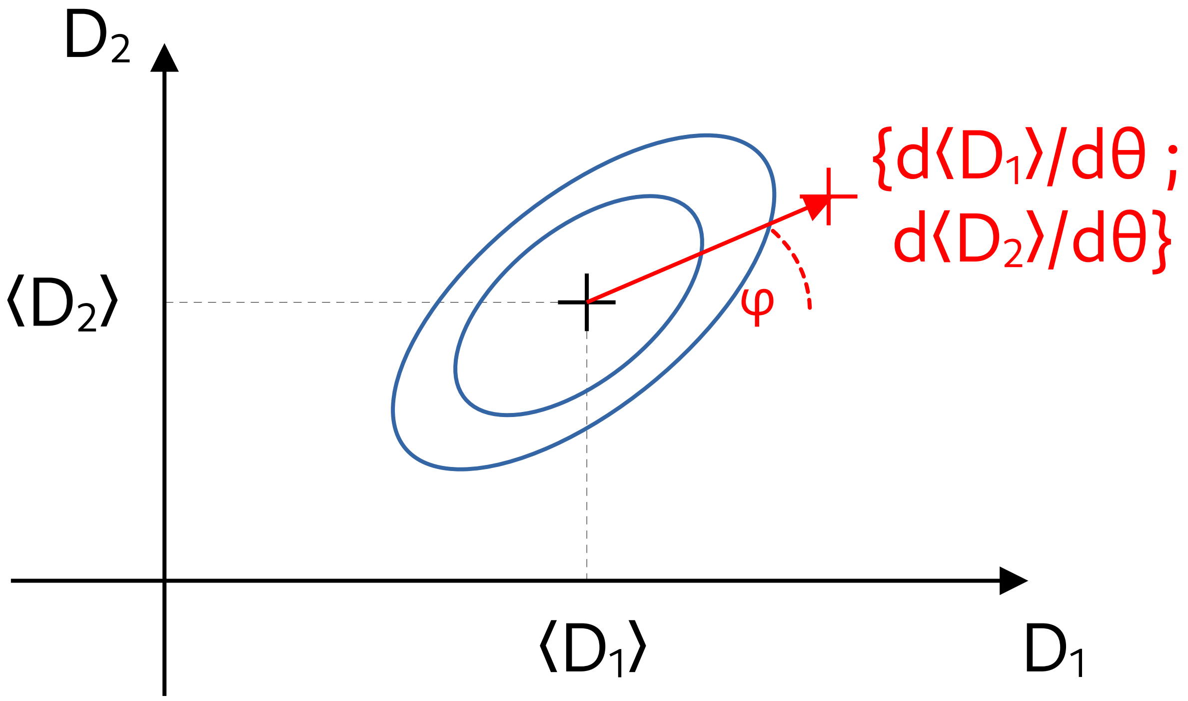
Origin of constraints



- $Var(D_1)=Var(D_2)=1$
- $Covar(D_1, D_2) = \rho$ (with $|\rho| <1$)
- $\{d\langle D1\rangle/d\theta ; d\langle D2\rangle/d\theta\} = \{\cos\varphi; \sin\varphi\}$

$$F_{\alpha\beta} = \frac{1}{2}\,\mathrm{Tr}\left[C^{-1}\frac{\partial C}{\partial\theta_\alpha}C^{-1}\frac{\partial C}{\partial\theta_\beta}\right] + \frac{\partial\boldsymbol{\mu}^T}{\partial\theta_\alpha}C^{-1}\frac{\partial\boldsymbol{\mu}}{\partial\theta_\beta}$$

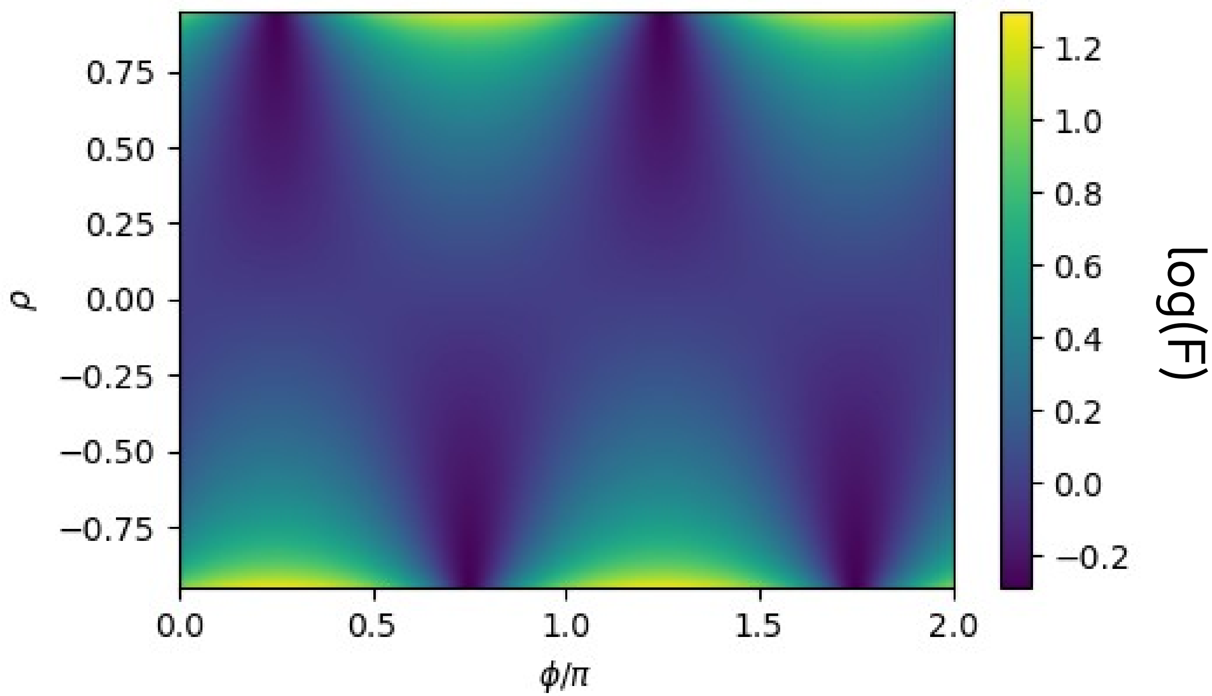
Origin of constraints



- Var(D_1)=Var(D_2)=1
- Covar(D_1, D_2) = ρ (with |ρ| <1)
- {d⟨D1⟩/dθ ; d⟨D2⟩/dθ} = {cos φ; sin φ}

$$F_{\alpha\beta} = \frac{1}{2}\,\mathrm{Tr}\left[C^{-1}\frac{\partial C}{\partial \theta_\alpha}C^{-1}\frac{\partial C}{\partial \theta_\beta}\right] + \frac{\partial \boldsymbol{\mu}^{T}}{\partial \theta_\alpha}C^{-1}\frac{\partial \boldsymbol{\mu}}{\partial \theta_\beta} \quad = \frac{\cos^2\phi - 2\rho\sin\phi\cos\phi + \sin^2\phi}{1-\rho^2}$$

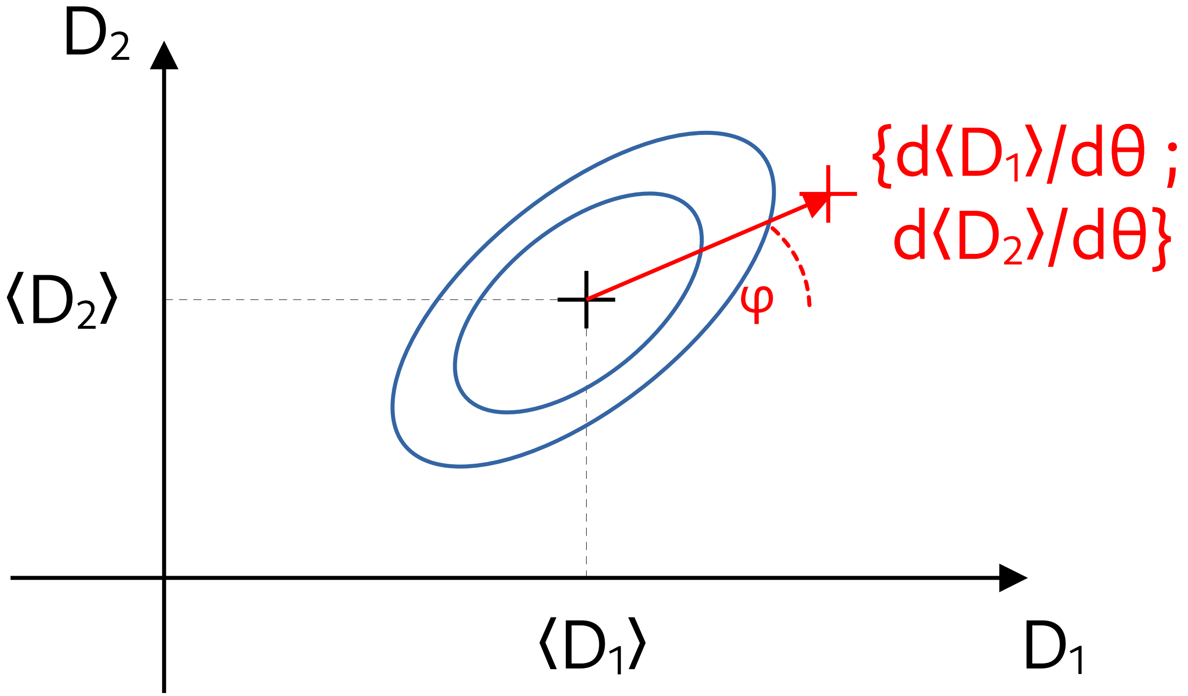
Origin of constraints



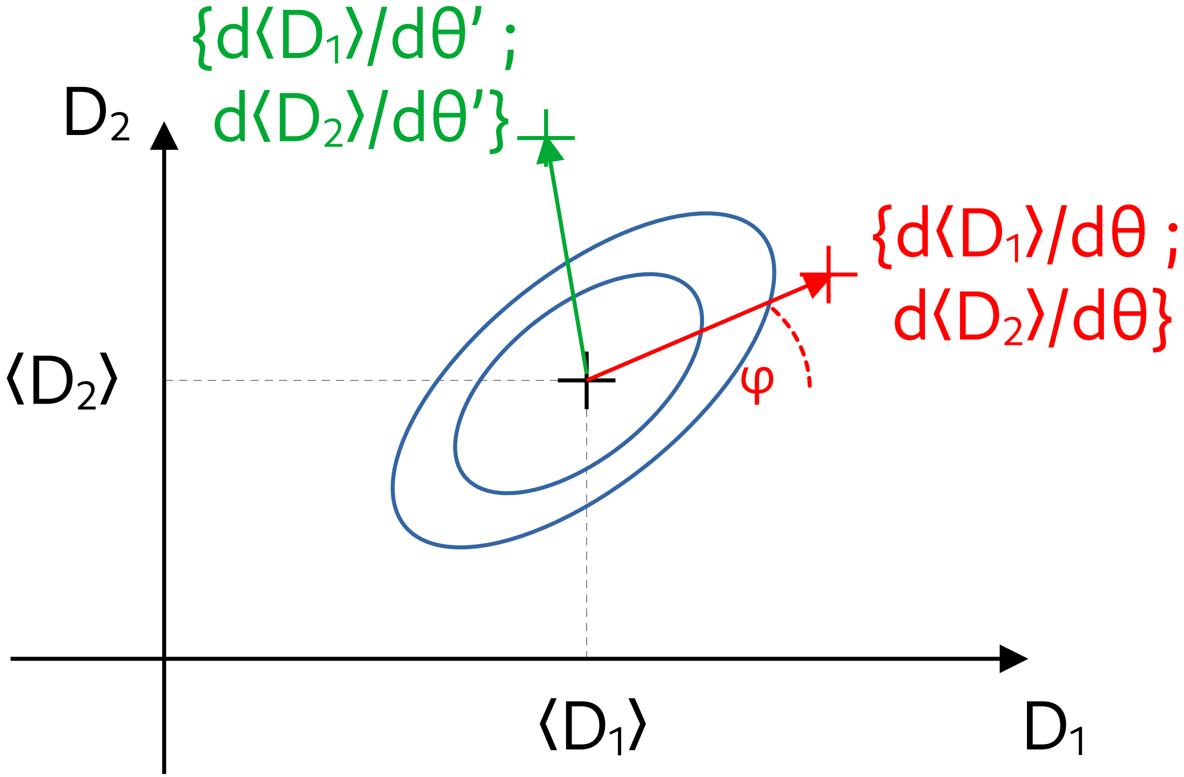
- $\mathrm{Var}(D_1)=\mathrm{Var}(D_2)=1$
- $\mathrm{Covar}(D_1, D_2) = \rho$ (with $|\rho| <1$)
- $\{d\langle D1\rangle/d\theta \,;\, d\langle D2\rangle/d\theta\} = \{\cos\varphi; \sin\varphi\}$

$$F_{\alpha\beta} = \frac{1}{2}\mathrm{Tr}\left[C^{-1}\frac{\partial C}{\partial\theta_\alpha}C^{-1}\frac{\partial C}{\partial\theta_\beta}\right] + \frac{\partial\boldsymbol{\mu}^T}{\partial\theta_\alpha}C^{-1}\frac{\partial\boldsymbol{\mu}}{\partial\theta_\beta} \quad = \frac{\cos^2\phi - 2\rho\sin\phi\cos\phi + \sin^2\phi}{1-\rho^2}$$

Origin of constraints

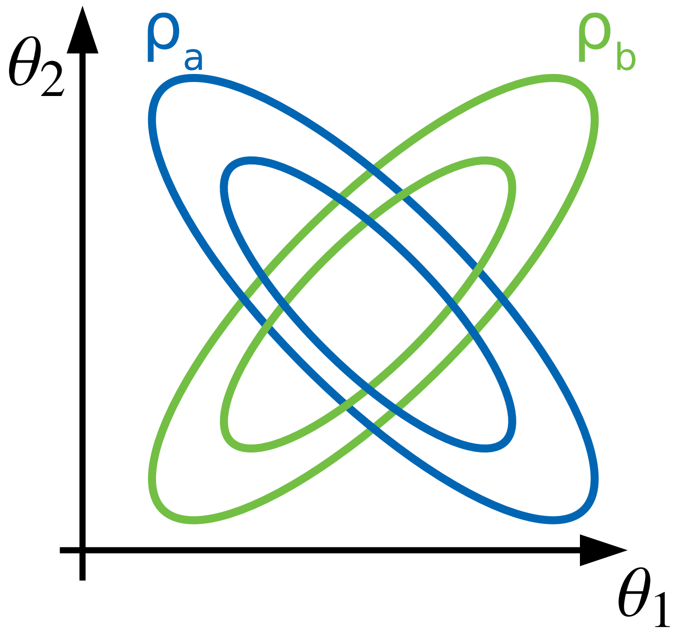


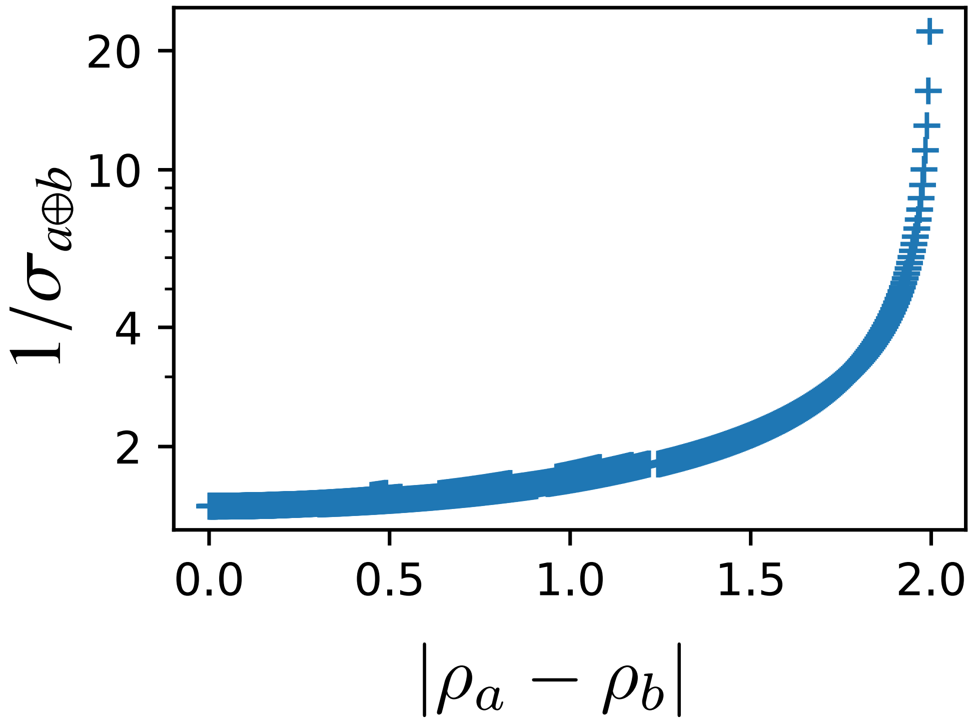
Origin of constraints



Origin of constraints

Breaking parameter degeneracies





$$\sigma^2_{a\oplus b} = \frac{\rho_a^2 + \rho_b^2 - 2}{(\rho_a + \rho_b - 2)(\rho_a + \rho_b + 2)}$$

Origin of constraints

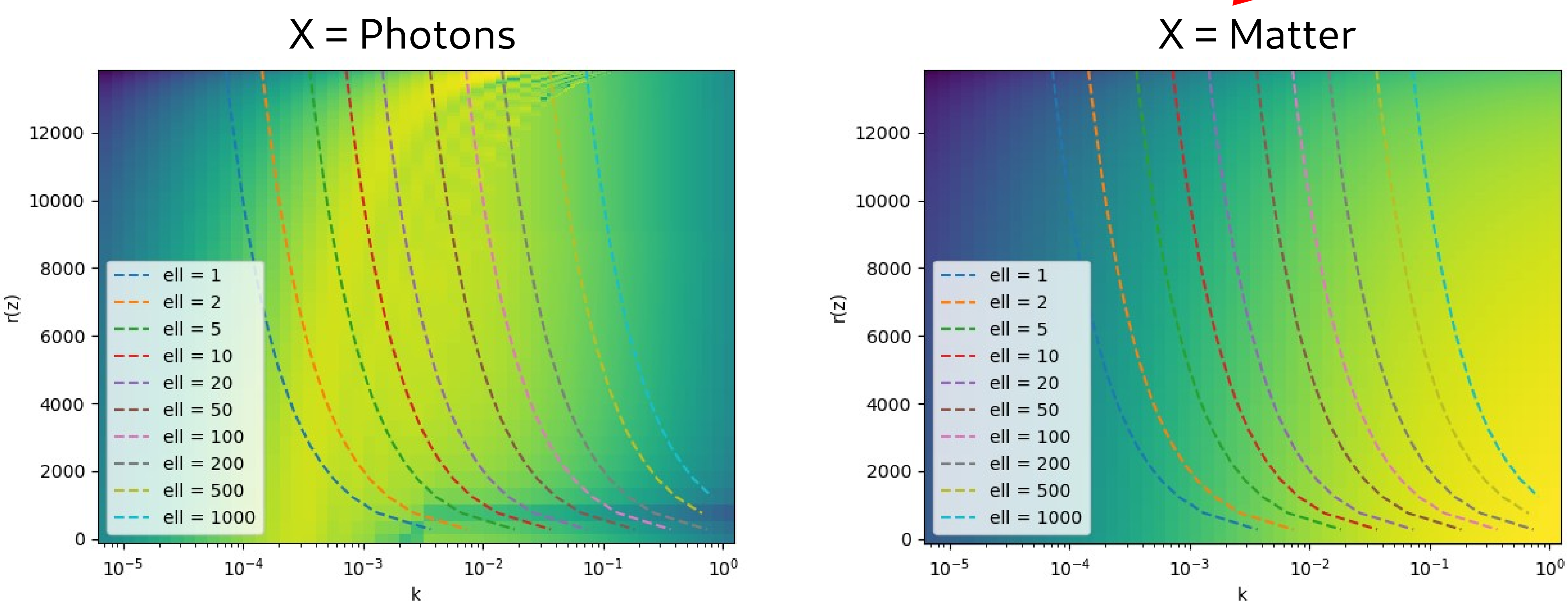
$$C_\ell^{XY} = 4\pi \int_0^\infty \mathrm{d}r_1\, \mathcal{W}^X(r_1) \int_0^\infty \mathrm{d}r_2\, \mathcal{W}^Y(r_2) \times \int_0^\infty \frac{\mathrm{d}k}{k}\, \mathcal{P}_\mathcal{R}(k)\, T_X(k, r_1)\, j_\ell(kr_1)\, T_Y(k, r_2)\, j_\ell(kr_2)$$

$$\mathrm{Cov}\left[\hat{C}_\ell^{XY}, \hat{C}_{\ell'}^{X'Y'}\right] = \frac{\delta^\mathrm{K}_{\ell\ell'}}{(2\ell+1)f_\mathrm{sky}} \times \left\{\left[C_\ell^{XX'} + N_\ell^{XX'}\right]\left[C_{\ell'}^{YY'} + N_{\ell'}^{YY'}\right] + \left[C_\ell^{XY'} + N_\ell^{XY'}\right]\left[C_{\ell'}^{YX'} + N_{\ell'}^{YX'}\right]\right\}$$

Origin of constraints

$$C_\ell^{XY} = 4\pi \int_0^\infty \mathrm{d}r_1\, \mathcal{W}^X(r_1) \int_0^\infty \mathrm{d}r_2\, \mathcal{W}^Y(r_2) \times \int_0^\infty \frac{\mathrm{d}k}{k}\, \mathcal{P}_\mathcal{R}(k)\, T_X(k, r_1)\, j_\ell(kr_1)\, T_Y(k, r_2)\, j_\ell(kr_2)$$

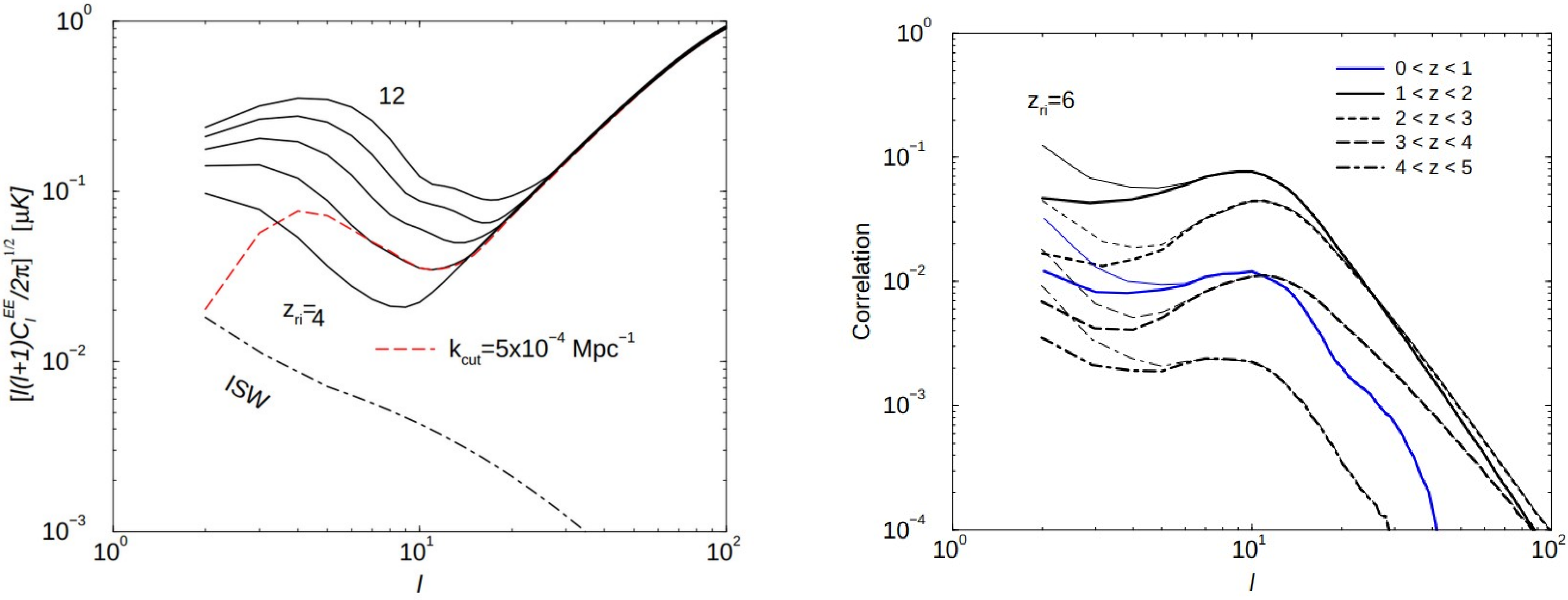
$$\mathrm{Cov}\left[\hat{C}_\ell^{XY}, \hat{C}_{\ell'}^{X'Y'}\right] = \frac{\delta^\mathrm{K}_{\ell\ell'}}{(2\ell+1) f_\mathrm{sky}} \times \left\{\left[C_\ell^{XX'} + N_\ell^{XX'}\right]\left[C_{\ell'}^{YY'} + N_{\ell'}^{YY'}\right] + \left[C_\ell^{XY'} + N_\ell^{XY'}\right]\left[C_{\ell'}^{YX'} + N_{\ell'}^{YX'}\right]\right\}$$



Some other avenues for X-correlations

Some other avenues for X-correlations

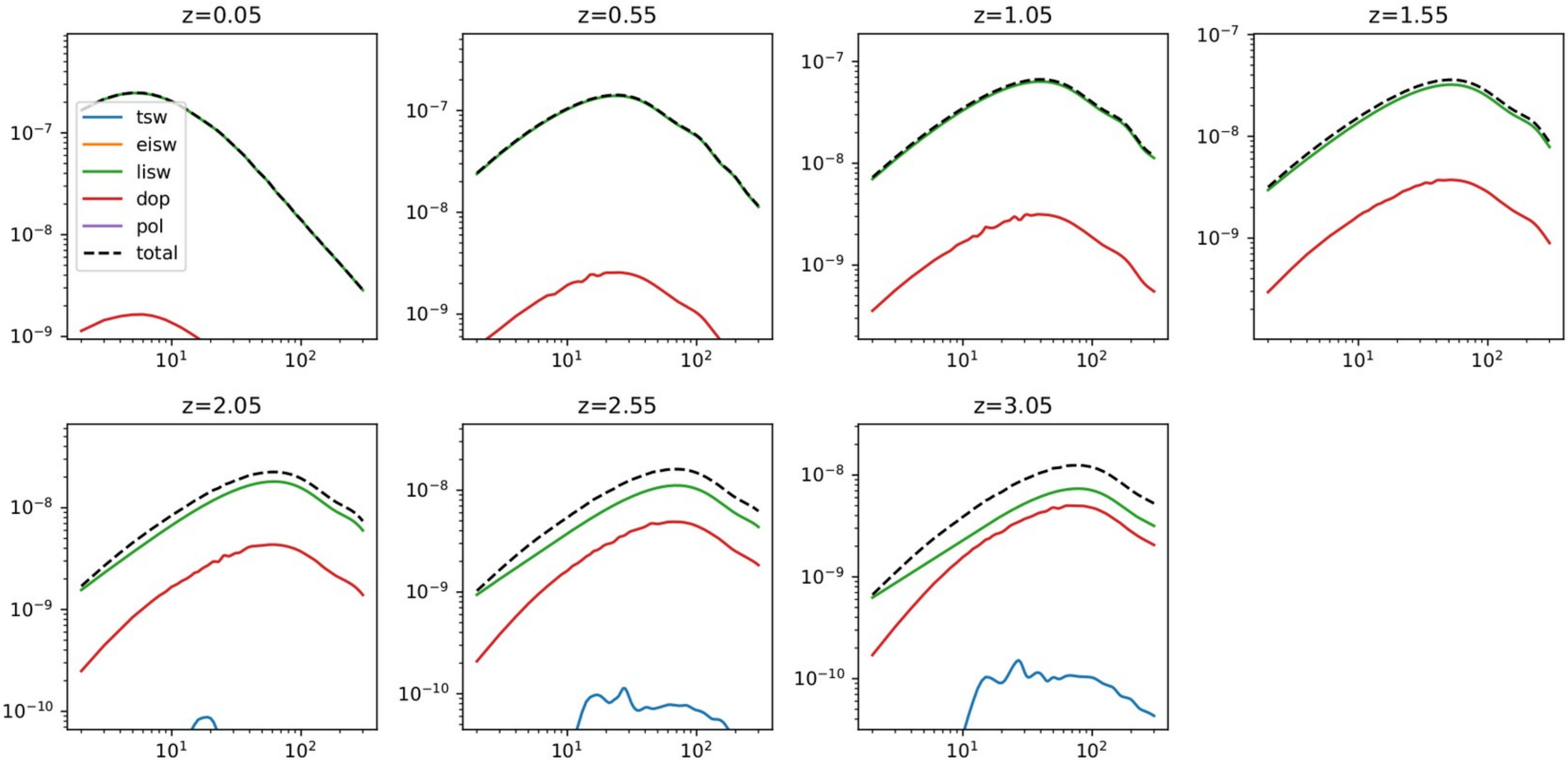
Integrated Sachs-Wolfe Effect in CMB Polarization



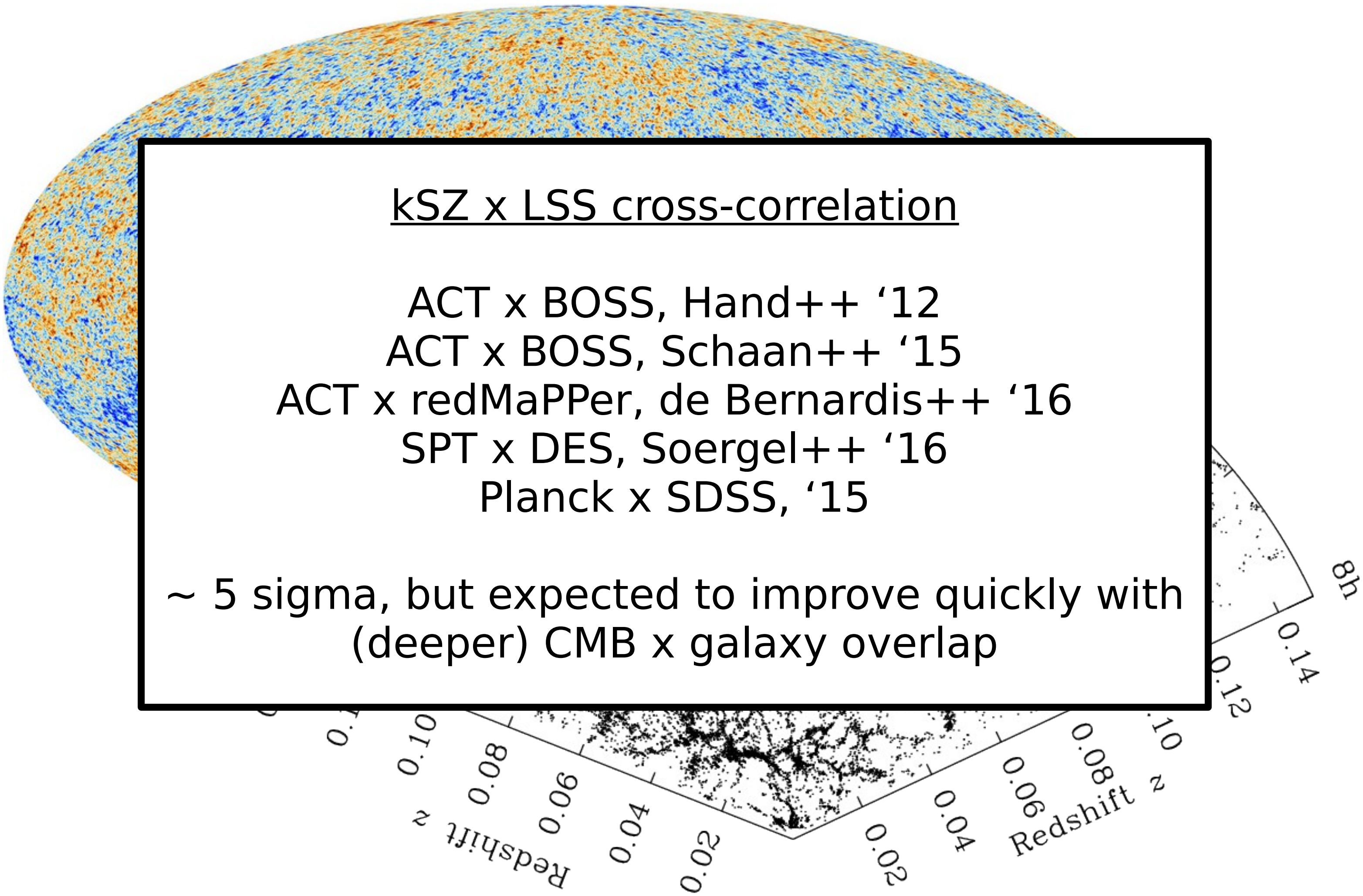
Cooray & Melchiorri, 2006

Some other avenues for X-correlations

Breakdown of CMB T x Galaxy cross-correlation



Some other avenues for X-correlations

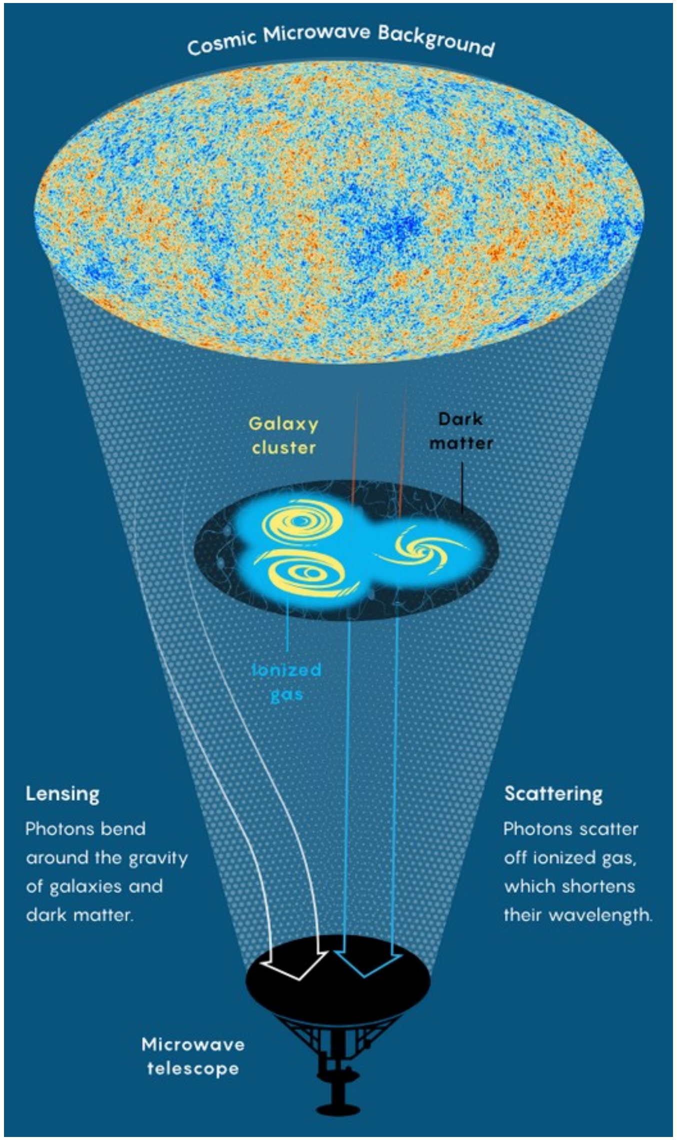


<u>kSZ x LSS cross-correlation</u>

ACT x BOSS, Hand++ ‘12
ACT x BOSS, Schaan++ ‘15
ACT x redMaPPer, de Bernardis++ ‘16
SPT x DES, Soergel++ ‘16
Planck x SDSS, ‘15

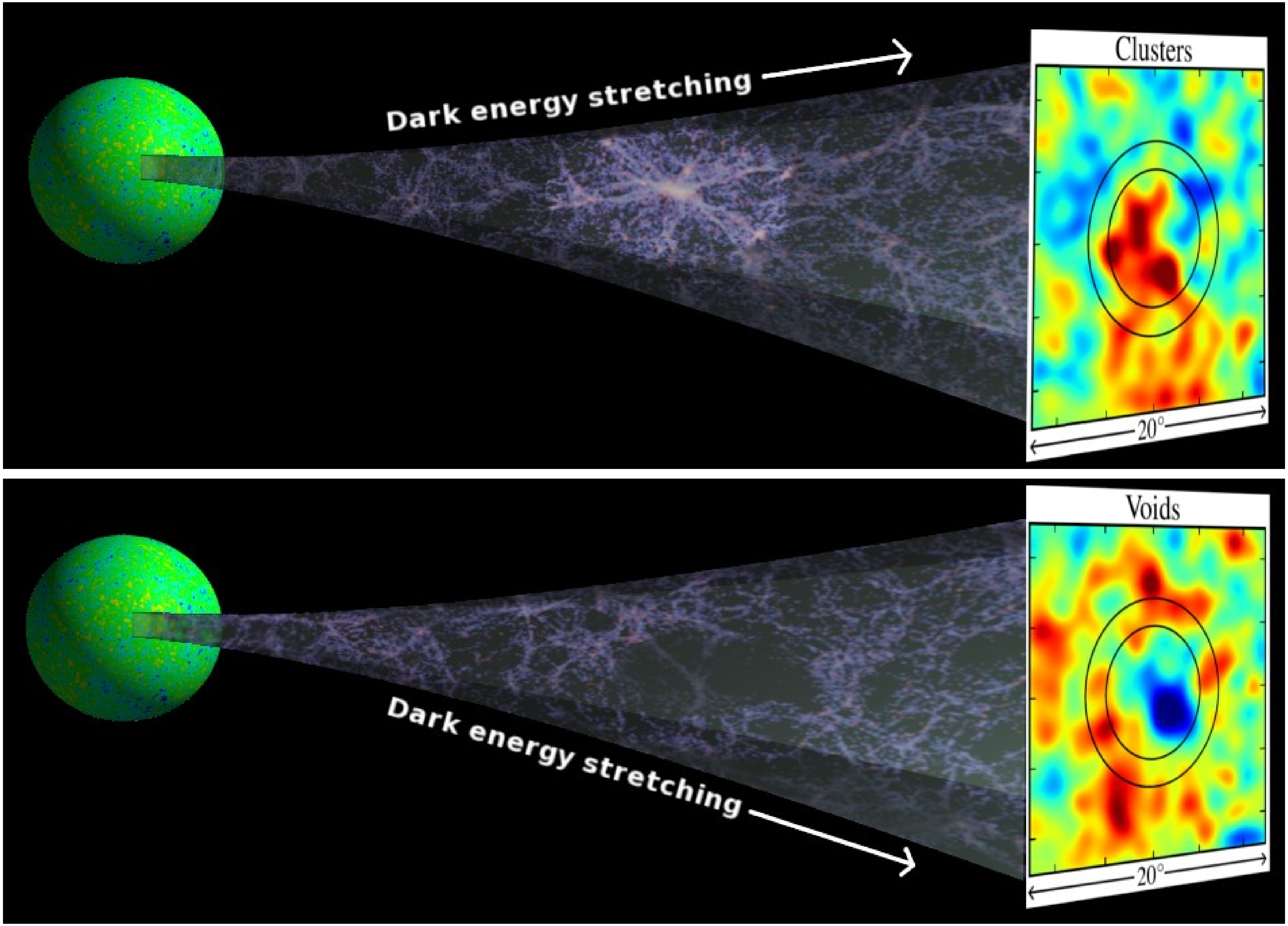
~ 5 sigma, but expected to improve quickly with (deeper) CMB x galaxy overlap

Some other avenues for X-correlations

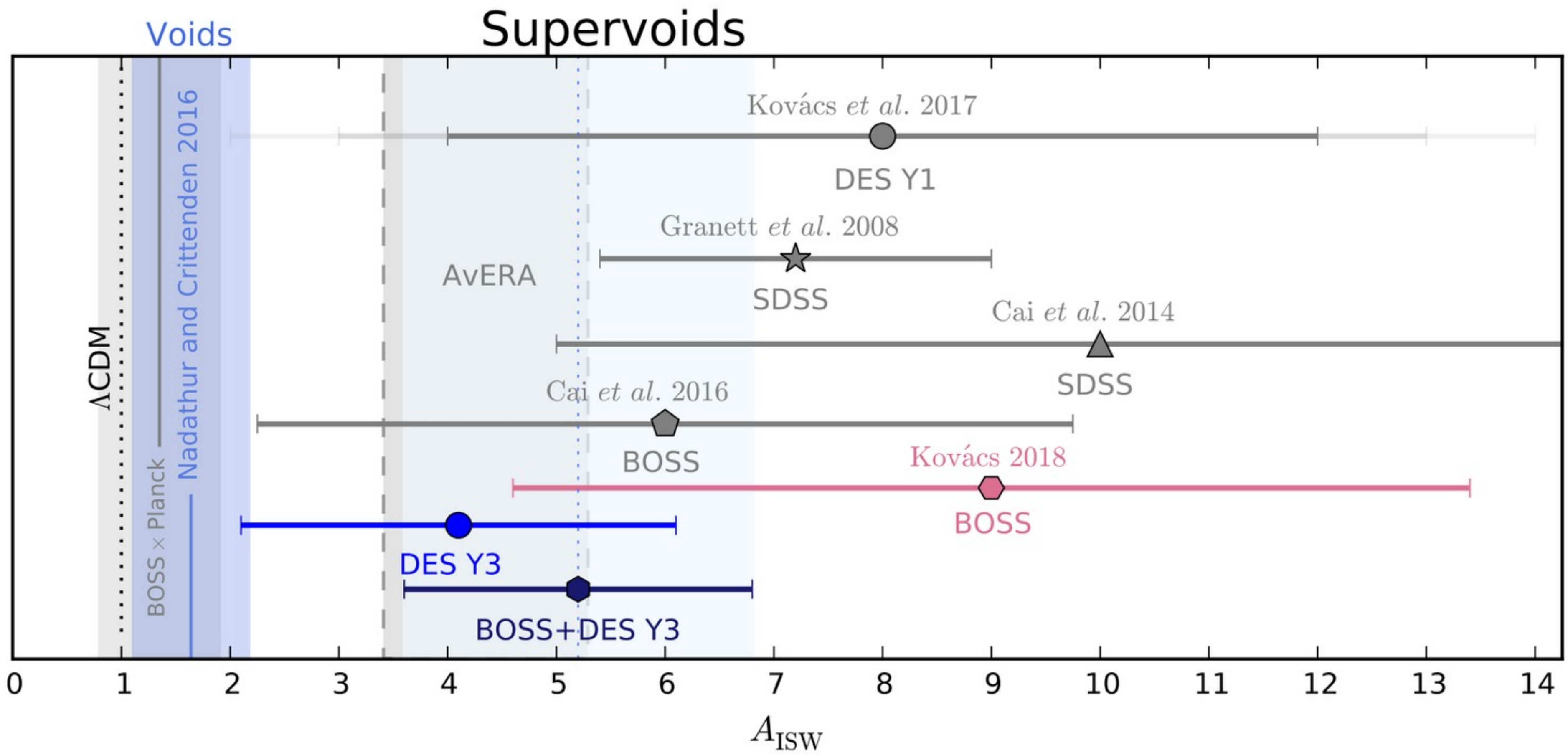


<u>Measuring the mass of galaxy cluster with CMB</u>

Some other avenues for X-correlations

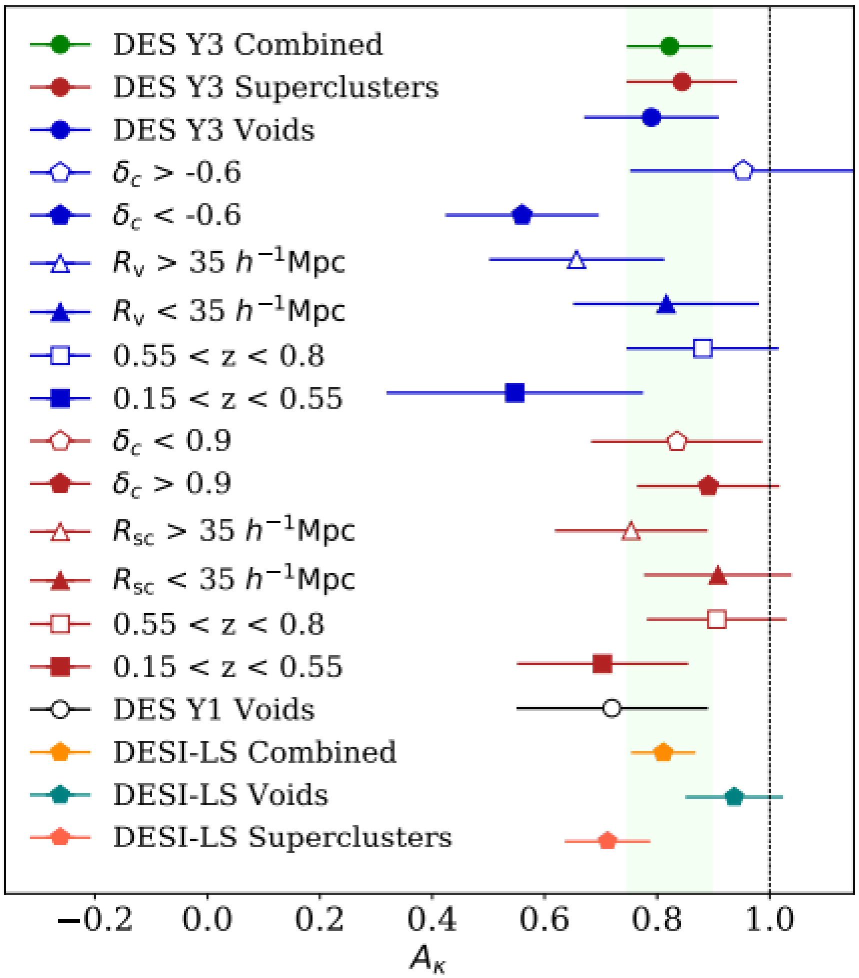


Some other avenues for X-correlations



Kovács et al. 2019

Some other avenues for X-correlations



Kovács et al. 2022

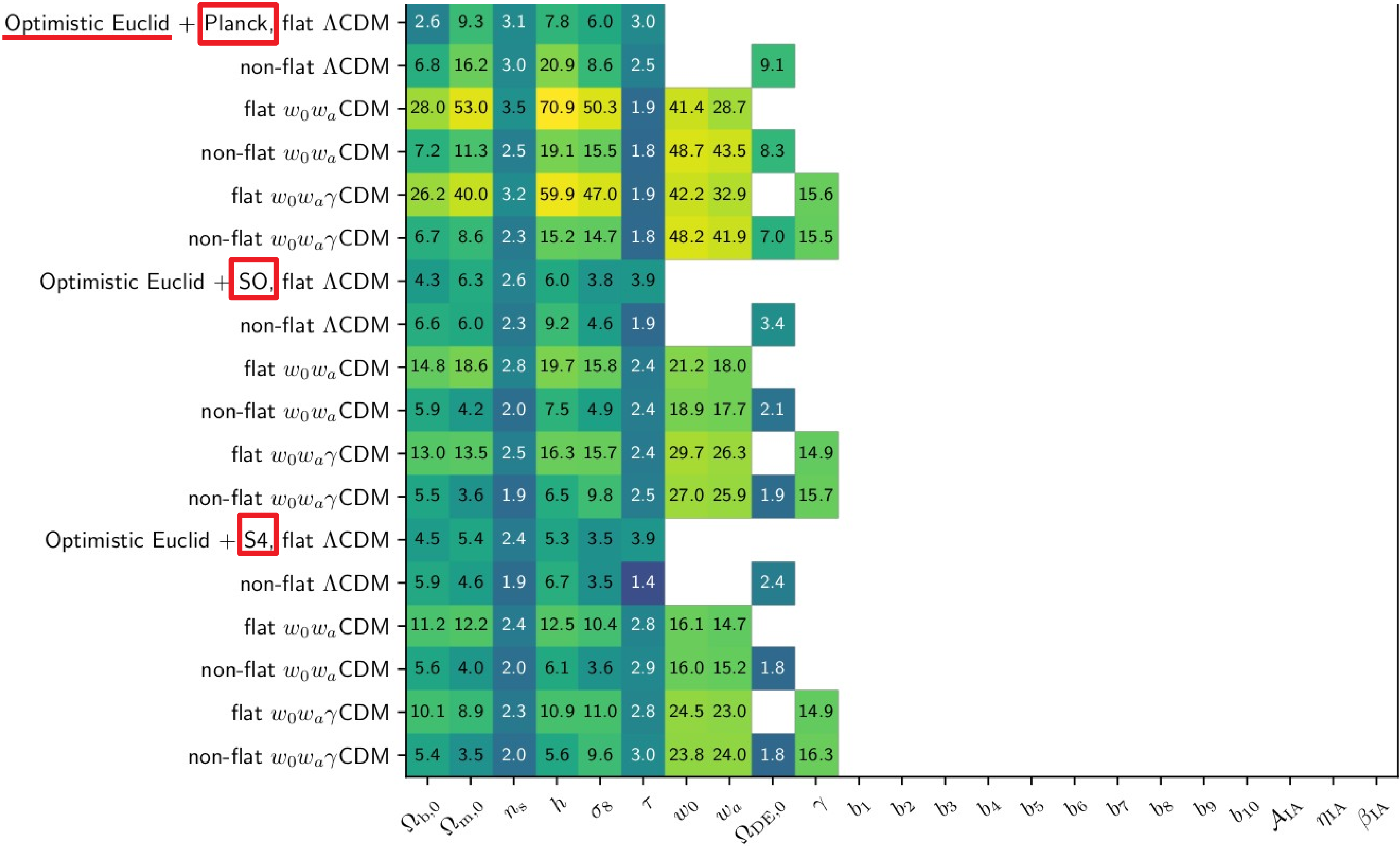
The end

Thank you for
your attention !

The end?

Extra
slides

The results: from CMB-only to Euclid×CMB



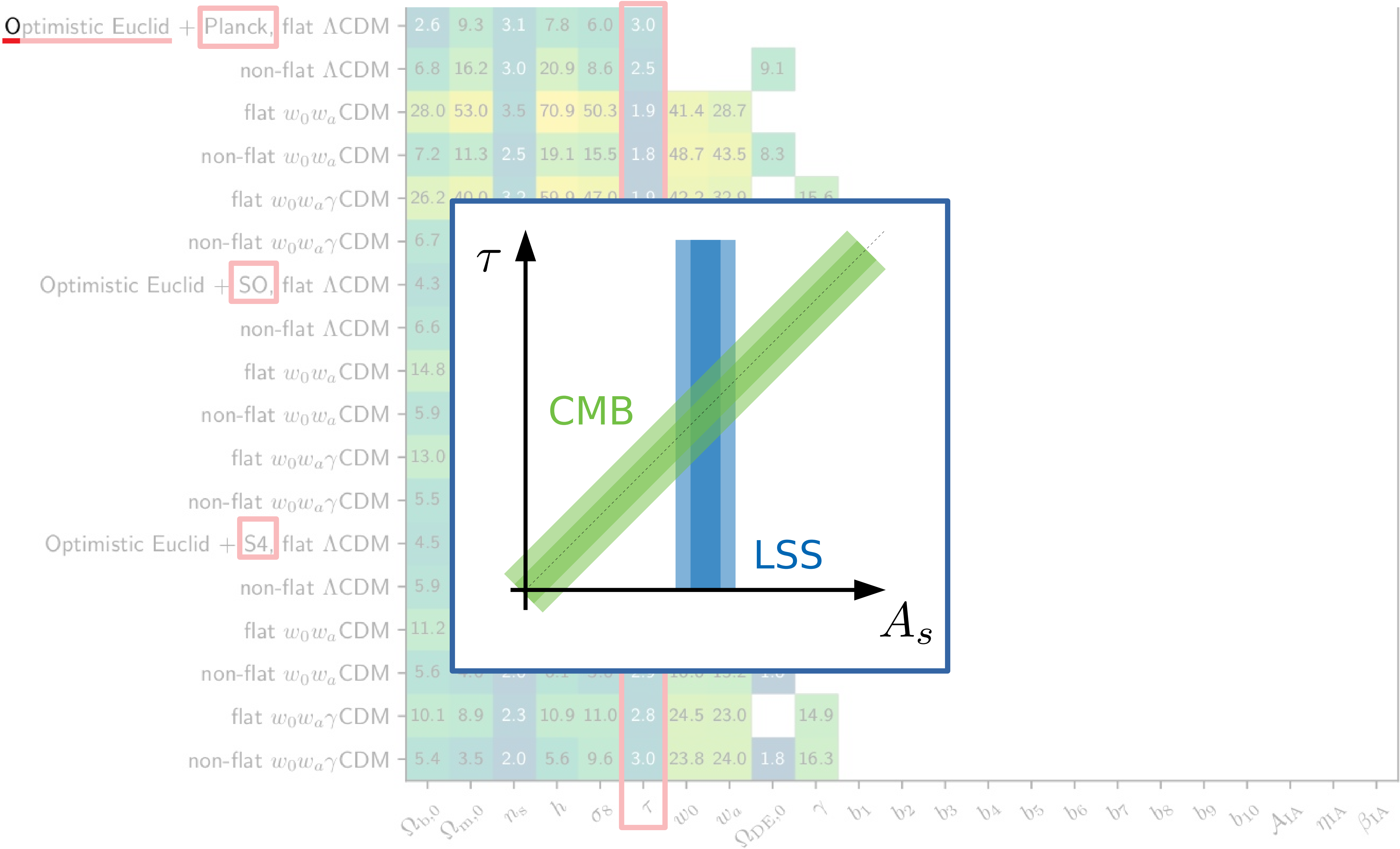
Improvement factors = σ_{before} / σ_{after}

The results: from CMB-only to Euclid×CMB

	$\Omega_{b,0}$	$\Omega_{m,0}$	n_s	h	σ_8	τ	w_0	w_a	$\Omega_{DE,0}$	γ	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	A_{IA}	η_{IA}	β_{IA}
Optimistic Euclid + Planck, flat ΛCDM	2.6	9.3	3.1	7.8	6.0	3.0																	
non-flat ΛCDM	6.8	16.2	3.0	20.9	8.6	2.5			9.1														
flat w_0w_aCDM	28.0	53.0	3.5	70.9	50.3	1.9	41.4	28.7															
non-flat w_0w_aCDM	7.2	11.3	2.5	19.1	15.5	1.8	48.7	43.5	8.3														
flat $w_0w_a\gamma$CDM	26.2	40.0	3.2	59.9	47.0	1.9	42.2	32.9		15.6													
non-flat $w_0w_a\gamma$CDM	6.7	8.6	2.3	15.2	14.7	1.8	48.2	41.9	7.0	15.5													
Optimistic Euclid + SO, flat ΛCDM	4.3	6.3	2.6	6.0	3.8	3.9																	
non-flat ΛCDM	6.6	6.0	2.3	9.2	4.6	1.9			3.4														
flat w_0w_aCDM	14.8	18.6	2.8	19.7	15.8	2.4	21.2	18.0															
non-flat w_0w_aCDM	5.9	4.2	2.0	7.5	4.9	2.4	18.9	17.7	2.1														
flat $w_0w_a\gamma$CDM	13.0	13.5	2.5	16.3	15.7	2.4	29.7	26.3		14.9													
non-flat $w_0w_a\gamma$CDM	5.5	3.6	1.9	6.5	9.8	2.5	27.0	25.9	1.9	15.7													
Optimistic Euclid + S4, flat ΛCDM	4.5	5.4	2.4	5.3	3.5	3.9																	
non-flat ΛCDM	5.9	4.6	1.9	6.7	3.5	1.4			2.4														
flat w_0w_aCDM	11.2	12.2	2.4	12.5	10.4	2.8	16.1	14.7															
non-flat w_0w_aCDM	5.6	4.0	2.0	6.1	3.6	2.9	16.0	15.2	1.8														
flat $w_0w_a\gamma$CDM	10.1	8.9	2.3	10.9	11.0	2.8	24.5	23.0		14.9													
non-flat $w_0w_a\gamma$CDM	5.4	3.5	2.0	5.6	9.6	3.0	23.8	24.0	1.8	16.3													

Improvement factors = σ_{before} / σ_{after}

The results: from CMB-only to Euclid×CMB



Improvement factors = $\sigma_{\text{before}} / \sigma_{\text{after}}$