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Dark Energy and Inhomogeneous Cosmologies

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Introduction

In 2007, David L. Wiltshire published several papers proposing that dark energy is not real but an apparent effect of an inhomogeneous cosmology described by the Fractal Bubble (FB) model with supporting observational evidence (see Fig. 1). Although other inhomogeneous models have since been discredited, [Ishibashi and Wald (2006), Caldwell and Stebbins (2008)] the FB model remains unchallenged. We investigate the validity of the predictions that the FB model makes.

Why inhomogeneous cosmologies?

The nature of dark energy and cosmic acceleration remains an unresolved problem with ΛCDM cosmology. This has prompted a number of authors to consider that the concept of large scale homogeneity, a fundamental assumption of the Friedmann-Robertson-Walker (FRW) metric, is a poor approximation even at the largest scales. Modelling an inhomogeneous cosmology requires either a pertubative approach on a 'backreaction' term that takes into account the 'lumpiness' of spacetime or a different geometry altogether, such as a Swiss Cheese model. The most attractive feature of these models is that they allow for the possibility that dark energy is just an artefact of fitting a homogeneous model to an inhomogeneous universe and that observable quantities, such as the distance modulus for supernova type 1a data, fitted with the wrong model leads to an apparent accelerated expansion of the universe. In most formalisms for an inhomogeneous cosmology, the predicted size of the backreaction term, and hence the deviation from homogeneity, is negligibly small.

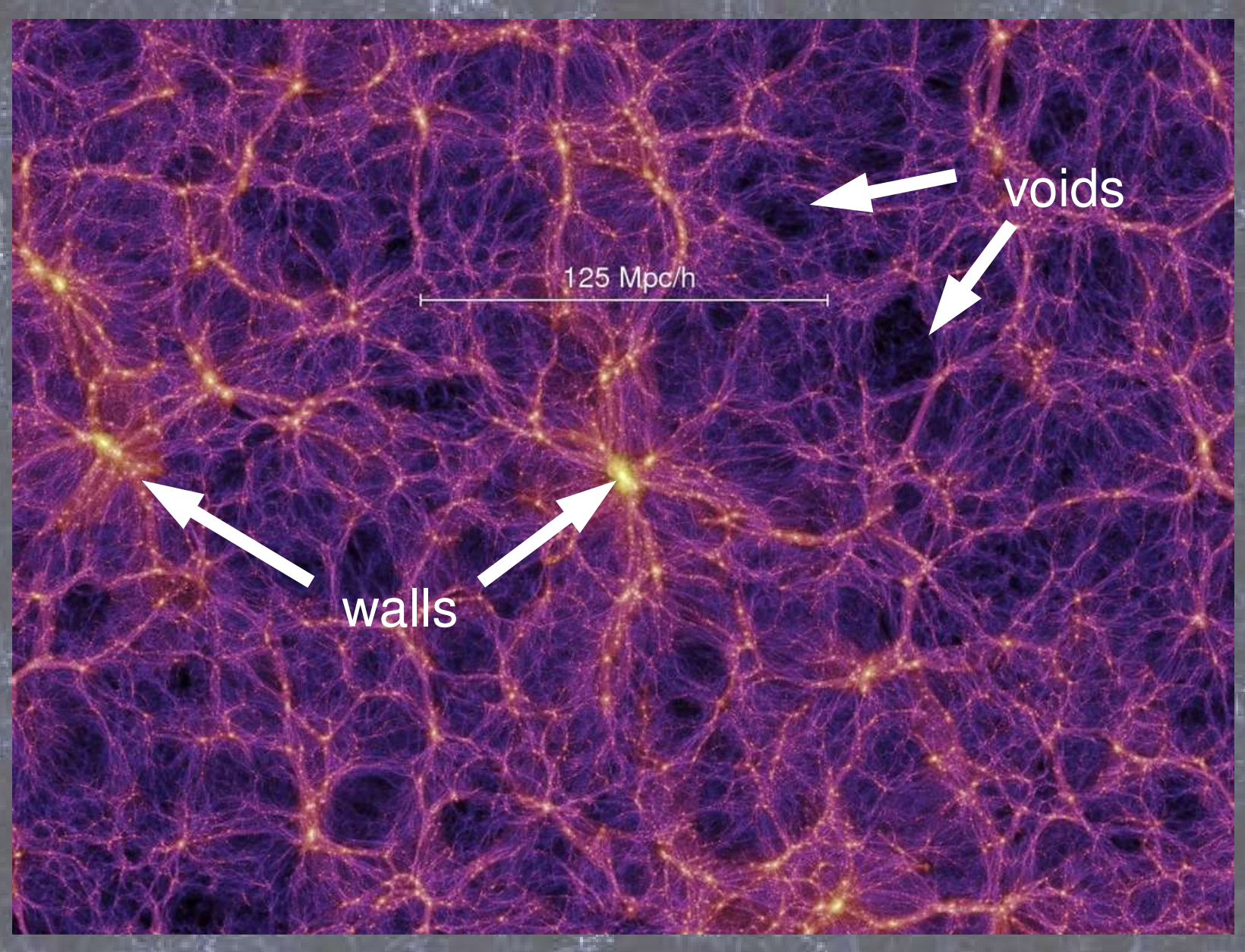
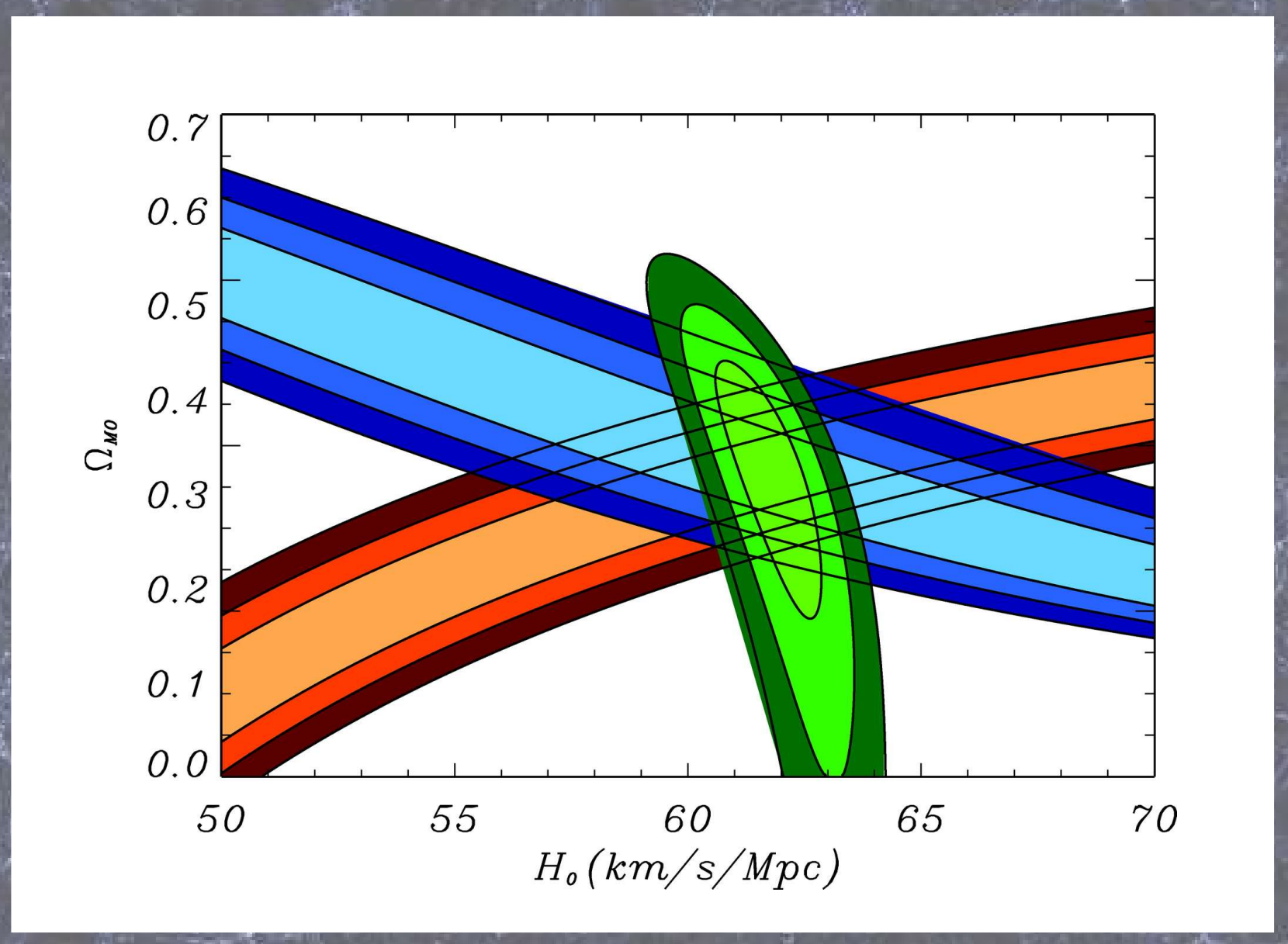


Figure 2. The lumpy universe. In the Fractal Bubble model, overdensities are termed walls and underdense regions are known as voids. Clocks in walls tick at a different rate to clocks in voids because of the difference in gravitational potential.

Image credit: The Millennium Simulation Project
`mpa-garching.mpg.de/galform/virgo/millennium`



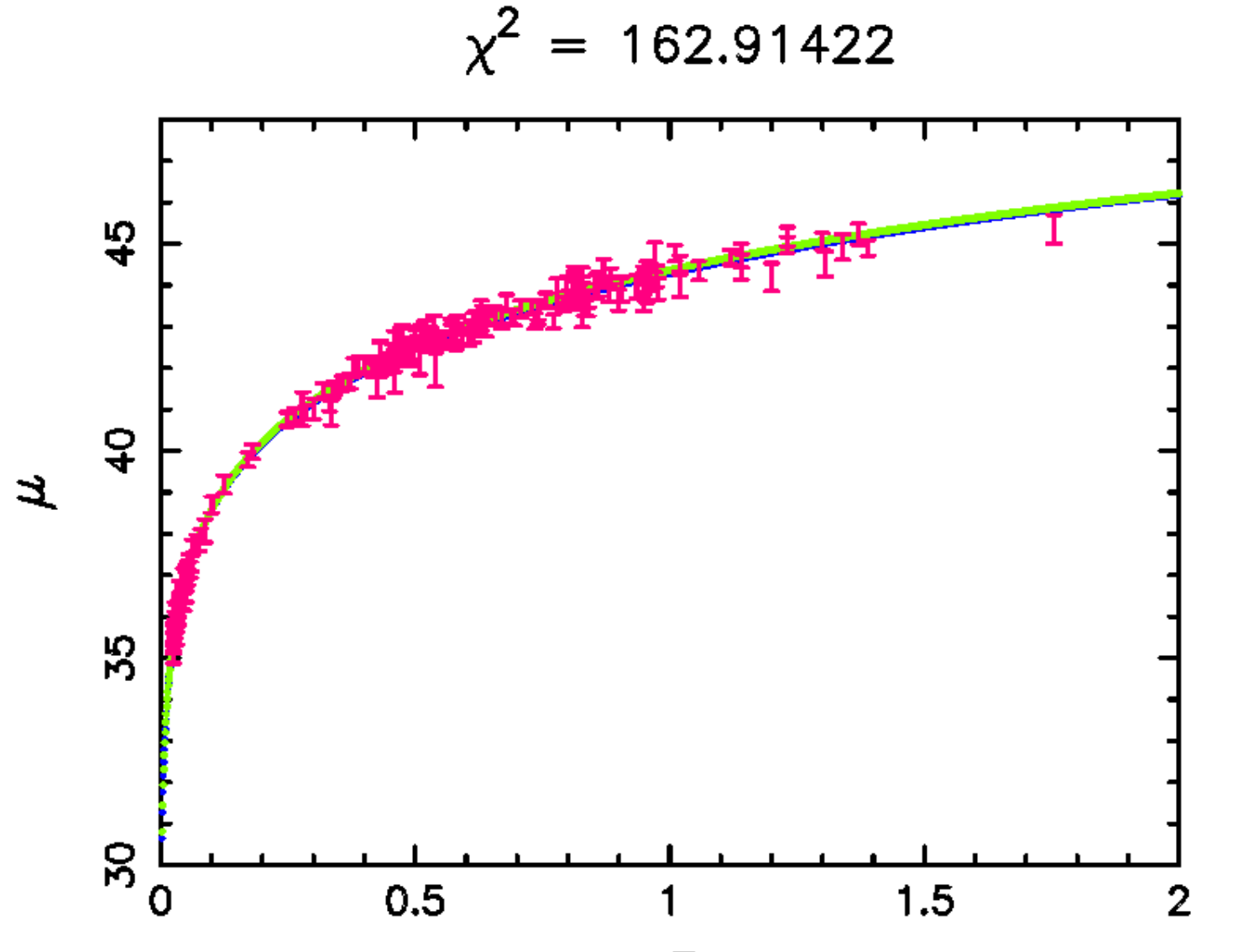


Figure 1. *(left)* 1σ, 2σ, & 3σ confidence limits from Leith et. al (2008), from fitting supernova data (green) [Riess et. al (2007)], angular scale of sound horizon (red) and baryon acoustic oscillations (blue) for the FB model. The overlapping regions implies that it can consistently predict the average matter density (Ω_{m0}) given observational data and H_0.

Figure 1. *(right)* Distance modulus (μ) against redshift (*z*) for best fit FB model (green) and ΛCDM concordance model (blue). Data points from Riess et. al (2007) are plotted in pink. For the FB model, $\chi^2 = 0.9$ per degree of freedom for $f_v = 0.759$ and $\bar{\gamma} = 1.38$. For comparison, the best χ^2 obtained for a ΛCDM model with $\Omega_{m0} = 0.29$ and $\Omega_{\Lambda 0} = 0.71$ is $\chi^2 = 1.2$ per degree of freedom.

How is the Fractal Bubble (FB) model different?

To overcome this problem, Wiltshire (2007) proposed the Fractal Bubble (FB) model, a two parameter model in which inhomogeneities are described by the lapse function, $\bar{\gamma}$ and the void fraction f_v. The lapse function is responsible for a difference between the time measured by a clock in a void compared to a clock in a wall (see Fig. 2), while the void fraction is a measure of the portion of total volume of the universe contained in void regions. Because we live in a wall, failing to take into account this difference by using FRW cosmology implies that we have incorrectly fitted data using the volume averaged quantities that are unobservable rather than the local quantities that we measure. Thus, according to the FB model, cosmic expansion is an observational effect, not a real physical phenomenon. From Fig 1., the FB model appears to fit observational data from a number of concordant sources *without dark energy*.

Testing the Fractal Bubble model

To test the predictiveness of the FB model we have generated mock supernova data from a range of ΛCDM universes with varying amounts of dark energy and calculated the model likelihood from fitting the FB model to the mock data. This would allow us to comment on the behaviour of the FB model when the cosmological parameters have changed; in particular, this would determine whether the FB model is sufficiently general to mimic every ΛCDM model or if some fine tuning is involved.

We chose to simulate supernova data (see Figure 3) with similar characteristics to the Gold data set from Riess et al. (2007), by binning the observational data according to redshift and calculating the median error in each bin. We then randomly draw the same number of data points from each bin as in the Gold sample and calculate their distance moduli assuming a FLRW universe for $\Omega_\Lambda = 0.50 – 0.90$ and $H_0 = 60$ -72 km/s/Mpc, such that the distribution of supernova with redshift is roughly the same as the observed set. The error bars on the mock data are then Gaussianly centred around the median error of the Gold data for the corresponding bin.

Calculating the Bayes factor (the ratio of Bayesian evidences between ΛCDM and the FB model) then provides a measure of how well the FB model describes the data compared to ΛCDM. This is then calculated for each set of supernova data and is shown in Figure 4 (left). We then perform the reverse comparison by simulating supernova data from the FB model; the Bayes factors for these are shown in Figure 4 (right).

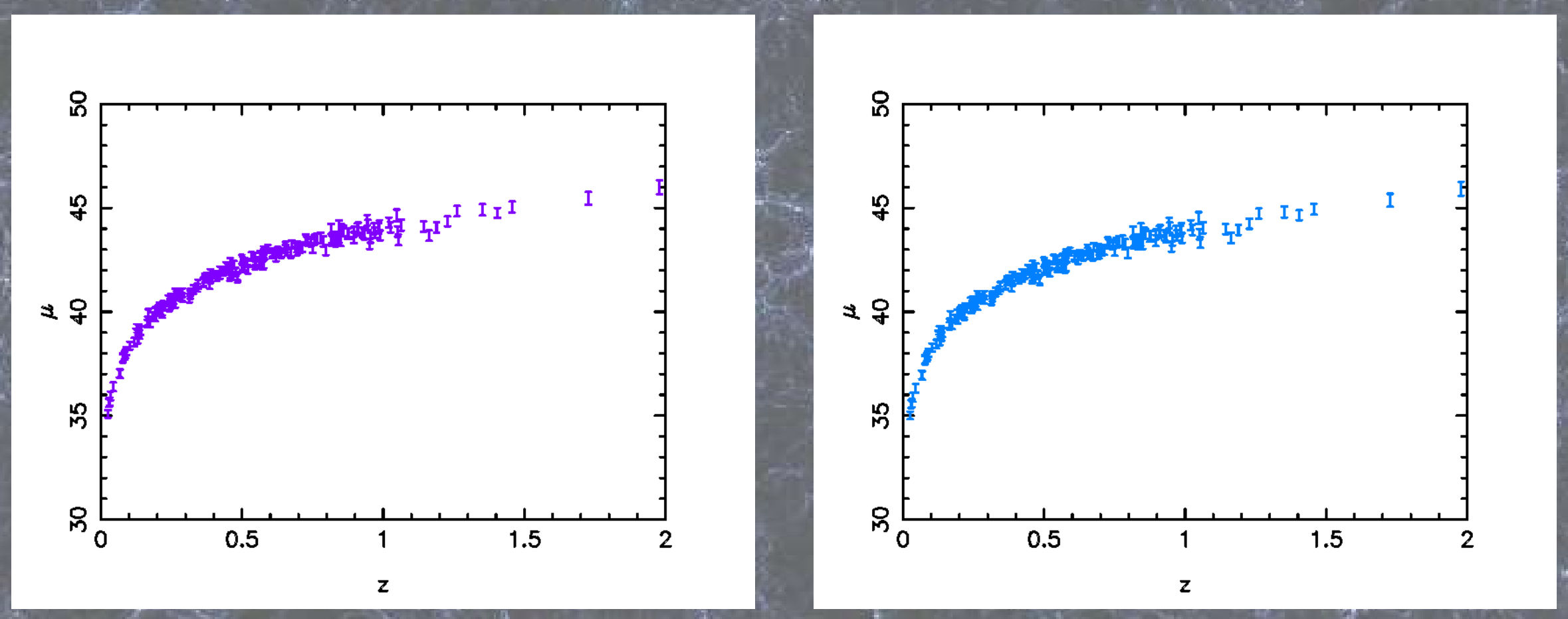


Figure 3. Mock supernova data generated from a LCDM model ($\Omega_{\Lambda 0}$ = 0.70, H_0 = 70 km/s/Mpc) in purple and a FB model in cyan (Ω_{m0} = 0.30, H_0 = 70 km/s/Mpc). We have retained the same redshift distribution for both sets of mock data.

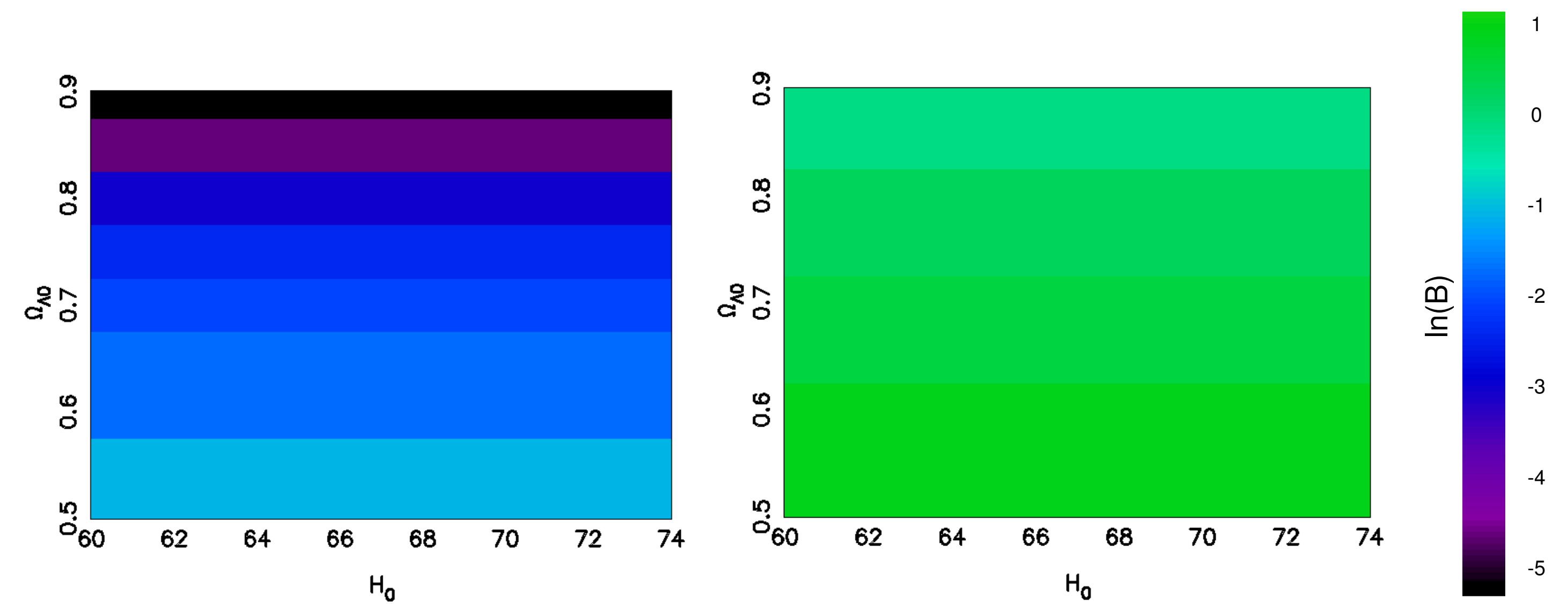


Figure 4. Bayes factors for fits to mock supernova data drawn from ΛCDM (left) and FB model (right). The colours show the strength of the evidence based on the logarithm of the Bayes factor. Shades of green show that the evidence is inconclusive ($0 < |\ln(B)| < 1$), while blue indicates weak evidence against the FB model and purple to black shades indicate strong evidence against the FB model.

If the predictions made by the FB model and ΛCDM are equivalent, then it is expected both plots in Figure 4 to look the same. But they don't; ΛCDM is capable of greater flexibility than the FB model. The FB model has a limited range of behaviour that the distance modulus can take, that is for the range of physically viable initial void fractions at z = 1100, the distance modulus as a function of redshift is scaled only by a small amount. ΛCDM is capable of describing these small variations when the initial void fraction is changed to generate mock supernova data and hence the Bayesian evidence shows that the two models are indistinguishable (Figure 4, right). However, for a ΛCDM universe with large quantities of dark energy (Ω_Λ = 0.85 - 0.90), the FB model is unable to describe the simulated supernova data from these models.

References

Caldwell, R. R. and Stebbins A. (2008), Phys. Rev. Lett., 100, 191302

Ishibashi A. and Wald, R. M. (2006), Class. and Quant. Gravity, 23, 235

Leith, B. M , Ng, C. and Wiltshire, D. L., (2008), ApJ,, 672, L91

Riess, A. et. al. (2007), ApJ, 659, 98.

Wiltshire, D. L (2007), New Journal of Physics, 9, 377

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