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Cosmodynamics in an accelerated universe: overview

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Outline

- Intro - Why use GR + FRW?
- The dark side
- A theoretical path - DE parametrizations
- Concluding remarks
- Future projects

What about the metric?

Curvature determine by content in the spacetime

Metric: way to describe distance/time

$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu$$

FRW: $$ds^2 = dt^2 - a^2(t)(dx^2 + dy^2 + dz^2)$$

How is metric (distance measure) determinated?

Intro -why use GR + FRW?

Specify way in which curvature determine/response to matter

$$\boxed{G_{\mu\nu}} = 8\pi \boxed{G_0} \boxed{T_{\mu\nu}}$$

Curvature

Newton's constant

Matter

$$G_{\mu\nu} \sim g, \partial g, \partial^2 g \qquad T_{\mu\nu} \sim \rho, P$$

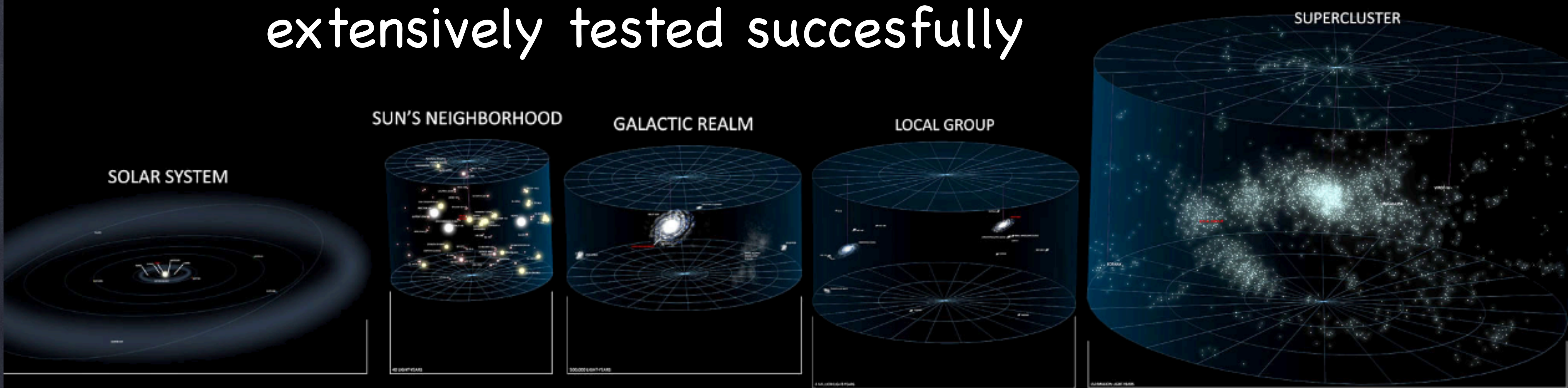
From Einstein equations in a FRW background:

$$1-\frac{\kappa\rho}{3H^2}-\frac{\Lambda}{3H^2}+\frac{kc^2}{a^2H^2}=0$$

The cosmodynamics is established!

Things we know:

- Einstein's General Relativity (GR) has been extensively tested succesfully



- General view → Couple the vacuum theory to matter

  - Assume a minimal coupling,
  - solve the full Einstein equations and
  - compare theoretical models with observations

Re-examine ingredients that went into the cosmological cookbook

Gravity...?
General Relativity

Maybe GR is not the gravitational theory on larger scales?
Applying to cosmology is an extrapolation of the validity of GR as the gravitational theory.
Modified Gravity

Geometry...?
Homogeneous and isotropic

Maybe the universe is not homogeneous/isotropic on larger scales.
Inhomogeneous universes

Content...?
Barions, photons, neutrinos...

Maybe there's more to the content of the universe than we realized.
Dark Matter and Dark Energy

Structure formation and galaxy rotations...

Cosmic acceleration

The dark side

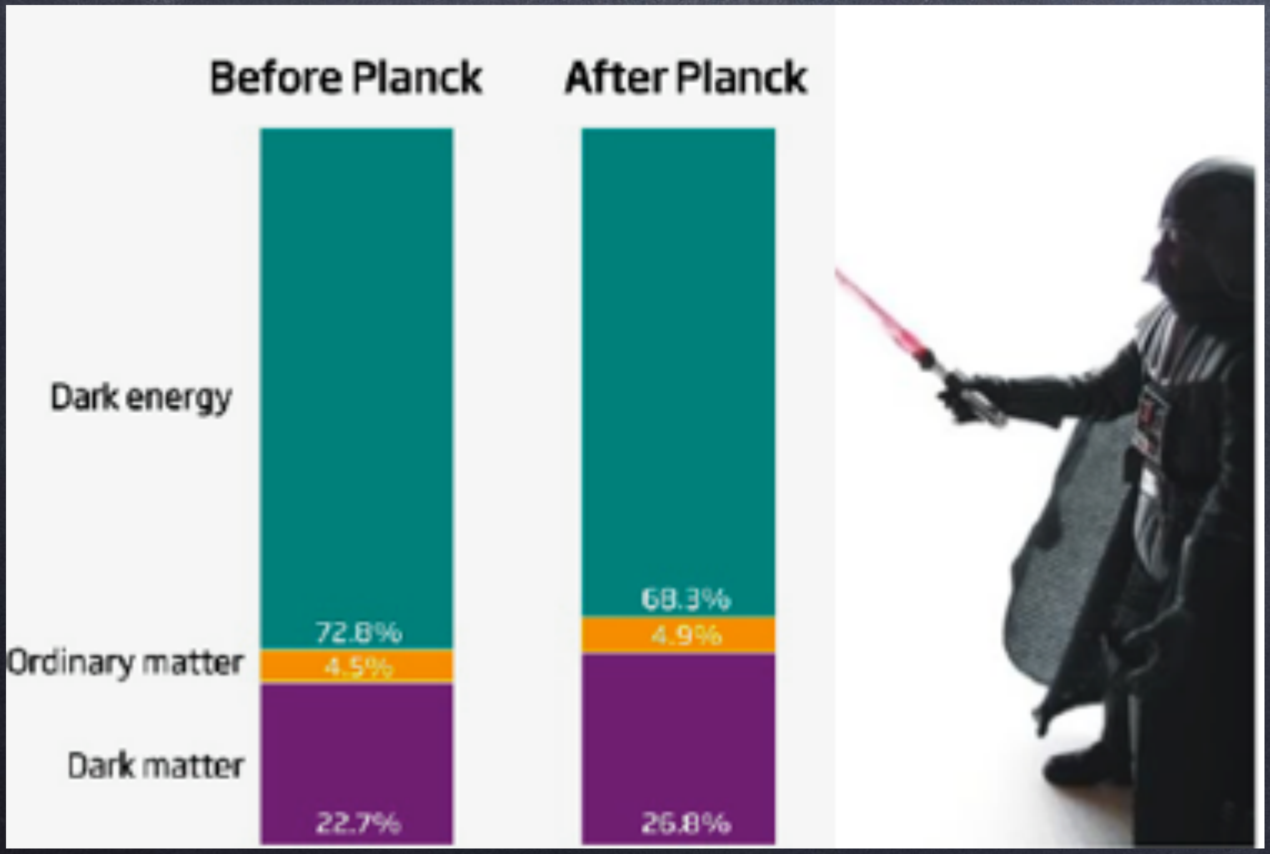
Data
(CMB, structure formation, BAO,...)

+

Gravity model
(GR+FRW)

=

Dark matter + dark energy



Standard model: GR + LCDM
Is 95% of the universe!

Assume FRW is correct

Assume GR is correct

$$P = w\rho, \quad w_{DE} < -1/3$$

Require 23% Dark Matter
68% Dark Energy

What is the Dark Energy?

The model zoo

Modify Gravity and Cosmology
T. Clifton, P. Ferreira, A. Padilla, and C. Skordis
1106.2476

$$\mathcal{L} = R + 2\Lambda$$ Cosmological constant

$$\mathcal{L} = R + F(R)$$

$$\mathcal{L} = R + F(R, R_{\mu\nu}R^{\mu\nu}, R_{\mu\nu\alpha\beta}R^{\mu\nu\alpha\beta})$$

$$\mathcal{L} = R + \partial_\mu\phi\partial^\mu\phi + 2V(\phi)$$ Quintessence

$$\mathcal{L} = R + F(R) + \partial_\mu\partial^\mu\phi + 2V(\phi)$$

$$\mathcal{L} = R - 2f(-\frac{1}{2}\partial_\mu\partial^\mu\phi, \phi)$$ K-essence

$$\mathcal{L} = R - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \lambda(A^\mu A_\mu - 1)$$ Einstein-Aether

$\vdots$

Phenomenological construction

Fundamental physics

Theories

Predictions for what such a universe will look like

...distance, abundance of structure, CMB, lensing...

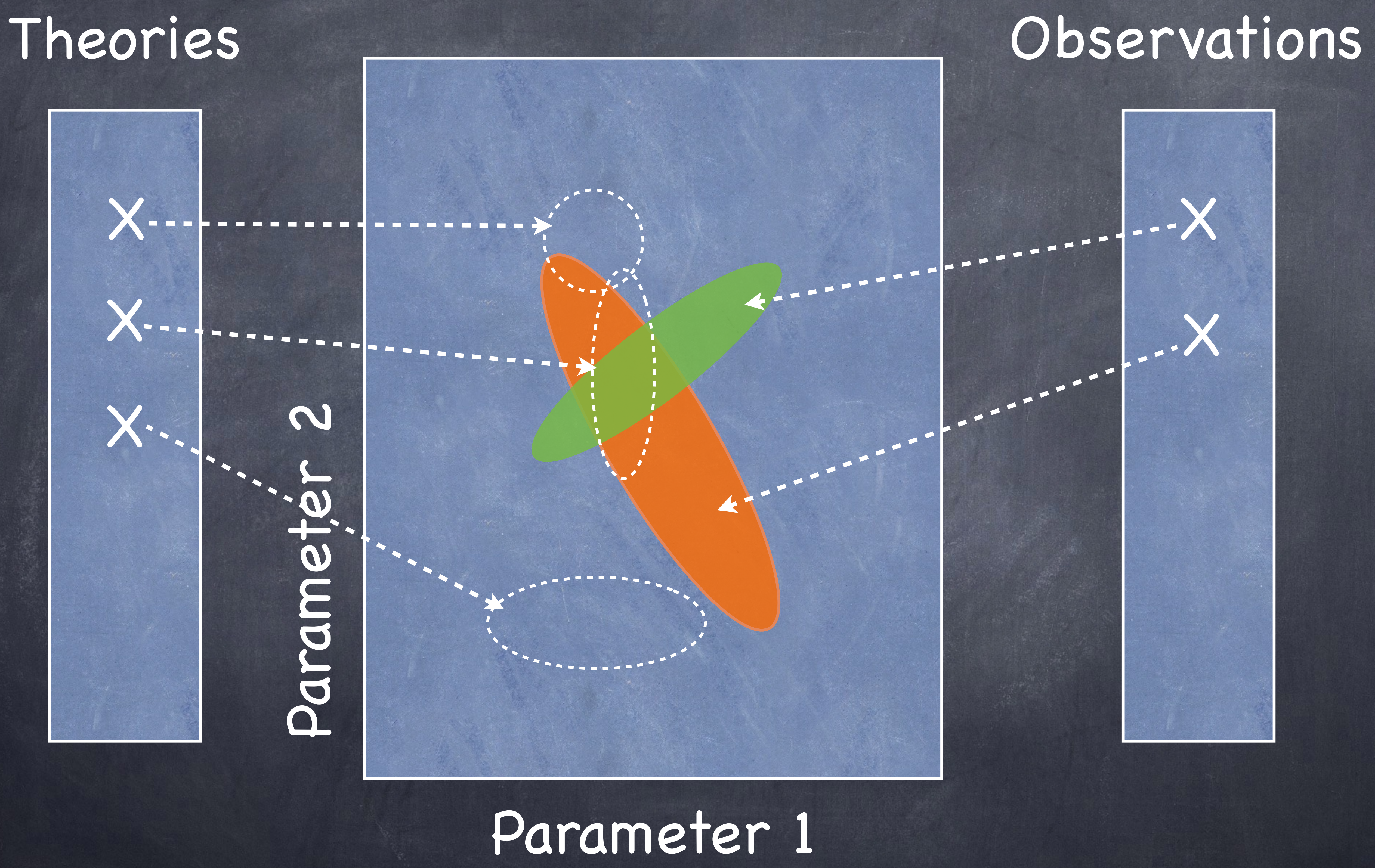
Phenomenological Framework

Characteristic observational signatures of broad classes of theories

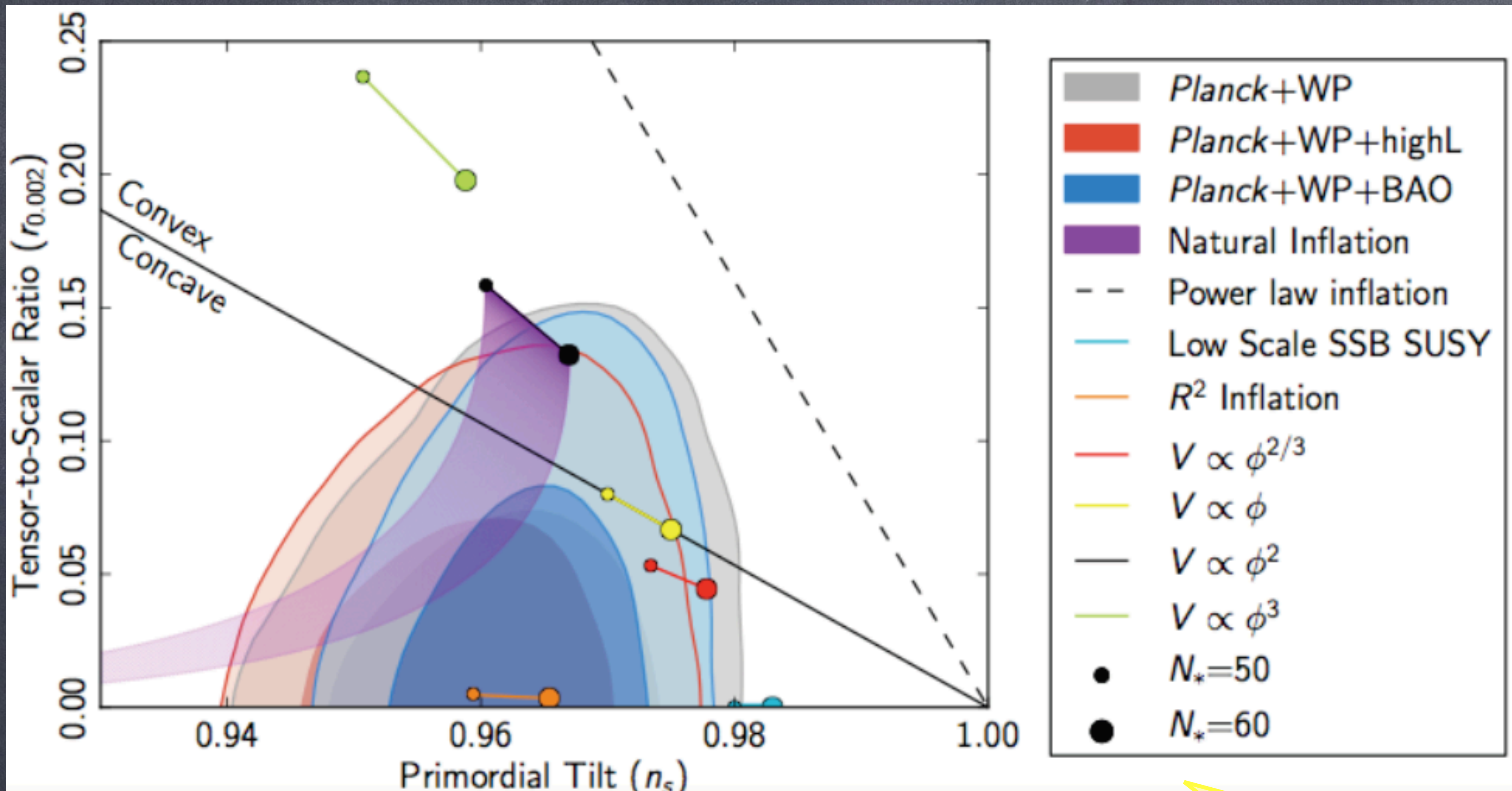
Constrained!

Observations

Use observational probes to uncover properties of dark sector theory


Theories
Observations
Parameter 2
Parameter 1

Planck constraints on inflation



Planck Collaboration: 1303.5082

Parameter space identified
Constrained
Populated with theories

Let's do this for Dark Energy

A theoretical path - DE parametrizations

Studying the nature of DE means: Studying the Equations of State

$$\Omega_X(a) \propto \exp\left[3\int_a^1 \frac{da'}{a'}(1+w(a'))\right]$$

which appears in the Hubble function as

$$H(a) = H_0\left[\Omega_m a^{-3} + \Omega_X(a)\right]^{1/2}$$

$$a \doteq \frac{1}{(1+z)}$$

CPL Parametrization

M. Chevallier, D. Polarski and E.V. Linder
gr-qc/009008

$$w(a) = w_0 + (1-a)w_a$$

$$E^2(z) = \Omega_m(1+z)^3 + (1-\Omega_m)(1+z)^{3(1+w_0+w_a)} \times \exp\left[\frac{-3w_a z}{1+z}\right]$$

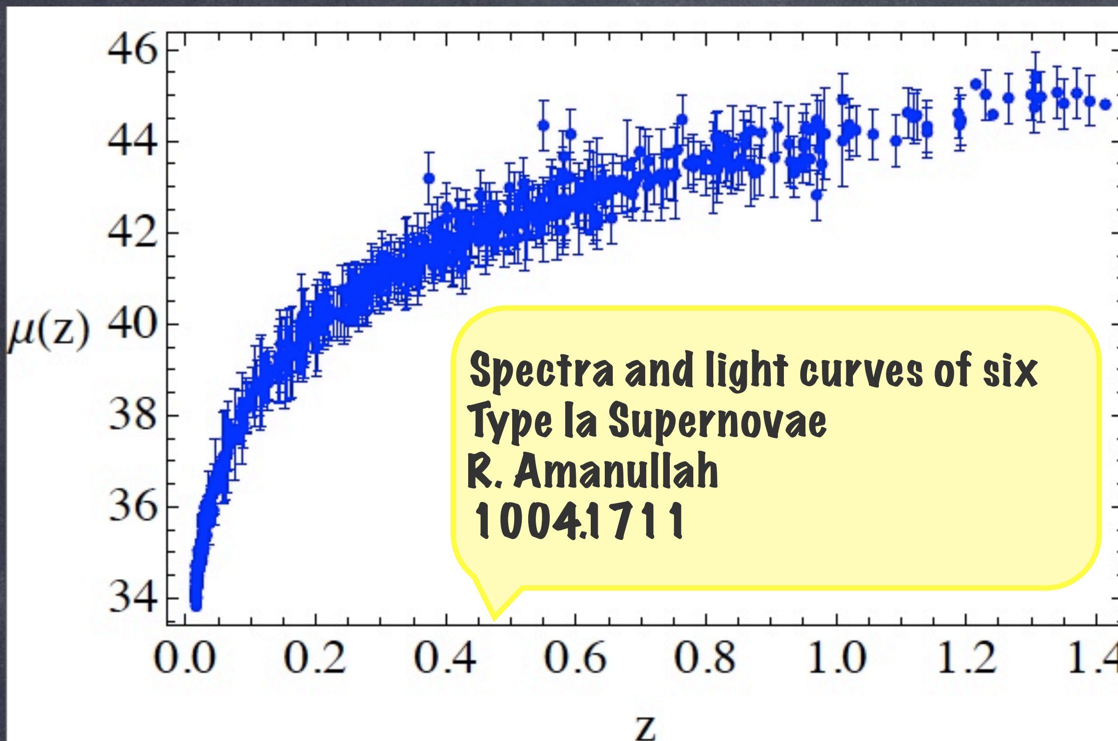
Low correlation Parametrization

Figures of merit for Dark Energy.
Y. Wang
08034295

$$w(a) = \left(\frac{a_c - a}{a_c - 1}\right) w_0 + \left(\frac{a-1}{a_c-1}\right) w_c$$

$$E^2(z) = \Omega_m(1+z)^3 + (1-\Omega_m)(1+z)^{3\left[1+\left(\frac{a_c w_0 - w_c}{a_c - 1}\right)\right]} \times \exp\left\{3\left(\frac{w_c - w_0}{a_c - 1}\right)\frac{z}{1+z}\right\}$$

Current astrophysical data

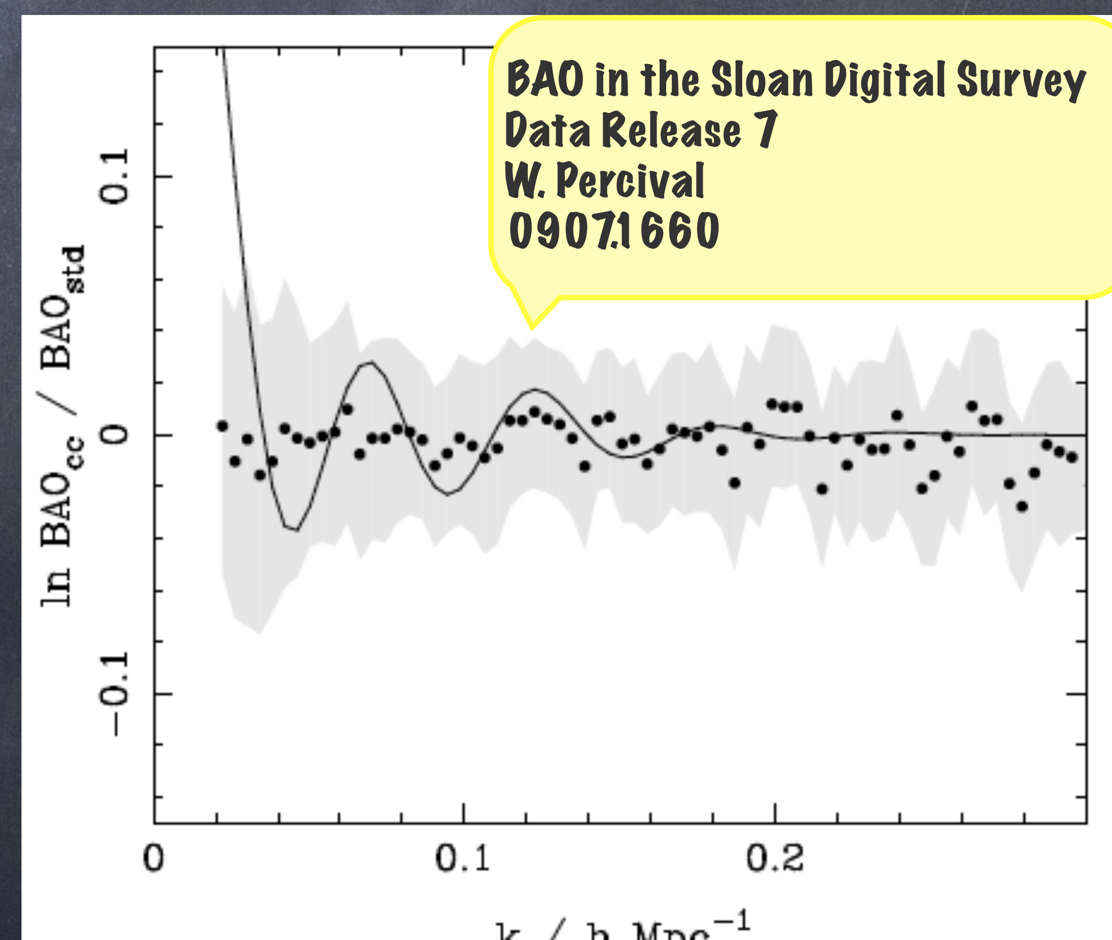


Supernovae: Union2 sample

$N_{SNeIa} = 557$ events over $0.015 < z < 1.4$

Baryonic Acoustic Oscillations

893319 galaxies over 9100 $\deg^2$



Mock data via iCosmo

SN simulations:

Taken into account the specifications of the Wide-Field Infrared Survey Telescope (WFIRST).

http://wfirst.gsfc.nasa.gov/

Analysis by using three fiducial models (WMAP7-year analysis):

1. Quiessence model derived by using only CMB data (CMB-oriented model): phantom model $w<-1$.
2. Quiessence model coming from combining CMB data with BAO (BAO-oriented model): regime is phantom (though only slightly).
3. Quiessence model coming from combining CMB data with SNeIa (SNeIa-oriented model): $w> -1$.

BAO simulations:

M. Martinelli, et al. 0901.4566

Observational targets + EUCLID survey

$$y(z) \equiv \frac{r(z)}{r_s(z_r)} \qquad \text{and} \qquad y'(z) \equiv \frac{r'(z)}{r_s(z_r)}$$

What about the priors?

$$\Omega_m h^2 = 0.1308 \pm 0.0008 \rightarrow \Omega_m = 0.237 \pm 0.023,$$
$$\Omega_b h^2 = 0.0223 \pm 0.0001 \rightarrow \Omega_b = 0.0405 \pm 0.0039.$$

And the "Tension" appears:

Indicates that the EoS parameters values obtained by using the dataset can differ from those obtained from another dataset.

C. Escamilla-Rivera, et al. 1103.2386

$$\chi^2_{tot} = \chi^2_{\mathrm{SNeIa}} + \chi^2_{\mathrm{BAO}},$$

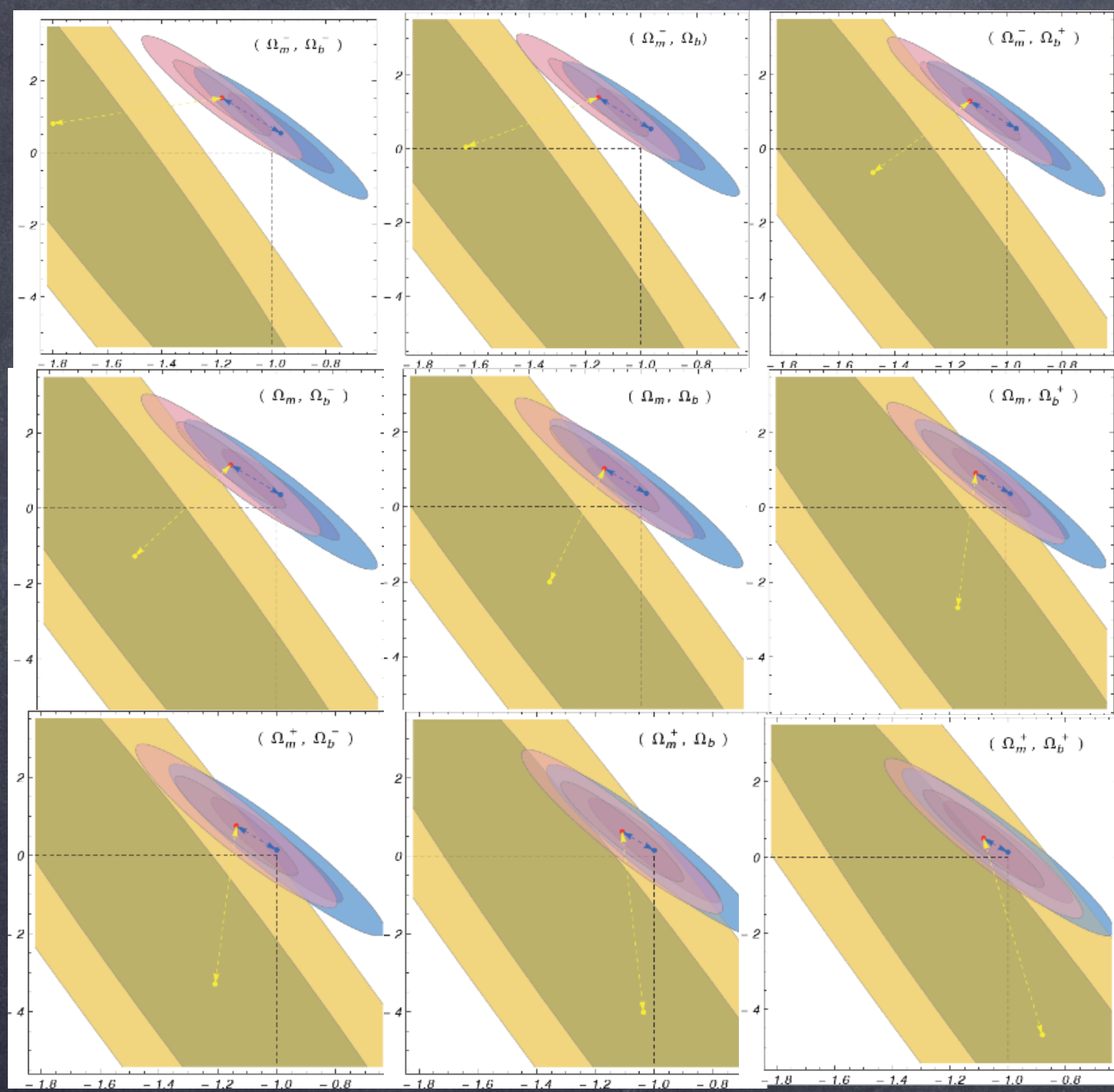
$$\Delta\chi^2_\sigma = \chi^2_{tot}(\theta_{\mathbf{SNeIa+BAO}}) - \chi^2_{tot}(\theta_{\mathbf{SNeIa}})$$

Real data

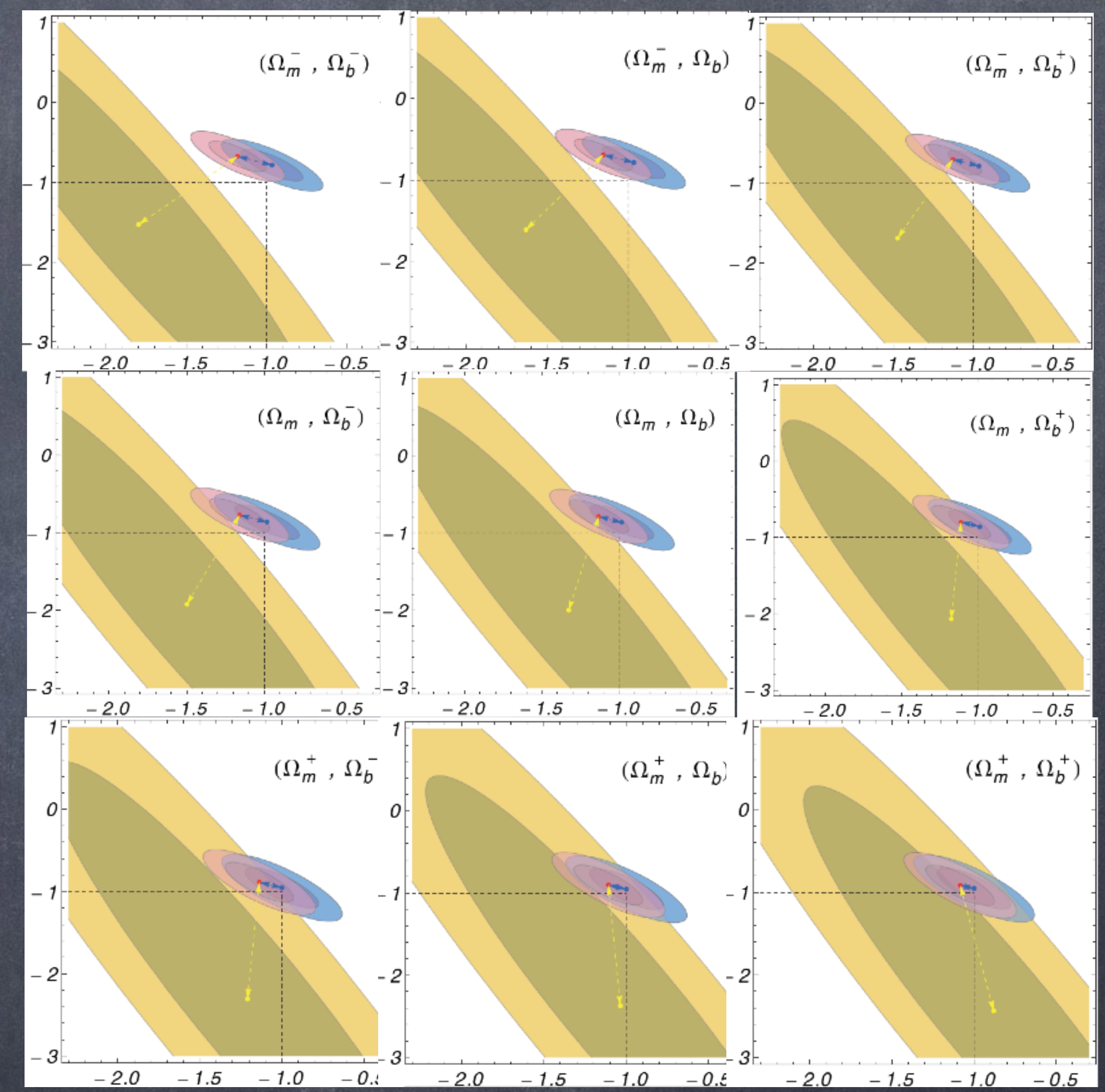
Ω_m

w_a

CPL parametrization



Low correlation parametrization



w_0

Ω_b

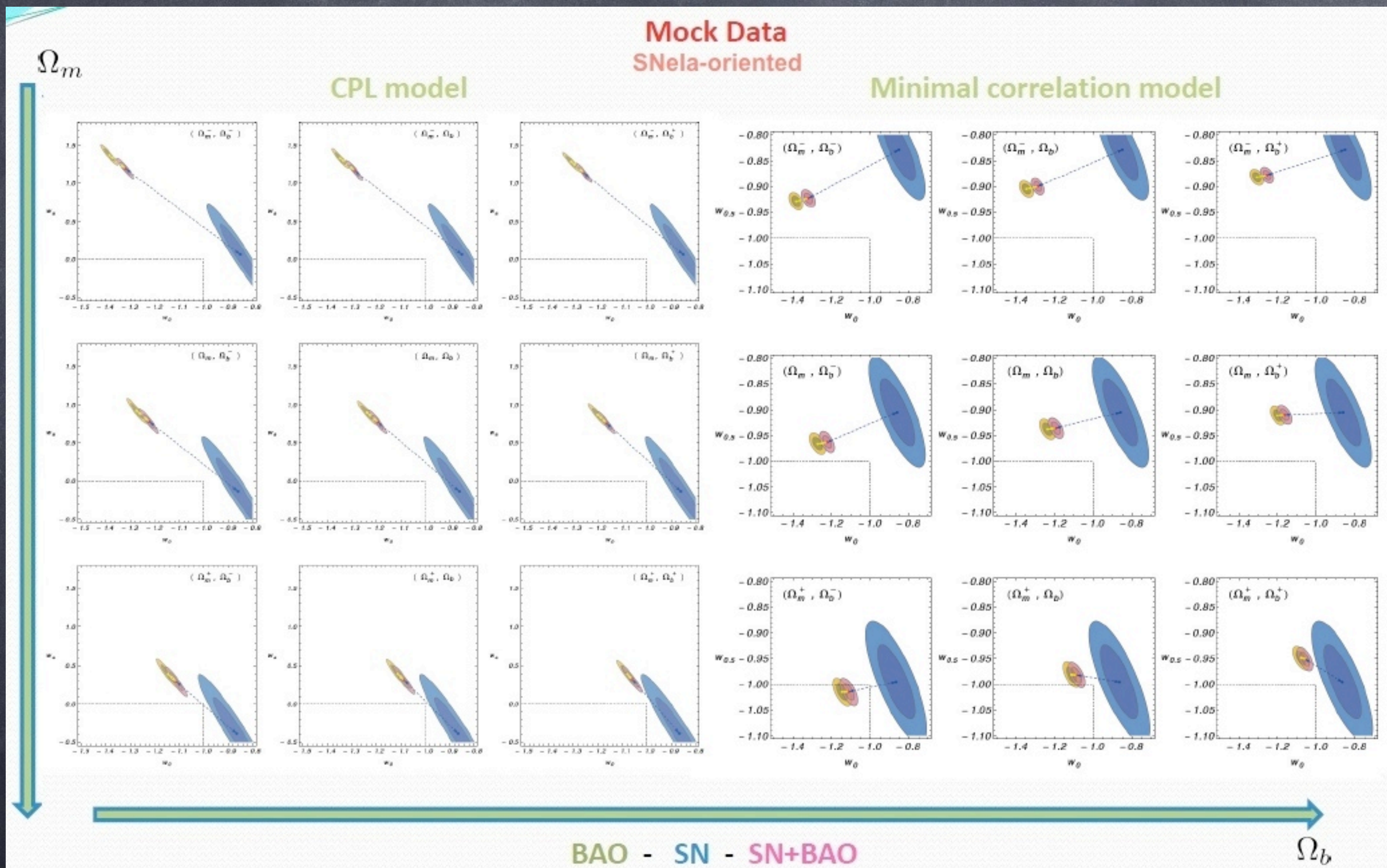
SN BAO SN+BAO

Mock data

Ω_m

CPL parametrization

Low correlation parametrization



w_a

w_0

Ω_b

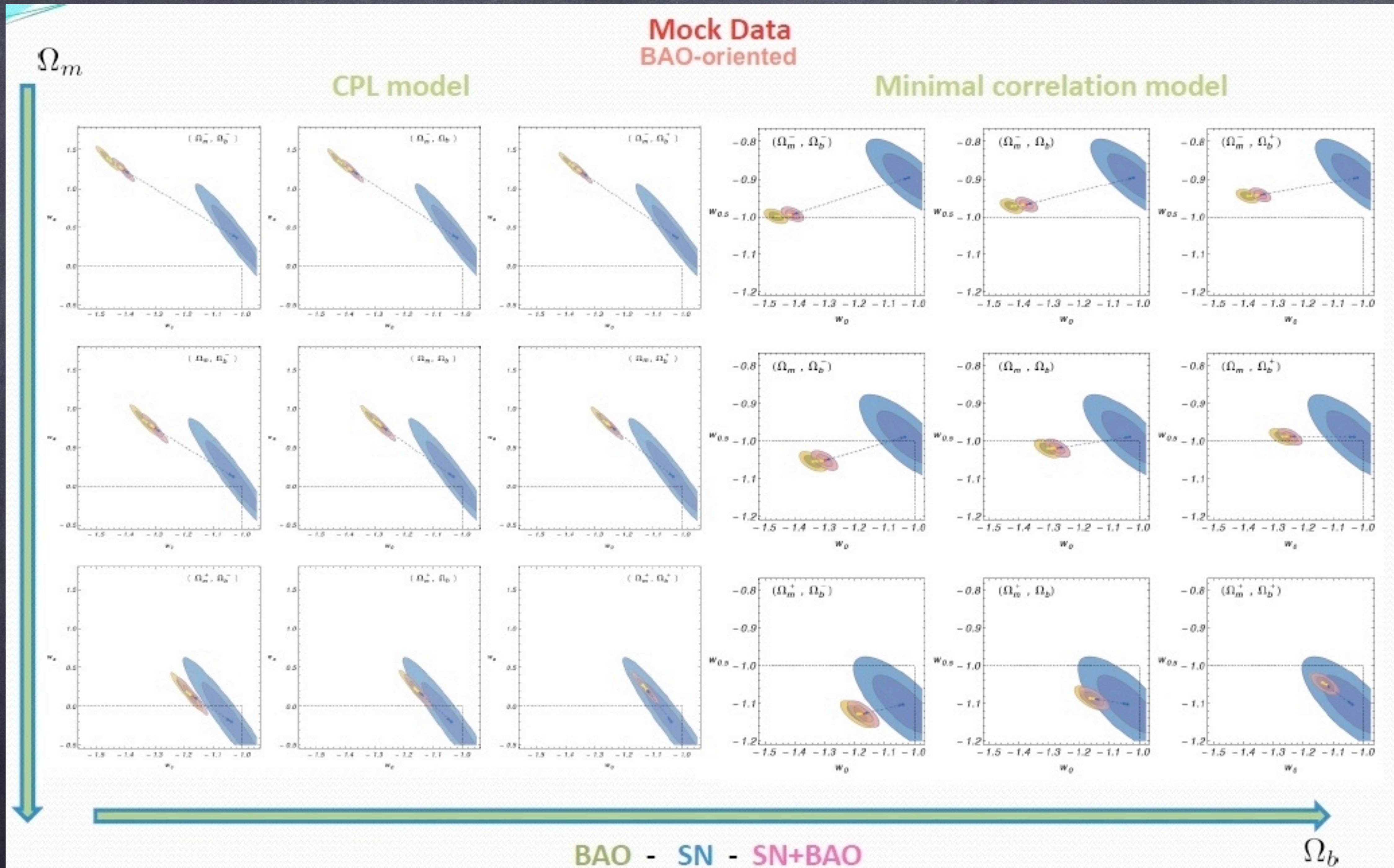
SN BAO SN+BAO

Mock data

Ω_m

CPL parametrization

Low correlation parametrization



w_a

w_0

Ω_b

SN BAO SN+BAO

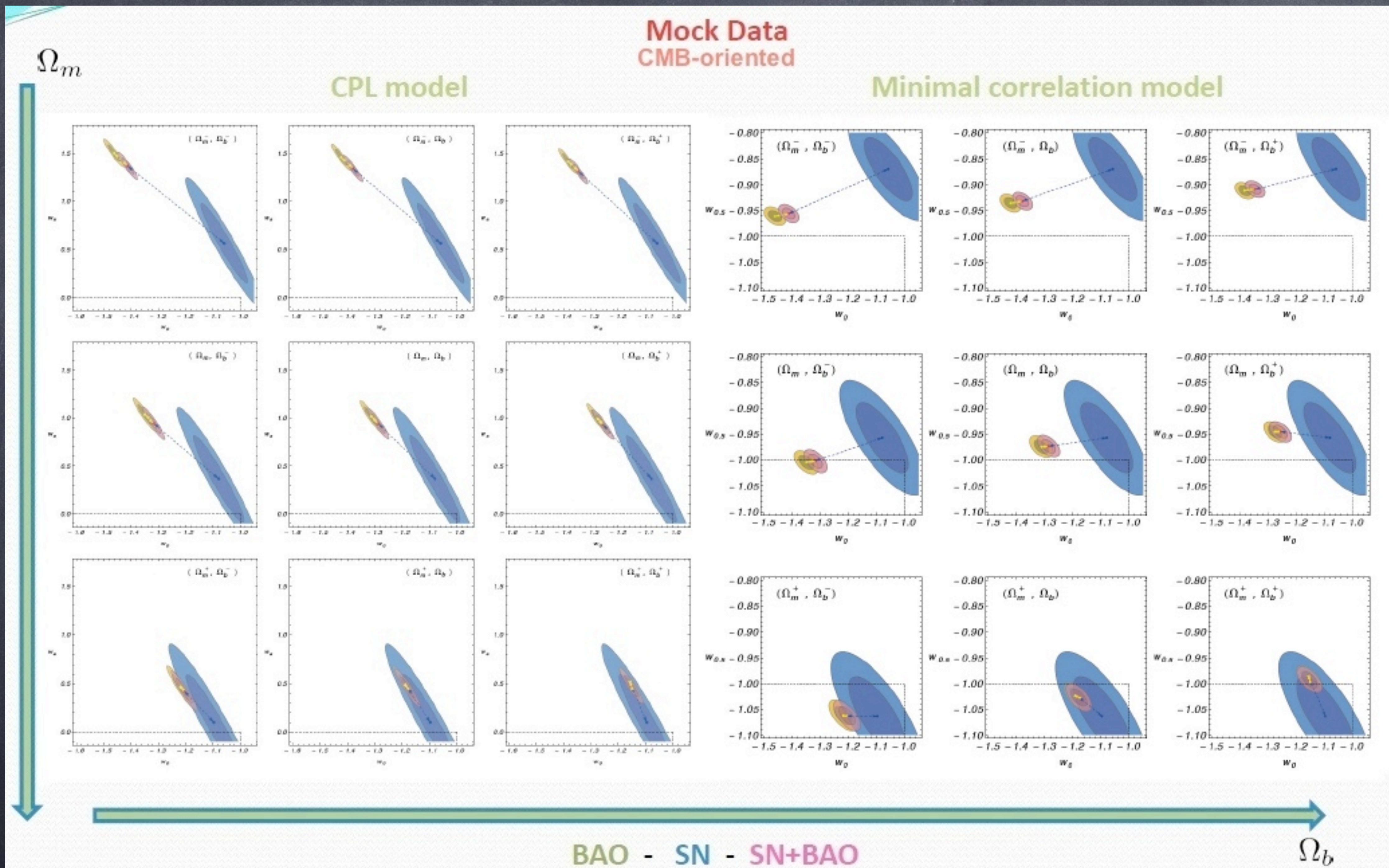
Mock data

Ω_m

CPL parametrization

Low correlation parametrization

w_a



w_0

Ω_b

SN BAO SN+BAO

Remarks

1. Confirmed that there is tension in the two datasets, it must be stressed that ours are the first time simulations of BAO data from both radial and transverse directions in the literature.

2. The tension depends strongly on the value of the cosmological priors.

3. For most priors and for the SNeIa+BAO combinations best fit, the Universe is currently phantom-like, its dark energy EoS parameter has become more negative recently, and was dark matter dominated at early times.

4. Future BAO data will improve constraints considerably making them far tighter.

And if you doubt its existence...

Future projects

Eddington inspire Born-Infeld gravity

Ingredients

- An Eddington action S_{Edd},

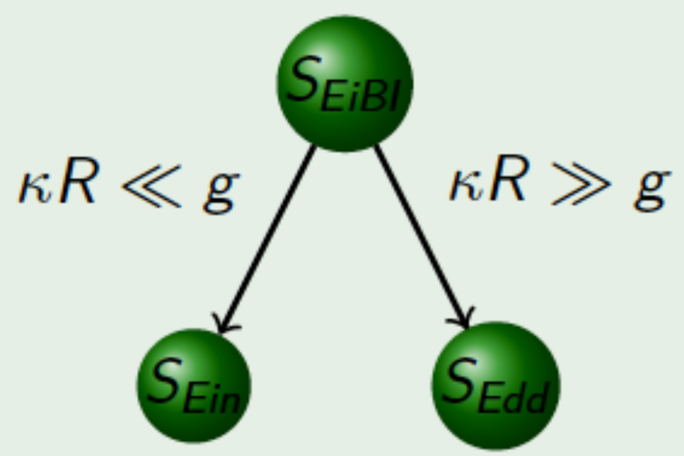
$$S_{Edd} = 2\kappa \int d^4x \sqrt{|R|}, \quad \text{where} \quad R_{\mu\nu} = R_{\mu\nu}(\Gamma).$$

Born-Infeld style + matter in the recipe

- Gravitational action

$$S_{EBI}[g, \Gamma, \Psi] = \frac{2}{\kappa} \int d^4x \left[\sqrt{|g_{\mu\nu} + \kappa R_{\mu\nu}(\Gamma)|} - \lambda\sqrt{g} \right] + S_m[g, \Psi].$$

EiBI Theory with $S_{Mat} = 0$



C. Escamilla-Rivera, M. Bañados and P. Ferreira. 1204.1691 and 1301.5264

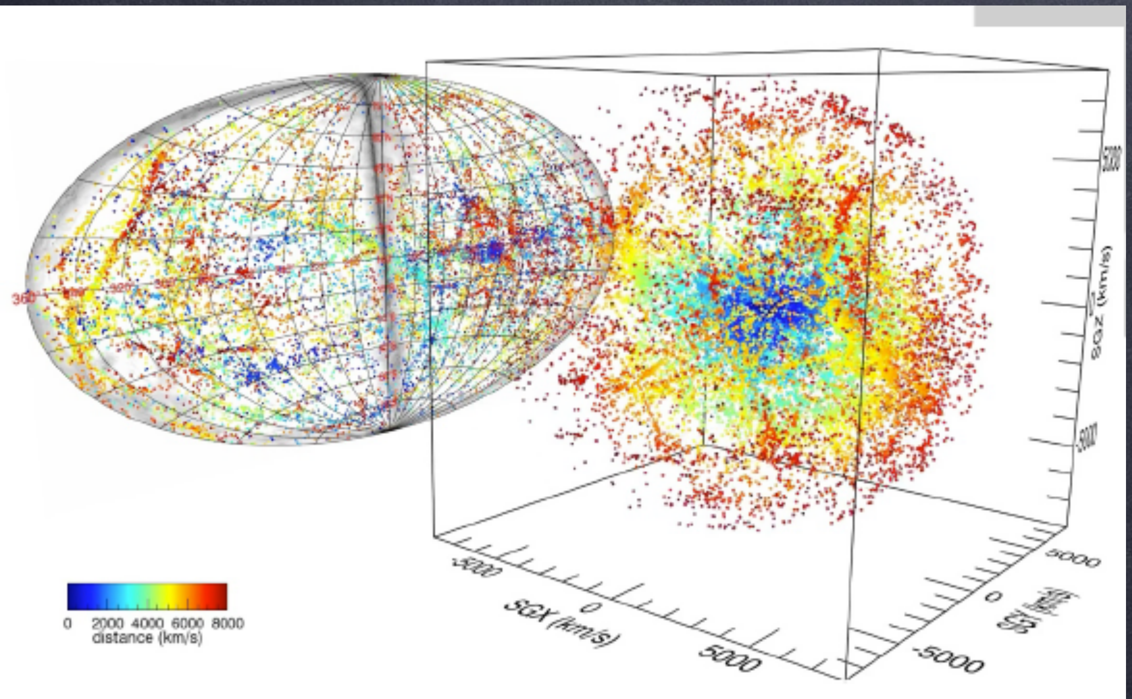
BAO Cosmography

Things we know:

- Cosmology: Sub-sector 1 $\rightarrow$ Cosmodynamics.
- Cosmology: Sub-sector 2 $\rightarrow$ Cosmography.
  1. Extracting the maximum amount of information from measured distance.
  2. Assuming Cosmological Principle.
  3. Studies without ever having to address how much dark energy and dark matter are needed.

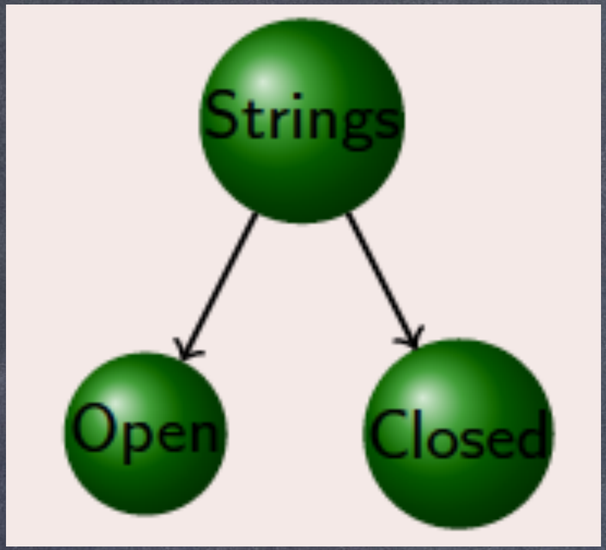
- Key relation $\rightarrow$ a Taylor expansion:

$$\begin{aligned}\frac{a(t)}{a(t_0)} &= 1 + H_0(t-t_0) - \frac{q_0}{2}H_0^2(t-t_0)^2 + \frac{j_0}{3!}H_0^3(t-t_0)^3 \\ &+ \frac{s_0}{4!}H_0^4(t-t_0)^4 + \frac{l_0}{5!}H_0^5(t-t_0)^5 + O[(t-t_0)^6],\end{aligned}$$

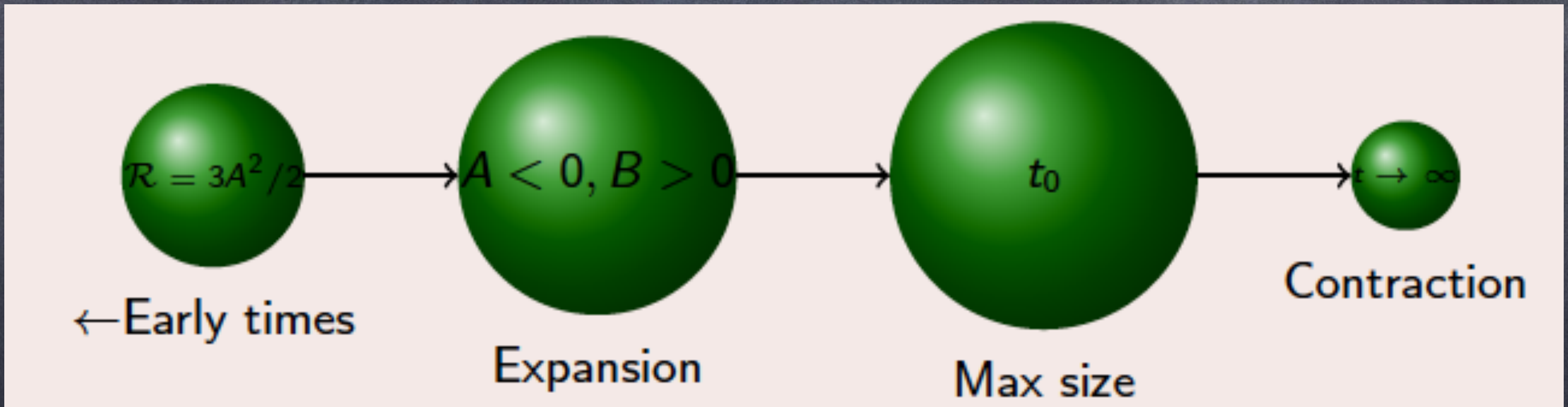


R. Lazkoz, J. Alcaniz, C. Escamilla-Rivera, V. Salzano. 1311.6817

Closed String Dark Energy



$$S = \frac{1}{2\kappa_0^2}\int d^{26}x\sqrt{-g_{26}}\; e^{-2\Phi_0}\left[R - (\nabla T)^2 - 2V(T)\right].$$



C. Escamilla-Rivera, O. Loaiza, O. Obregon
1110.6223, 1301.4915 and 1302.1644

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