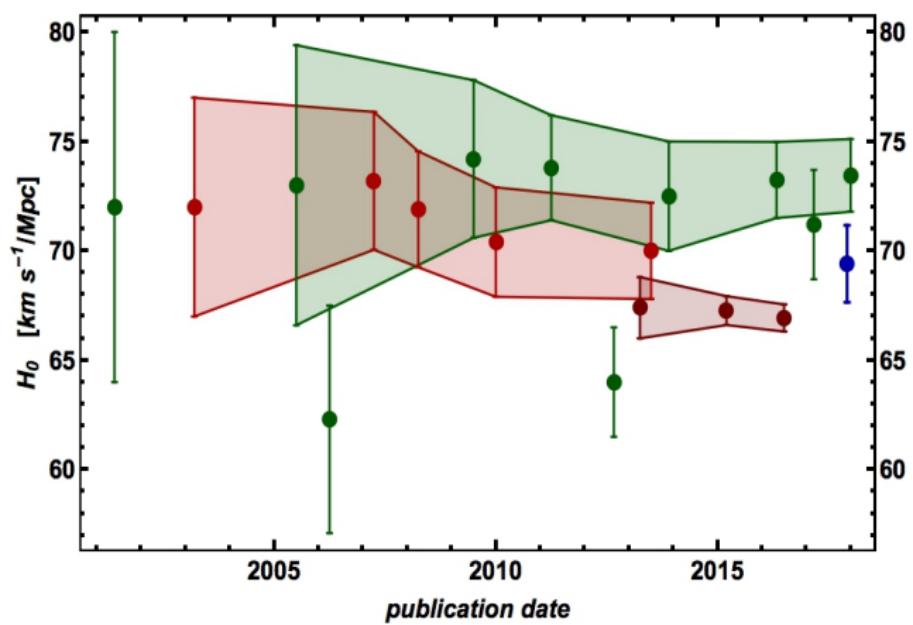


## Late time dynamics of cosmic expansion

Vladimir Luković,  
B. S. Haridasu, F. Tosone, N. Vittorio  
University of Tor Vergata

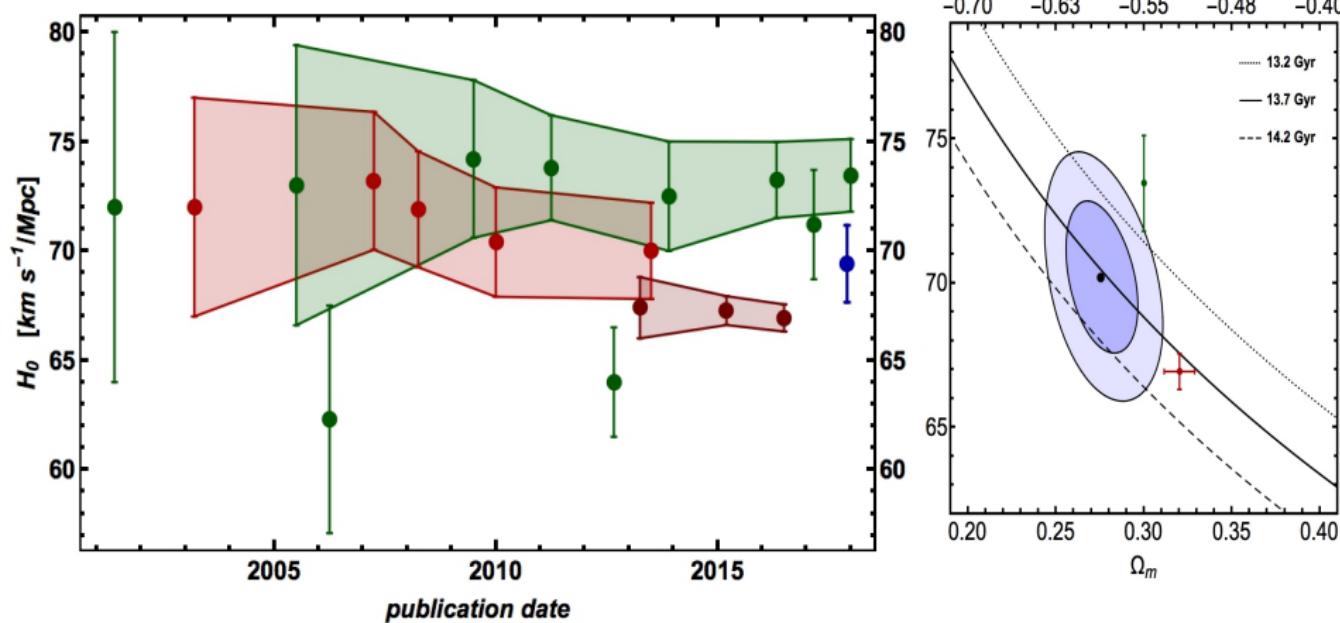
June 26, 2018, Ferrara

# $H_0$ problem

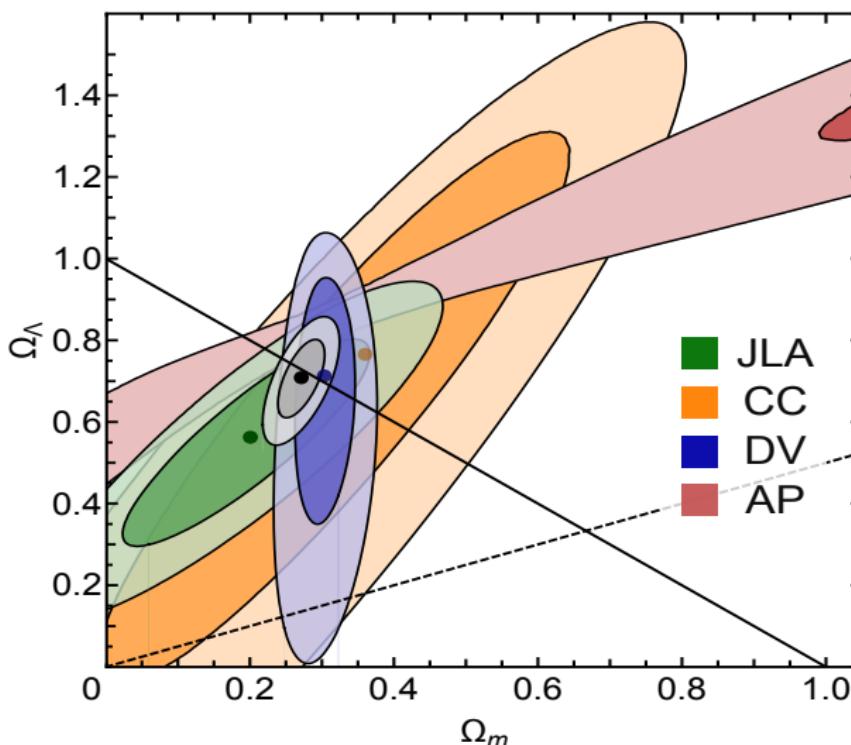


arXiv:1801.05765, arXiv:1607.05677

# $H_0$ problem



arXiv:1801.05765, arXiv:1607.05677

$k\Lambda$ CDM model

JLA – supernovae Ia  
CC – cosmic chronometers  
DV – isotropic component  
of BAO data  
AP – Alcock-Paczynski  
parameter

$$\begin{aligned}r_d &= 145.0 \pm 3.6 \text{ Mpc} \\H_0 &= 70.0 \pm 2.0 \text{ km/s Mpc} \\\Omega_m &= 0.272 \pm 0.021 \\\Omega_\Lambda &= 0.710 \pm 0.064\end{aligned}$$

arXiv:1711.03929

# FLRW metric

Einstein field equations

+

Cosmological principle

# FLRW metric

Einstein field equations

+

Cosmological principle



$$ds^2 = c^2 dt^2 - R(t)^2 \left[ \frac{dr^2}{1-kr^2} + r^2(d\theta^2 + \sin^2 \theta d\varphi^2) \right]$$

Friedmann-Lemaître-Robertson-Walker metric

# Inhomogeneous pressureless cosmic fluid

Einstein field equations

+

Isotropy

+

Homogeneity

↓↓

Standard Model

# Inhomogeneous pressureless cosmic fluid

Einstein field equations

+

Isotropy

+

~~Homogeneity~~

# Inhomogeneous pressureless cosmic fluid

Einstein field equations  
+  
Isotropy

# Inhomogeneous pressureless cosmic fluid

Einstein field equations

+

Isotropy

+

$p = 0$

# Inhomogeneous pressureless cosmic fluid

Einstein field equations

+

Isotropy

+

$p = 0$

↓↓

$$ds^2 = c^2 dt^2 - \frac{(\partial R/\partial r)^2}{1+K(r)} dr^2 - R(t, r)^2 (d\theta^2 + \sin^2 \theta d\varphi^2)$$

Lemaître-Tolman-Bondi metric

## Cosmic expansion

$$\frac{H^2}{H_0^2} = \Omega_\gamma \frac{{R_0}^4}{R^4} + \Omega_m \frac{{R_0}^3}{R^3} + \Omega_k \frac{{R_0}^2}{R^2} + \Omega_\Lambda$$

FLRW metric

# Cosmic expansion

$$\frac{H^2}{H_0^2} = \Omega_\gamma \frac{R_0^4}{R^4} + \Omega_m \frac{R_0^3}{R^3} + \Omega_k \frac{R_0^2}{R^2} + \Omega_\Lambda$$

FLRW metric

# Cosmic expansion

$$\frac{H^2}{H_0^2} = \Omega_m \frac{R_0^3}{R^3} + \Omega_k \frac{R_0^2}{R^2} + \Omega_\Lambda$$

FLRW metric

# Cosmic expansion

$$\frac{H(t)^2}{H_0^2} = \Omega_m \frac{{R_0}^3}{R(t)^3} + \Omega_k \frac{{R_0}^2}{R(t)^2} + \Omega_\Lambda$$

FLRW metric

# Cosmic expansion

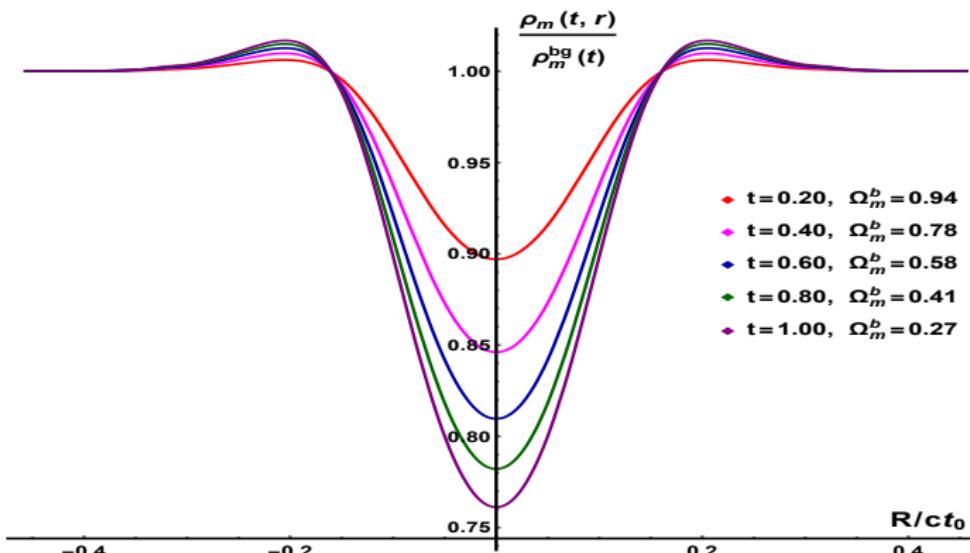
$$\frac{H(t)^2}{H_0^2} = \Omega_m \frac{R_0^3}{R(t)^3} + \Omega_k \frac{R_0^2}{R(t)^2} + \Omega_\Lambda \quad \text{FLRW metric}$$

$$\frac{H(t, r)^2}{H_0(r)^2} = \Omega_m(r) \frac{R_0(r)^3}{R(t, r)^3} + \Omega_k(r) \frac{R_0(r)^2}{R(t, r)^2} + \Omega_\Lambda(r) \quad \text{LTB metric}$$

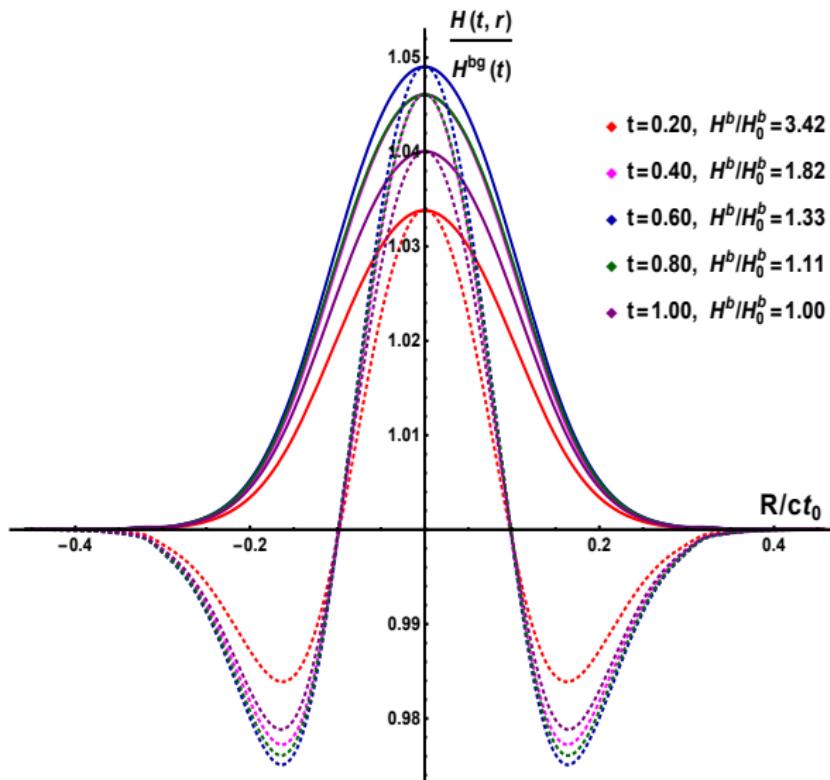
## Cosmic expansion

$$\frac{H(t)^2}{H_0^2} = \Omega_m \frac{R_0^3}{R(t)^3} + \Omega_k \frac{R_0^2}{R(t)^2} + \Omega_\Lambda \quad \text{FLRW metric}$$

$$\frac{H(t, r)^2}{H_0(r)^2} = \Omega_m(r) \frac{R_0(r)^3}{R(t, r)^3} + \Omega_k(r) \frac{R_0(r)^2}{R(t, r)^2} + \Omega_\Lambda(r) \quad \text{LTB metric}$$



# $\Lambda$ LTB model



$$\Delta = \frac{\Delta \rho_m}{\rho_m} = -30\%$$

fitting the data:

$$r_d = \sim 145.0 \text{ Mpc}$$

$$H_0 = \sim 73.2 \text{ km/s Mpc}$$

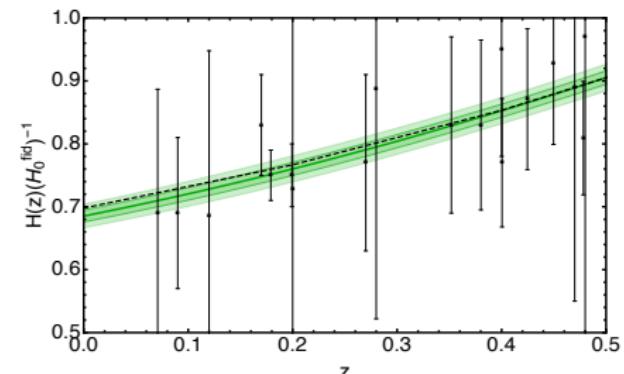
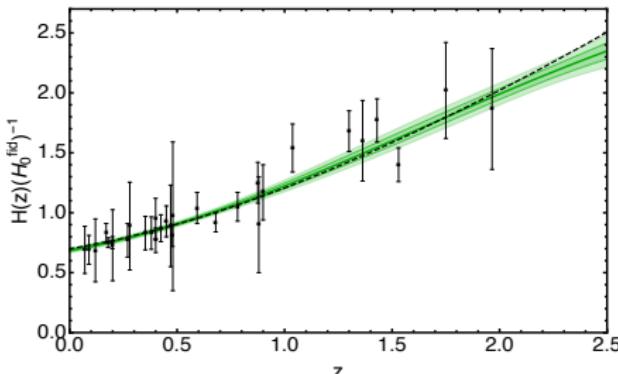
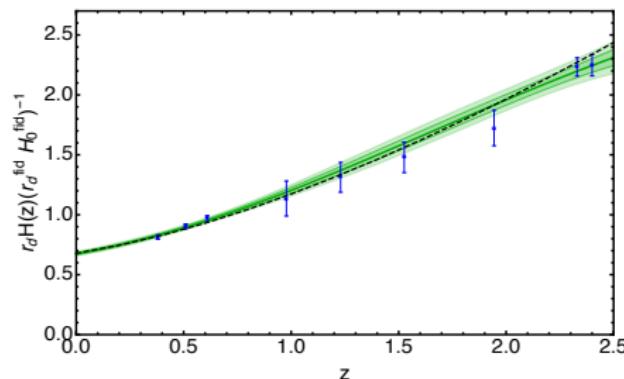
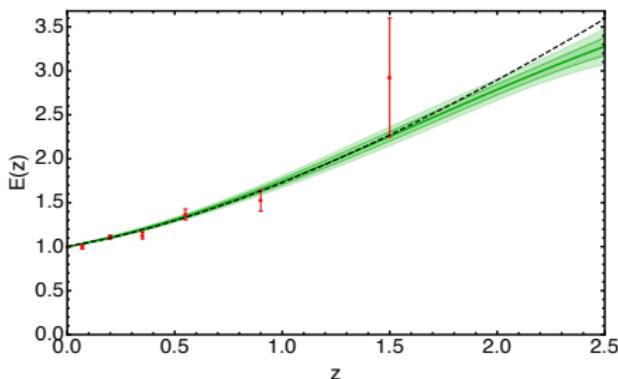
$$\Omega_m = \sim 0.27$$

$$\Omega_\Lambda = \sim 0.73$$

$$\Delta \text{ AIC} = \sim 0.8$$

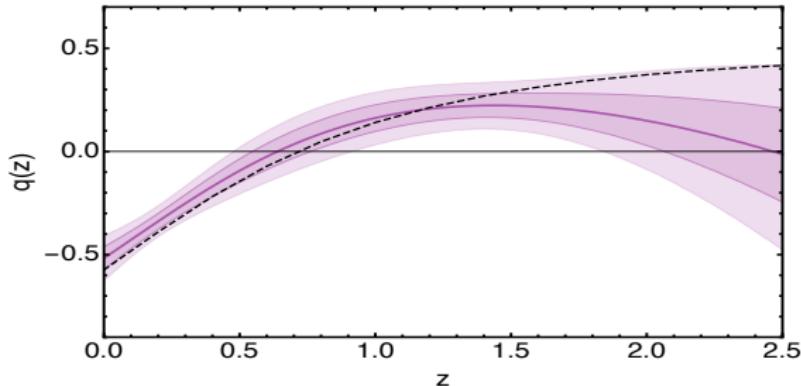
– work in progress –

## Gaussian process reconstructions, arXiv:1805.03595

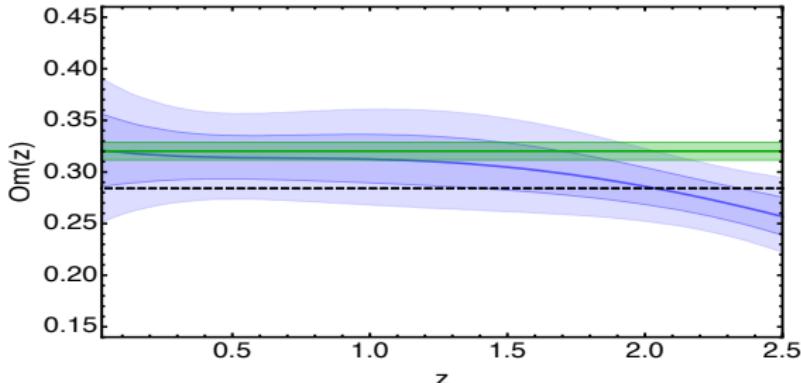


## Model diagnostics

$$q(z) = (1+z) \frac{H'(z)}{H(z)} - 1$$



$$Om(z) = \frac{E(z)^2 - 1}{(1+z)^3 - 1}$$



arXiv:1805.03595

# Scalar field models

CPL parametrization

$$w(z) = w_0 + w_a \frac{1}{1+z}$$

scalar field Lagrangian

$$\mathcal{L} = -\frac{1}{2} \partial^\mu \phi \partial_\mu \phi - V$$

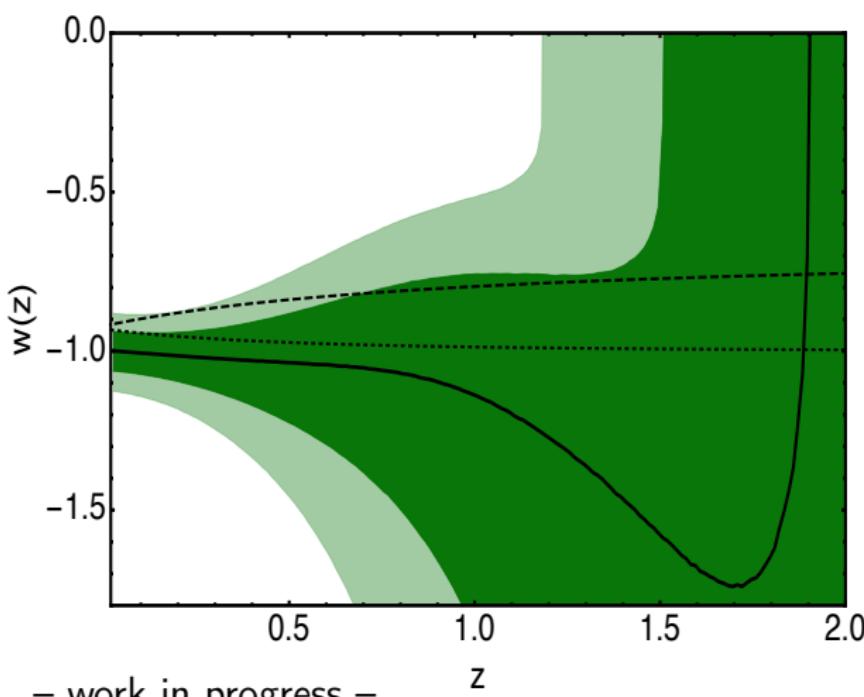
$V(\phi)$

PL  $\phi^n$

IPL  $\phi^{-n}$

**PNGB**  $\cos \frac{\phi}{f} + 1$

SUGRA  $\phi^{-n} \exp \frac{\phi^2}{2M_{Pl}^2}$



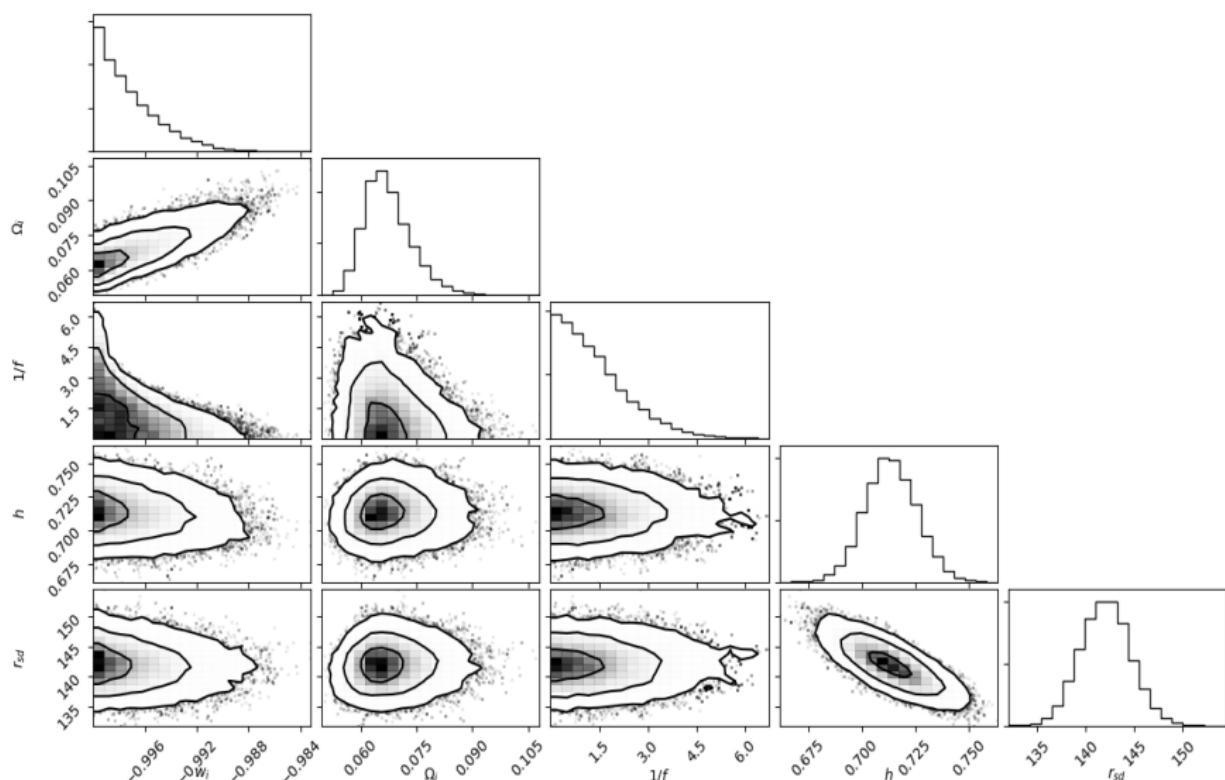
$H_0$  problem  
oo

$\Lambda$ LTB model  
oooo

Model-independent  
oo

Dark energy models  
ooo

# PNGB constraints



# Conclusions & To-do list

What we have done:

- Low-redshift observables
- Constraints on FLRW models
- Effect of local matter density profile
- Model-independent reconstruction
- Scalar field models

# Conclusions & To-do list

What we have done:

- Low-redshift observables
- Constraints on FLRW models
- Effect of local matter density profile
- Model-independent reconstruction
- Scalar field models

What more we can do:

- CMB data
- Gravitational lensing & structure formation data
- Reconstruction of local density profile & observer's position
- Wider application of model-independent reconstructions
- ...