## Scalar field dark energy reconstruction from SNe Ia data



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## Plan

- Modern problems of physics
- Alternative theories of gravity
- General approaches on the way of searching DE
- **Mock data analysis**
- Real data analysis
- **EXEC** Conclusion

# Why we do cosmology?



*Why we are not satisfied by Einstein GR?* 



## Modern physics problems and questions addressed by cosmologists

- We have several questions to be answered: DE, DM, Inflation, Hierarchy, Quantum gravity (black holes) and a dream of unification
- Can we touch all these questions?-is a bigger dream.
- We also have excellent working theory for many cases so the physicists are reasonably sceptic.





# Galaxy Rotational curve

*Dark Matter or …*



## Data and theory



## Suggested theories

### Modified Theories of Gravity

Dark Energy model

Extra dimensional theories



## GR and Lambda

*data and logics wants more*

# General approaches

### Horndensky





### Equations of motion Here we show that there always exist a single field potential *V* () that reproduces any observed Hubble parameter I. POTENTIAL SUPERIOR SU Here we show that there always exist a single field potential *V* () that reproduces any observed Hubble parameter Here we show that there always exist a single field potential *V* () that reproduces any observed Hubble parameter as a function of redshift, *H*(*z*). We assume the Universe contains matter with a known generic equation of state *w<sup>m</sup>* and a single canonical minimally coupled scalar field. The two independent Einstein equations are (we put 8⇡*G* = 1) as a function of redshift, *H*(*z*). We assume the Universe contains matter with a known generic equation of state *w<sup>m</sup>* and a single canonical minimally coupled scalar field. The two independent Einstein equations are (we put 8⇡*G* = 1)

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The project is to find constraints on the potential at various redshifts (i.e without parameters or, alternatively,  $\mathbb{R}$ 

some simple parametrization as eg inflationary slow roll parameters) from present and future supernovae and BAO

guarantee however that the formal solution solution

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<sup>2</sup> <sup>+</sup> *<sup>V</sup>* () (1)

<sup>2</sup>*H*˙ <sup>=</sup> ˙<sup>2</sup> ⇢*m*(1 + *<sup>w</sup>m*) (2)

<sup>2</sup> <sup>+</sup> *<sup>V</sup>* () (1)

Friedmann equations  $3H^2 = \rho_m + \frac{\phi^2}{2} +$ Lets write them in terms of z  $3H^2 = \rho_m + \frac{\dot{\phi}^2}{2}$  $\frac{2}{2} + V(\phi)$  $2\dot{H} = -\dot{\phi}^2 - \rho_m(1 + w_m)$  $\int^{2}(1+z)^{2} \left(\frac{d\varphi}{dz}\right) = 2(1$  $dz$ <sup>*i*</sup>  $H(z)^2(1+z)^2\left(\frac{d\phi}{dz}\right)^2 = 2(1+z)H(z)\frac{dH}{dz} - \rho_m(z)$ *dz* ⇢*m*(*z*)(1 + *<sup>w</sup>m*(*z*)) (3) (1 + *z*)  $\frac{1}{2}$   $\frac{1}{2}$  $dz$   $2$   $(\infty m(\infty) -1)$  $3H^2 = 0$  $3H^2 = \rho_m + \frac{\phi^2}{2} + V(\phi)$  $2\dot{H} = -\dot{\phi}^2 - \rho_m(1+w_m)$  $\bullet$  Lets write them in terms of z  $= 2(1 + z)H(z)$ *dH*  $H(z)^2(1+z)^2\left(\frac{dy}{dz}\right) = 2(1+z)H(z)\frac{dZ}{dz} - \rho_m(z)(1+w_m(z))$  $(3H(z))^2$  $V = 3H(z)^2 - (1+z)H(z)\frac{dH(z)}{dz} + \frac{\rho_m(z)}{2}(w_m(z) - 1)$  $\frac{1}{2}$  in terms c = 2(1 + *z*)*H*(*z*) *dz* ⇢*m*(*z*)(1 + *<sup>w</sup>m*(*z*)) (3)  $(1 + z)$  $d\rho_m$  $(1+z)\frac{w\mu_m}{dz} = 3\rho_m(z)(1+w_m(z))$ <sup>2</sup> (*wm*(*z*) 1) (5)  $\beta = -\phi^2 - \rho_m(\phi)$  $\frac{1}{1}$  $d + w_m$ zolo *maxo* diom n (1 + *z*) *d*⇢*<sup>m</sup> dz* ∴ *wm*(*x*)(1 + *wm*(*x*)) (4)  $V = 3H(z)^2 - (1+z)H(z)$  $\frac{dH(z)}{dz} + \frac{\rho_m(z)}{2}(w_m(z) - 1)$ 



## Ia type SuperNova as a standard candle

*The farer it is the fainter it gets*

### How we will use data from Ia Type SN case. rom la is voe Sisteman  $\log$  binded dota from la ima  $\mathbb{C}$  $s = 0.1$  and  $s = 0.0$  becomes the different so we have different so we keep this notation for general  $s = 0.0$ 1 I li use data .t rom  $\sqrt{1}$  $\mathbf{u}$ use data n'e  $rac{1}{\sqrt{1-\frac{1}{2}}}$ same value for alternative binning it will be different so we keep this notation for general be different so w  $\mathcal{N}$ The process of binned data is as follows: first we transform distance modulus and its errors into

<sup>i</sup> )/N<sup>j</sup> , where N<sup>j</sup> is the number of supernovae in jth bin. We also define δz – the

σµ<sup>j</sup> =

comoving distance DM:

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same value for δz but for alternative binning it will be different so we keep this notation for general

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 $\mathcal{F}_{\mathcal{A}}$  are equal to each other, but in the general case it is not true, so we keep it is not true, so we keep

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error propagation  $\frac{1}{\epsilon}+|D'_M|\frac{\delta z}{\epsilon}$  $\delta z_1 + \delta z_2$ z2 − z1  $\overline{D_{M}}$  $M,2$  $\left( \frac{-D_{M,1}}{2} \right) = \cdots = \frac{\delta}{\delta}$  $\delta$ <sup>2</sup>  $\overline{a}$  $+\delta D_{M,1}$ <br>+  $|D'_M|$  $\frac{\delta z_2 + \delta z_1}{\delta z_1 + \delta z_2 + \delta z_1}$  $\frac{2 + 0z_1}{2}$ ation  $E(G(D_M) - 0$   $\frac{z_2 - z_1}{z_2 - z_1} - \cdots - \frac{z_2 - z_1}{z_2 - z_1}$  $\delta(D'_M) = \delta\left(\frac{D_{M,2} - D_{M,1}}{z_2 - z_1}\right) = \cdots = \frac{\delta D_{M,2} + \delta D_{M,1}}{z_2 - z_1} + |D'_M|\frac{\delta z_2 + \delta z_1}{z_2 - z_1}$  $\mathbf{t}$  $(D_{M,2} - D_{M,1})$  $z_2 - z_1$  $\bigg) = \cdots = \frac{\delta D_{M,2} + \delta D_{M,1}}{\delta D_{M,2}}$  $z_2 - z_1$  $+$   $|D'_M|$  $\delta z_2 + \delta z_1$  $z_2 - z_1$ 

### Reconstruction of the field δ stru  $\overline{1}$  $\overline{\phantom{a}}$  $\cdot$  tion  $\overline{1}$  of  $\overline{1}$  $+ h$  $\Delta$  $field$ The equations (4)–(5) give us  $\mathcal{L}(\mathcal{A})$  and (depending between  $\mathcal{L}(\mathcal{A})$  and  $\mathcal{L}(\mathcal{A})$

3H(z)H<sup>2</sup>

<sup>0</sup> (1 + <sup>z</sup>) <sup>−</sup> <sup>Ω</sup><sup>0</sup>

<sup>H</sup><sup>2</sup> ,

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### Then we need to calculate

dz "2

3H<sup>2</sup>  $\overline{a}$ 

dz 2022 **.** 

$$
\frac{d\phi}{dz} = \sqrt{\left(\frac{d\phi}{dz}\right)^2} \Rightarrow \delta\left(\frac{d\phi}{dz}\right) = \delta\left(\left(\frac{d\phi}{dz}\right)^2\right) / \left(2\frac{d\phi}{dz}\right);
$$
  

$$
\phi = \int \left(\frac{d\phi}{dz}\right) dz \cong \left(\frac{d\phi}{dz}\right) |_{z_{central}} \Delta z \Rightarrow \delta\phi = \Delta z \times \delta\left(\frac{d\phi}{dz}\right)
$$

In the section state described scheme first on the described scheme first on the synthetic and then on the real then on the real then on the synthetic and then on the real then on the real then on the real then on the rea

 $\mathcal{L}^{\text{max}}_{\text{max}}$  with H0  $\mathcal{L}^{\text{max}}_{\text{max}}$  and  $\mathcal{L}^{\text{max}}_{\text{$ 

integrated to get  $\phi$  (with an additive constant) and  $\phi$  (z) and  $\phi$  (z) and  $\phi$  (z) could be used be used by us

Note that the reconstruction will be done up to unknown constant  $\cdot$  11.1 1  $I$  this section we test our section with synthetic  $\mathcal{A}$  and  $\mathcal{A}$  for data. We generate binned data for d

### Error propagation r pro **2** <del>−</del> ppagatic  $\overline{v}$  $\mathbf{m}$  $\mathcal{L}(\mathcal{L})$  (see Eq. (2)) and H/ (see Eq. (3)) and H/ (see Eq. (3)) calculated, we can recover the potential eq. (3) derivative of H(z) with respect to z: - Η + Θ  $\overline{H}$ general for of the errors expression. Similarly to the described above procedure, we calculate the described a

Potential  $\tilde{v} =$  $8\pi G$  $\overline{3H_0^2}$  $V(z) = \frac{H(z)^2}{H^2}$  $\overline{H^2_0}$  $-\frac{H(z)H'(z)(1+z)}{2H^2}$  $\overline{3H_0^2}$  $-\frac{\Omega_m^0(1+z)^3}{2}$  $\frac{1}{2}$  $V = \frac{3H_0^2}{8H_0^2}V(z) - \frac{H_0^2}{H_0^2} - \frac{3H_0^2}{8H_0^2}$  $\mathcal{R}_{\pi} C = H(z)^2 - H(z)H'(z)(1 + z) = \Omega^0 (1 + z)^3$  $\frac{1}{2}$  $Q<sup>0</sup>$   $\ell$  $N = \frac{1}{3H^2}V(z) = \frac{V}{H^2} - \frac{V}{3H^2}V(z) = \frac{1}{3}$ 

derivative of H(z) with respect to z:

error

$$
\delta\tilde{V}=\frac{2H\delta H}{H_0^2}+\frac{(1+z)H'\delta H+H(1+z)\delta H'+HH'\delta z}{3H_0^2}+\frac{3(1+z)^2\Omega_m^0\delta z}{2}
$$

general for other expression. Similarly to the errors expression. Similarly to the described above procedure, we calculate the measurement above procedure.

to reconstruct  $\alpha$  ( $\alpha$  ) (again  $\alpha$  ), with a discussion constant kept in mind). For simplicity we are using  $\alpha$ 

rectangle method for integration, so the error propagation for the remaining steps is as follows:

= δ

#!dφ

= δ

2

dz "2

/

/ ! 2

2

rectangle method for integration, so the error propagation, so the error propagation for the remaining steps is

adhaniy <u>da "</u>

dz "

The equations (4)–(5) give us  $\mathcal{A}$  (d) and (d) and (d) and (d) below  $\mathcal{A}$  (if  $\mathcal{A}$ 

integrated to get  $\phi$  (with an additive constant). And  $\phi$  (z) and  $\phi$  (z) and  $\phi$  (z) and  $\phi$  could be used be used by used by

to reconstruct V ( $\frac{1}{\sqrt{2}}$  ( $\frac{1}{\sqrt{2}}$  ). For simplicity we are using in mind, we are using  $\frac{1}{\sqrt{2}}$ 

 $\mathbb{R}$  for other expression. Similarly to the described above procedure, we calculate the described above processes  $\mathbb{R}$ 

 $\mathcal{L}(\mathcal{L})$  (see Eq. (2)) and H $\mathcal{L}(\mathcal{L})$  and H $\mathcal{L}(\mathcal{L})$  can recover the potential eq. (3)) can recover the potential eq. (3)

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dz "

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. (3)

δz2 + δz1

z2 − z1

 $\mathcal{A}$ 

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kinetic energy error ene<sup>.</sup> ≡ energy  $\left(\frac{dz}{dz}\right)^{2} = \frac{2}{3}$  $\frac{3\pi}{2}$  $\int$  =  $\frac{1}{2}$  $H_0^2(1+z)$  -  $H^2$ ≡  $\overline{Y}$  $\lambda$  $\tilde{u}$   $\tilde{$ <sup>=</sup> <sup>2</sup>  $\lim_{\omega \to 0}$   $\lim_{\omega \to 0}$ δz  $\left(\frac{d\tilde{\phi}}{dz}\right)^2$ ≡  $8\pi G$  $\overline{3H_0^2}$  $\int d\phi$  $\left(\frac{d\phi}{dz}\right)^2$ =  $2H'(z)$  $\frac{2H'(z)}{3H(z)H_0^2(1+z)}-\frac{\Omega_m^0(1+z)}{H^2}$  $\frac{(1+z)}{H^2}$ ergy 0 3H<sup>2</sup> 0 <sup>2</sup> ;  $\left(\frac{dz}{dz}\right)^2 \equiv \frac{3H_0^2}{3H_0^2}$  $\equiv \frac{1}{3H_0^2} \left( \frac{dz}{dz} \right)^{-1} = \frac{1}{3H(1)}$  $\partial \Pi(z)$ 

dz = 2

dz <sup>=</sup>

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<sup>2</sup> ⇒ δ

 $\left(\tilde{d}_{\phi}\right)^{2}$  g [ $\delta H'$   $H'\delta H$   $H'\delta z$  ]  $\left(\delta z - 2(1+z)\delta H\right)$  $\left(\begin{array}{cc} dz \\ z \end{array}\right)$   $3H_0^2 \left[H(1+z)$   $H^2(1+z)$   $H(1+z)^2\right]$   $\left(\begin{array}{cc} m \\ H^2 \end{array}\right)$   $H^3$  $\left(\left(\frac{d\phi}{d}\right)^2\right) = \frac{2}{2\pi i^2} \left[\frac{\delta H'}{H(1+\phi)} + \frac{H'\delta H}{H(1+\phi)} + \frac{H'\delta z}{H(1+\phi)^2}\right] + \Omega_m^0 \left(\frac{\delta z}{H^2} + \frac{2(1+z)\delta H}{H^2}\right)$ integrated to get  $\phi$  (with an additive constant) and  $\phi$  (z) and  $\phi$  (z) and  $\phi$  (z) and  $\phi$  could be used be used by u  $\int \delta H'$  $\frac{\delta H'}{1+z}$  +  $\frac{1}{\sqrt{11}}$  $\overline{E}$  $\overline{1+z}$  $H'\delta$  $+\frac{H\,\,\delta z}{H(1+z)^2}\bigg]$  $\delta$   $\zeta$  $-\Omega_m^0\left(\frac{\partial z}{H^2} + \frac{2Q}{\sigma^2}\right)$ z $\delta H$  $\delta\left(\left(\frac{x\varphi}{dz}\right)^2\right) = \frac{1}{3H_0^2}\left[\frac{\sin}{H(1+z)} + \frac{H\sin}{H^2(1+z)} + \frac{H\cos}{H(1+z)^2}\right] + \Omega_m^0\left(\frac{\cos}{H^2} + \frac{2(H+\cos)\sin}{H^3}\right)$  $\left(\left(\frac{d\tilde{\phi}}{dz}\right)^2\right) = \frac{2}{3H}$  $\overline{3H_0^2}$  $\lceil \quad \delta H'$  $\frac{311}{H(1+z)} +$  $H'\delta H$  $\frac{H^{2}(1+z)}{H^{2}(1+z)}$  +  $H'\delta z$  $H(1+z)^2$  $+ \Omega_m^0$  $\left(\frac{\delta z}{H^2}+\frac{2(1+z)\delta H}{H^3}\right)$  $\setminus$ 

V (z) and the kinetic part (dφ/dz)2. The equations for them and their errors are the following:





*wigglings are numerical effects, kinetic term is positive which is a good news*

 Real SN data Union2.1(580 SNe Ia up to  $z=1.414$ JLA (740 SNe Ia up to  $z=1.3$ )

 $\int$ . Union2.1, equal-z:10 green,15 cyan,20 dark green 2:Union2.1, equal-N:5 green,10 dark green  $3:$ JLA, equal-N:5 cyan, 10 dark green

*We see reconstructed real data (Union2.1 (580 SN Ia up to z=1.414) and JLA (740 SN Ia up to z=1.3)) Equal-z binnin and equal SN number binning* 



 $($ e) Effect of H $_0$ , black-60, red-64, green-68, blue-7

 $3:$  or (f) Effect of Om …



*For the real data we see that the method will not work and we have complete mess*



# Stability

 $409.6$ 

*So if we are mistaken with the choice of Om and H\_0 We will get wrong reconstructed potential (fake potential)*



## Conclusion

For good data the method may work For the real data it is a complete mess reconstruction result highly depends on the accuracy of H\_0 and Om\_m

## Շնորհակալուխյուն *Merci :)*

*Thank you for your attention*