Title: Everpresent Lambda in CosmoMC

Speakers: Nosiphiwo Zwane

Collection: Everpresent Lambda: Theory Meets Observations

Date: November 13, 2019 - 11:00 AM

URL: http://pirsa.org/19110070

Everpresent Λ in CosmoMC

Nosiphiwo Zwane

University of Swaziland

November 13, 2019

work with N. Afshordi and R. Sorkin

1:34

Outline

- Everpresent Λ Models
- Everpresent Λ and Cosmic Microwave Background
- Baryon Acoustic Oscillations (BAO) Measurements

N CosmoMC

Model 1

Proposed by Ahmed et al.

- The universe is assumed to be spatially homogeneous.
- In this model dark energy undergoes a random walk as described by these equations

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{1}{3}\rho_m(t) - \frac{\rho_\Lambda(t)}{3},$$

$$V(t) = \frac{4\pi}{3}\int_0^t dt' a(t')^3 \left(\int_0^{t'} dt'' \frac{1}{a(t'')}\right)^3 \text{ for k=0},$$

$$N(t) = V(t)/\ell_p^4,$$

$$\rho_\Lambda(t+\Delta t) = \frac{S(t) + \alpha\xi\sqrt{N(t-\Delta t) - N(t)}}{V(t)}.$$

Ahmed, Dodelson, Greene, Sorkin, Phys. Rev. D 69 (May, 2004) 103523.

CosmoMC

Model 2

- Simpler to simulate.
- The universe is assumed to be spatially homogeneous.
- Λ is again assumed to be a random function of cosmic time.
- Two parameters are introduced: $\alpha-$ controls the magnitude of fluctuations and $\mu-$ controls the coherence time.
- Λ is a Gaussian process with the correlation at different times being

$$\left\langle \hat{\Omega}_{DE}(\lambda_1)\hat{\Omega}_{DE}(\lambda_2) \right\rangle = \alpha^2 e^{-\frac{\mu}{2}(\lambda_1-\lambda_2)^2}$$

where

$$\lambda = log(a)$$

$$\alpha = \text{characteristic scale of the fluctuations}$$

$$\mu^{-1/2} = \text{characteristic e-fold}$$

$$\Omega_{DE} = \tanh\left(\hat{\Omega}_{DE}\right)$$

Everpresent Λ

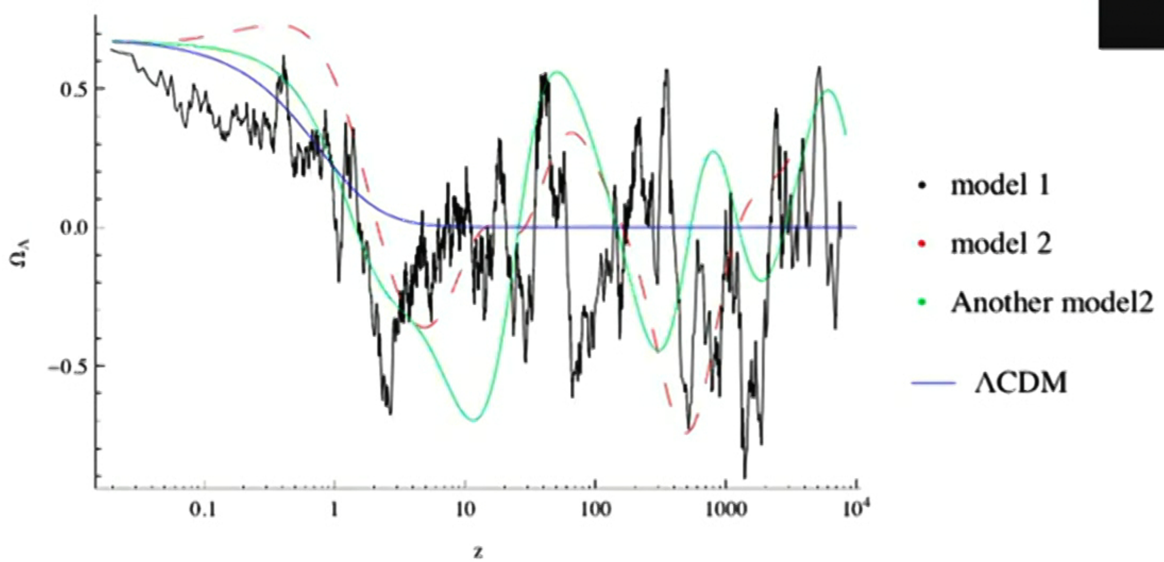


Figure : Ω_{DE} for different Cosmological Models.

Everpresent Λ and the CMB

- Cosmic Microwave Background (CMB) anisotropies currently provide the most precise tests of cosmological models.
- To fit our Everpresent Λ model, we use CosmoMc together with CAMB.
- Model is stochastic.
- We assume the universe is flat.

Simulations and Analysis

Table : Table for Likelihoods

	ΛCDM	Everpresent Λ (Model 2)
CMB: BKPLANCK	45.117	44.336
CMB: lensing	12.157	13.030
plik	1164.783	1165.278
lowTEB	10098.485	10097.864
BAO: 6DF	0.087	0.291
BAO: MGS	0.927	1.217
BAO: DR11CMASS	2.856	3.015
BAO: DR11LOWZ	1.098	1.142
BAO-Busca: DR11LyaAuto	4.265	2.636
BAO-Andreu: DR11LyaCross	4.748	4.245
Total	11332	11334

Everpresent Λ and the CMB

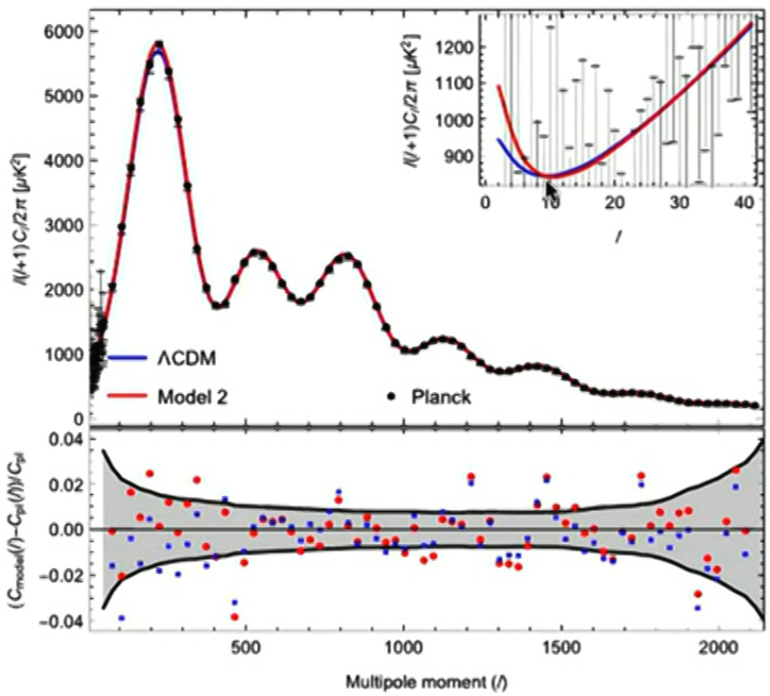


Figure : Temperature fluctuations for ΛCDM model ($\chi^2 = 11334$), everpresent Λ model 2 ($\chi^2 = 11335$) and Planck 2015 data.

CosmoMC

Everpresent Λ

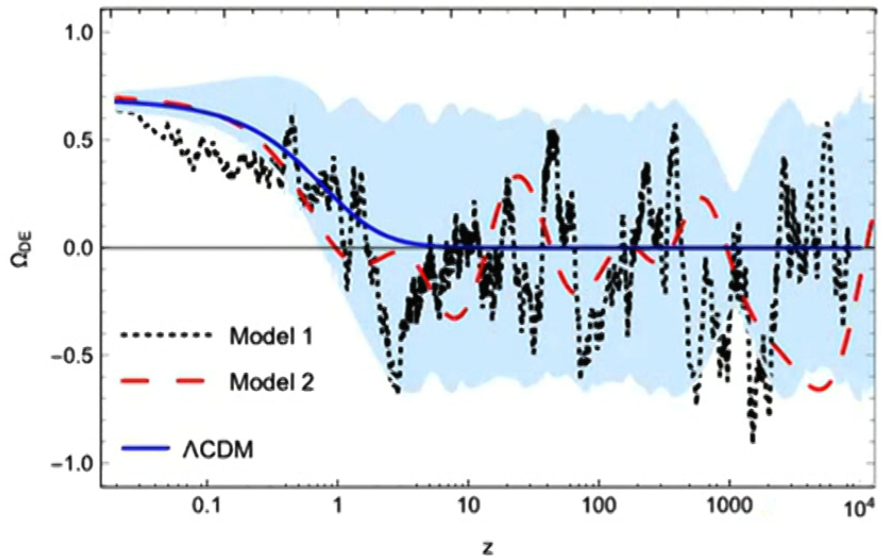


Figure : Ω_{DE} for different Cosmological Models.

χ^2 for model

χ^2 probability distribution for histories of dark energy

$$p(\chi^2(\tilde{\Omega}_{de})) = \in D\tilde{\Omega}_{de} \exp\left(-\frac{\chi^2(\tilde{\Omega}_{de})}{2}\right) \delta(\chi^2(\tilde{\Omega}_{de}) - \chi^2_{red}(\tilde{\Omega}_{de}))$$

where

$$\chi^2_{red} = \frac{\chi^2}{\sum_\omega \#\omega} \quad \text{and} \quad \chi^2 = \sum_\omega \frac{\left|\tilde{\Omega}_{de}(\omega)\right|^2}{\left\langle \left|\tilde{\Omega}_{de}(\omega)\right|^2 \right\rangle}$$

To check how often one can get such a good fit from everpres
Λ, we calculate reduced χ^2 for the good fit.

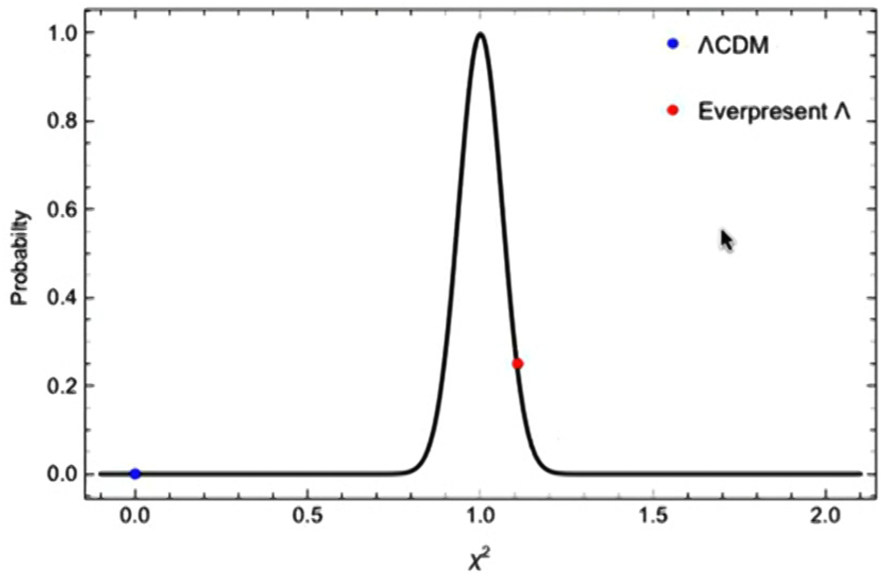


Figure : Probability of χ^2 for the models

N
CosmoMC

Baryon Acoustic Oscillations

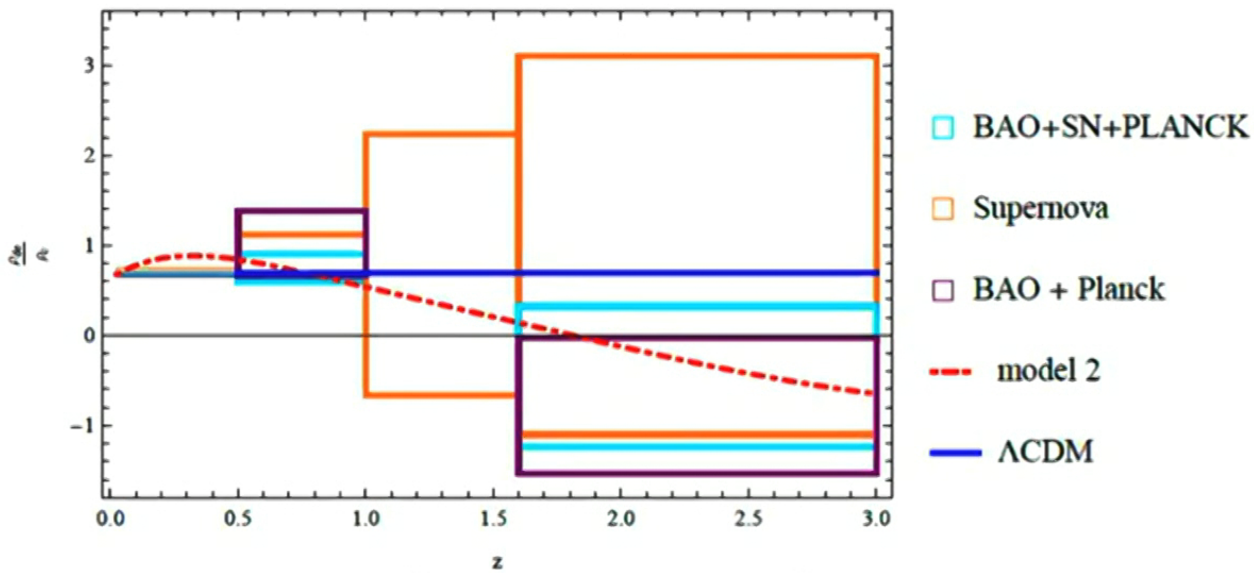
- Baryon acoustic oscillations (BAO) matter clustering provides a standard ruler for length scales in cosmology.
- BAO can be used to measure the acceleration of the expansion of the universe (or dark energy) by comparing the sound horizon at recombination with the sound horizon, r_d, at different time.

Baryon Acoustic Oscillations

- Baryon acoustic oscillations (BAO) matter clustering provides a standard ruler for length scales in cosmology.
- BAO can be used to measure the acceleration of the expansion of the universe (or dark energy) by comparing the sound horizon at recombination with the sound horizon, r_d, at different time.

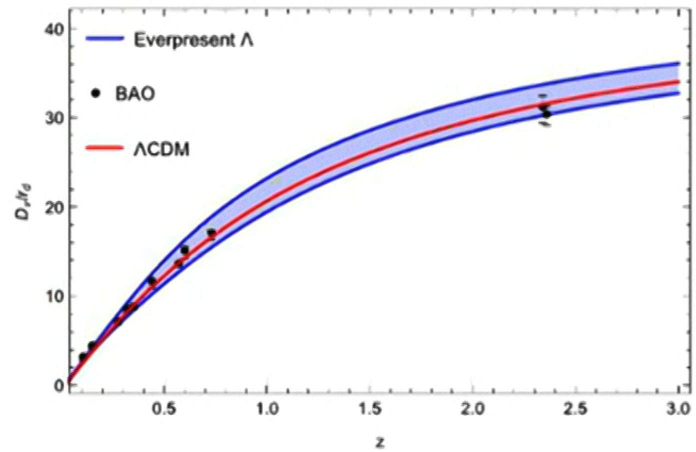
Baryon Acoustic Oscillations (BAO)

- Baryon Oscillation Spectroscopic Survey (BOSS) 2013 results suggest tha $\Omega_{DE}(z)$ is negative at $z = 2.34$ at $\sim 2.5\sigma$ tension with standard ΛCDM.
- A number of other models that Aubourg *et al.* examined fail to fit BAO 2 data, unless one assumes that $\Omega_{DE} < 0$ at $z \sim 2 - 3$.



N CosmoMC

Baryon Acoustic Oscillations (BAO)



	z	Distance(Mpc)		z	Distance(Mpc)
6dF (D_v) [25]	0.106	457 ± 27	SDSS DR9 LRG (D_A)[26]	0.57	1386 ± 45
SDSS DR7 (D_v) [27]	0.15	664 ± 25	WiggleZ (D_v) [28]	0.6	2221 ± 101
SDSS DR7+2dF (D_v) [29]	0.275	1059 ± 27	WiggleZ (D_v) [28]	0.73	2516 ± 86
SDSS DR11 (D_v) [30]	0.32	1264 ± 25	Lyα auto-corr (D_A) [15]	2.34	1662 ± 96
SDSS DR7 LRG (D_v) [31]	0.35	1308 ± 25	Lyα auto-corr (D_H) [14]	2.36	226 ± 8
WiggleZ (D_v) [28]	0.44	1716 ± 83	Lyα auto-corr (D_A) [14]	2.36	1590±60

N CosmoMC

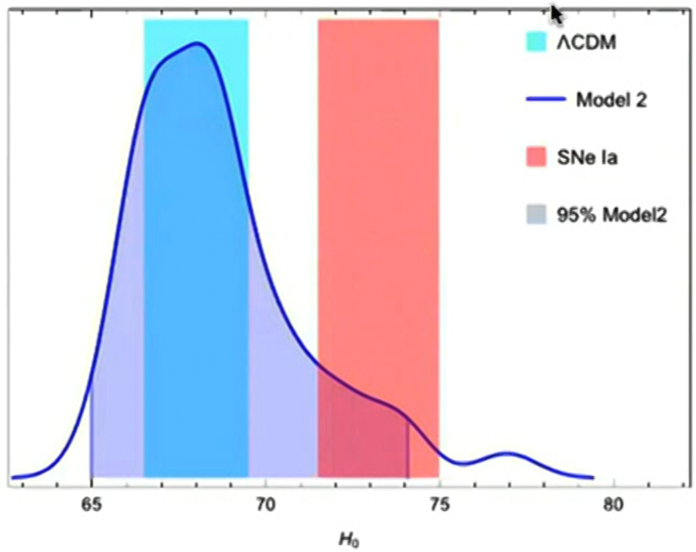
Summary

- There are histories of dark energy that are a good fit to the CMB, these histories have $\Omega_{de} \approx 0.7$ at $z \approx 0$ and $\Omega_{de} \approx 0$ at $z \approx 1000$.
- There are histories of dark energy that are a good fit to the BAO.
- If Λ really is fluctuating and "everpresent", should become more clearly evident as observations accumulate for high redshift.

CosmoMC

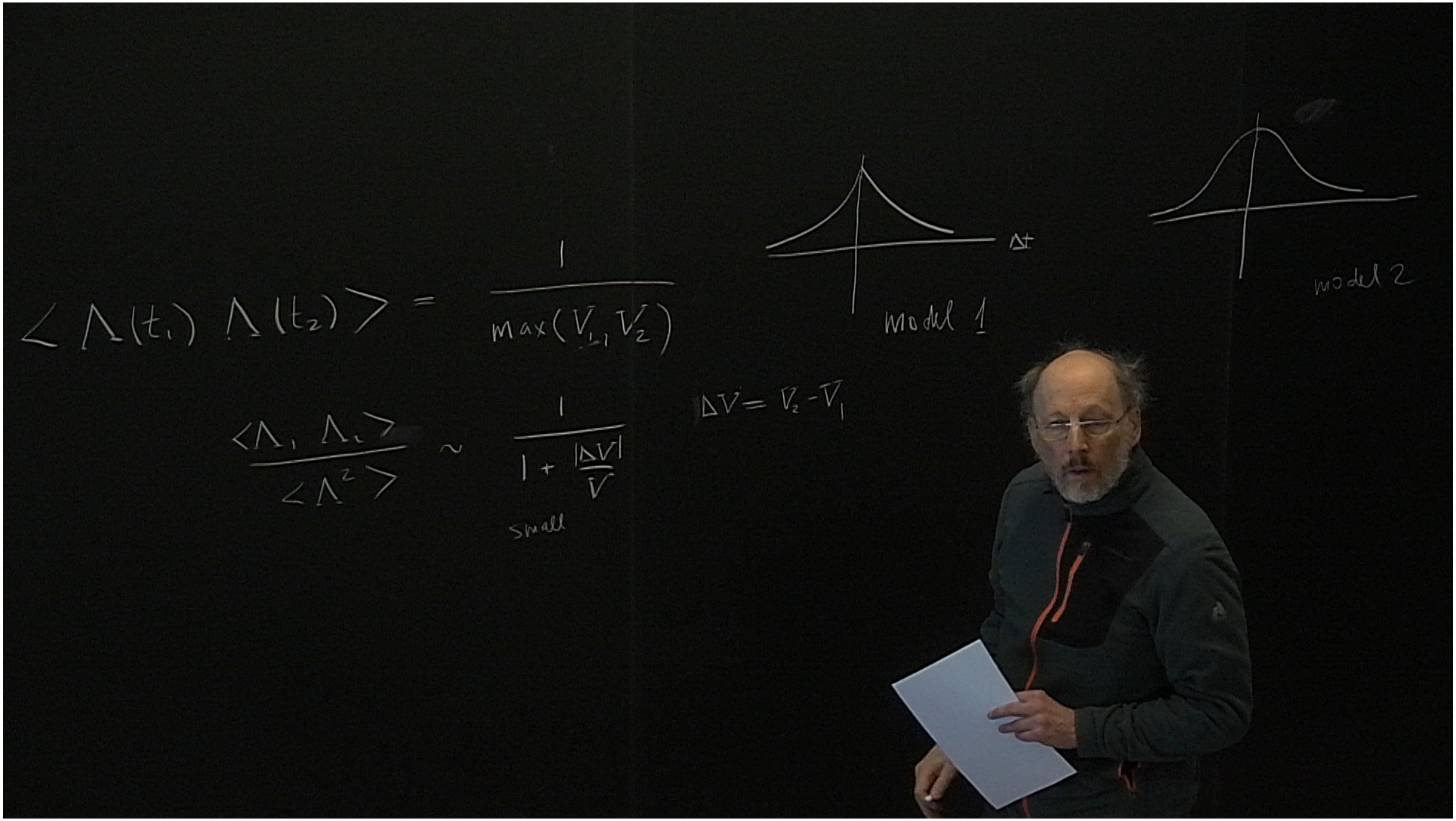
The Value of Hubble Constant today H_0

In the past few years, we have seen a divergence between the local measurements of the Hubble constant and the best fits inferred fro[m] Planck CMB and BAO observations.

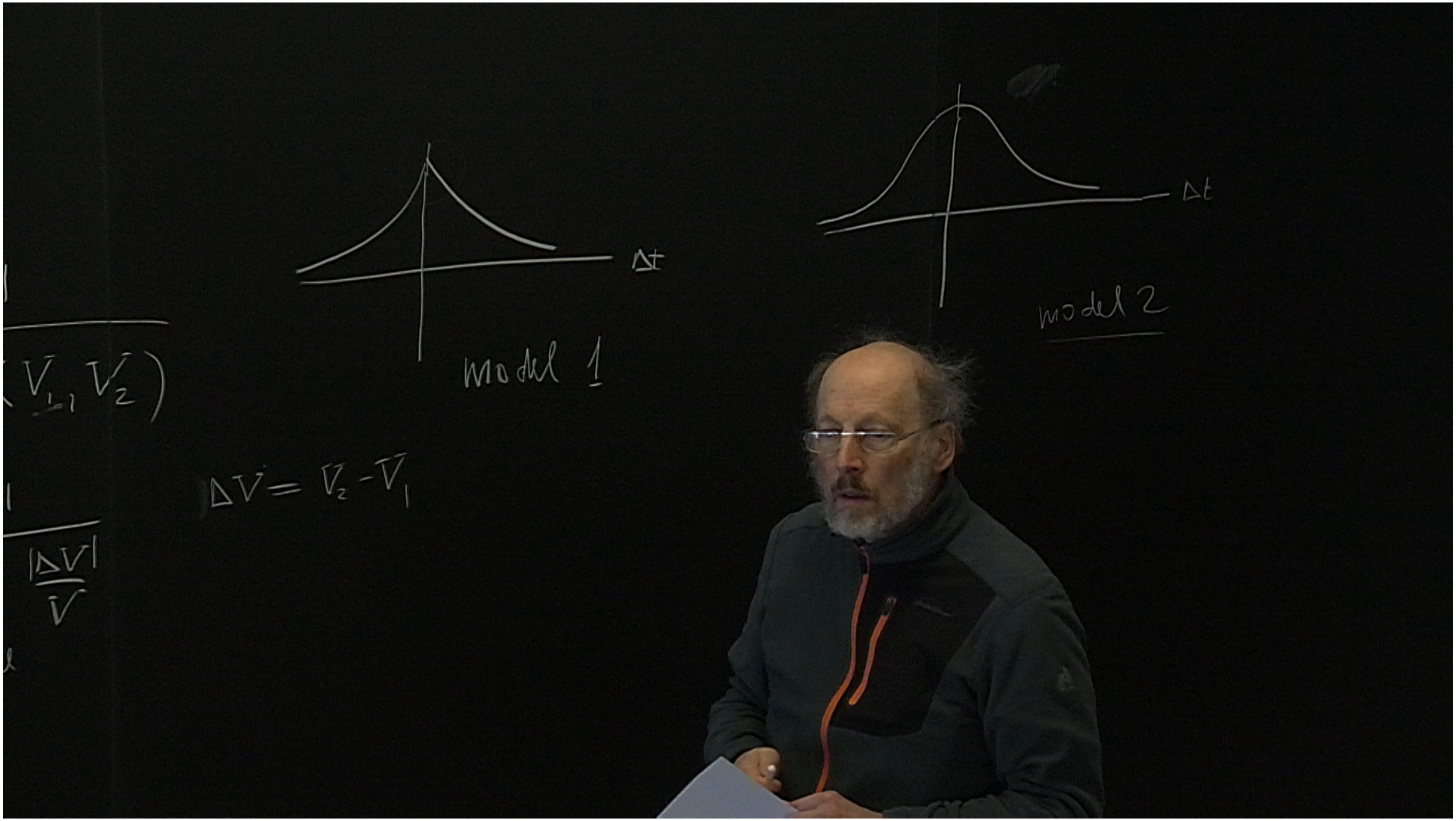


- Planck Collaboration, arXiv:1502.0158.

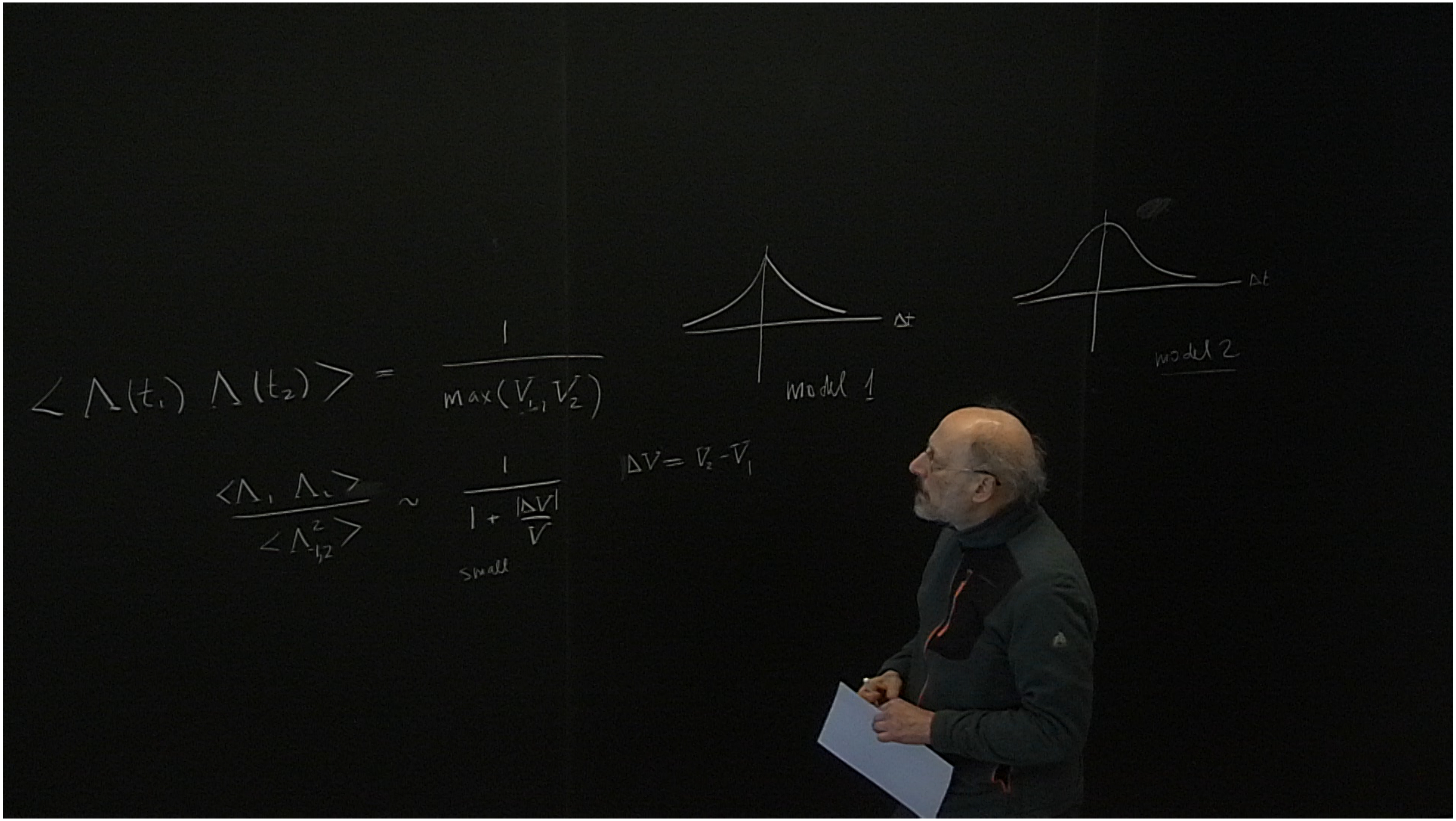
- A. G. Riess *et al.*, arXiv:1604.0142.

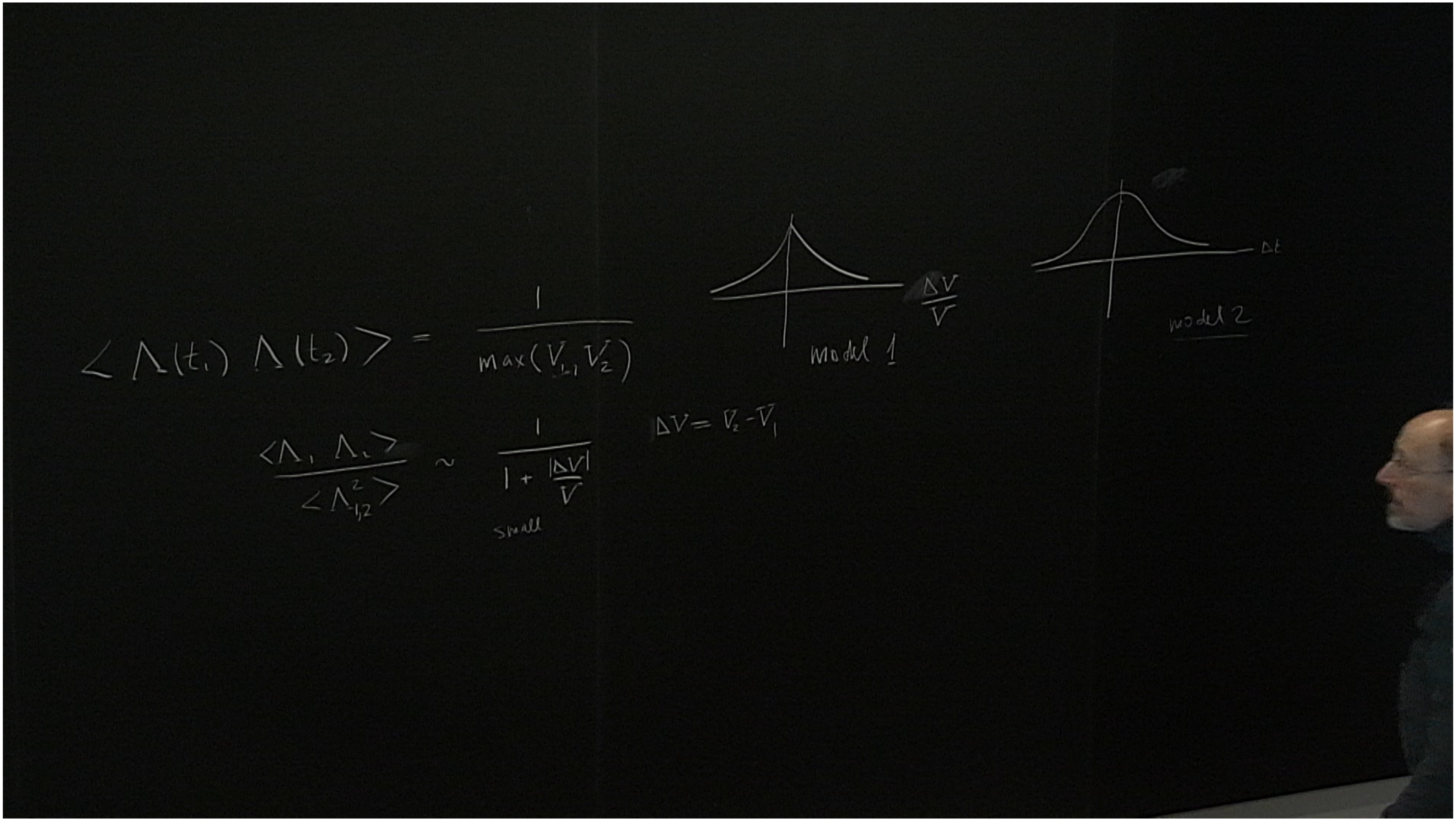


<Λ(t₁) Λ(t₂)> = 1 / max(V₁, V₂)
<Λ₁ Λ₂> / <Λ²> ~ 1 / (1 + |ΔV|/V)
small
ΔV = V₂ - V₁
Δt
model 1
model 2

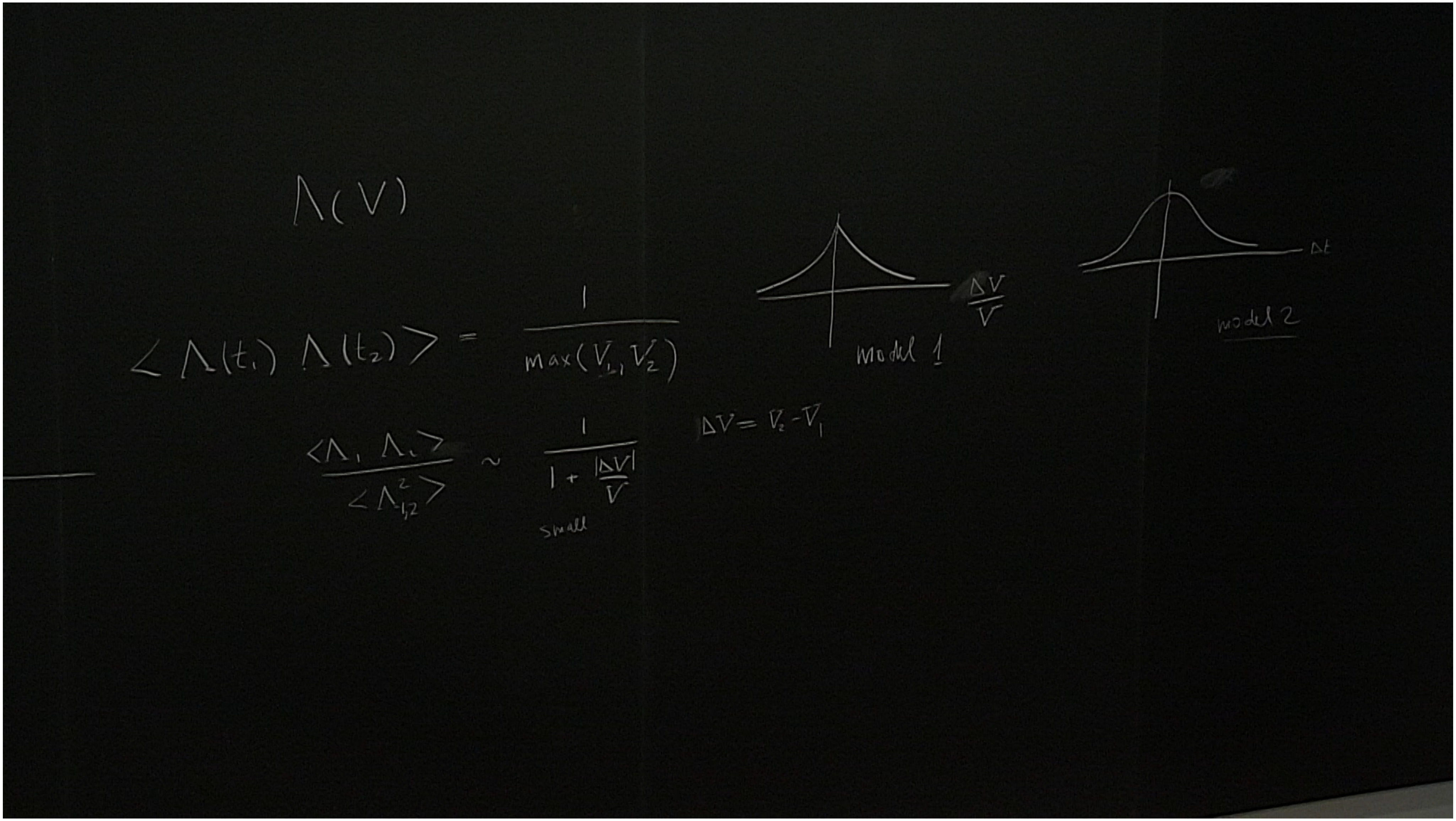


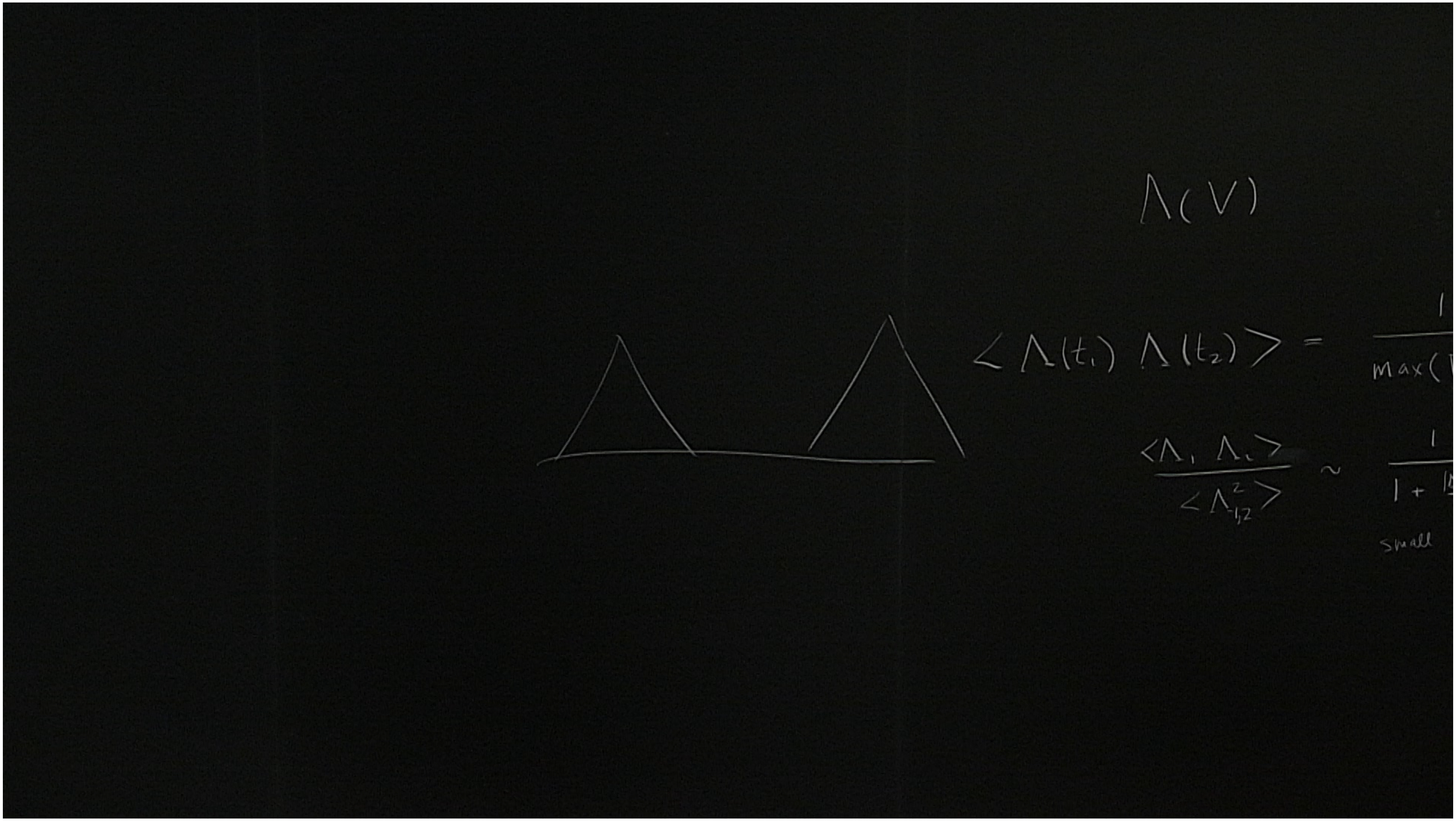
Δt
model 1
Δt
model 2
$\Delta V = V_2 - V_1$


model 1
model 2
Δt
Δt
small



⟨Λ(t₁) Λ(t₂)⟩ = 1 / max(V₁, V₂)
⟨Λ₁ Λ₂⟩ / ⟨Λ²₁,₂⟩ ~ 1 / (1 + |ΔV|/V)
small
ΔV = V₂ - V₁
ΔV/V
model 1
Δt
model 2


Λ(V)
<Λ(t₁) Λ(t₂)> = 1 / max(V₁, V₂)
<Λ₁ Λ₂> / <Λ²₁,₂> ~ 1 / (1 + |ΔV|/V)
small
ΔV = V₂ - V₁
ΔV/V
model 1
Δt
model 2


Λ(V)
⟨Λ(t1) Λ(t2)⟩ =
1
max(
⟨Λ1, Λ2⟩
⟨Λ²1,2⟩
~
1
1 +
small