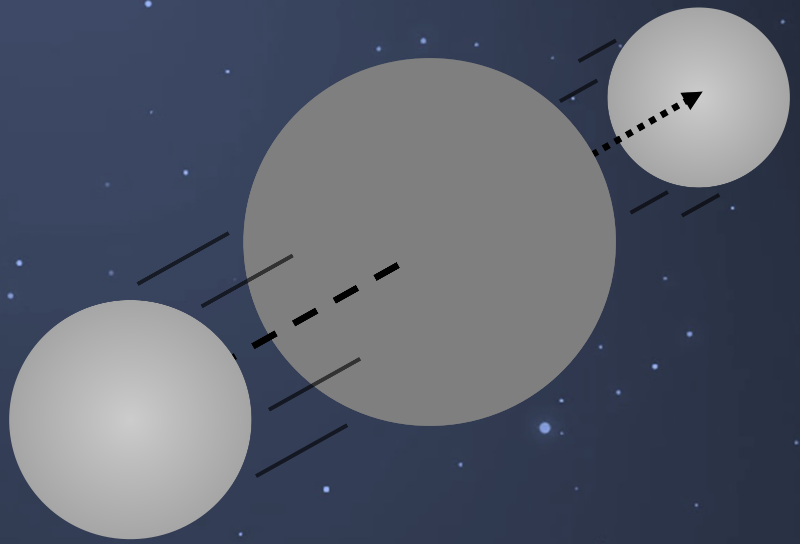
A FREQUENTIST ANALYSIS OF

DECAYING DARK MATTER

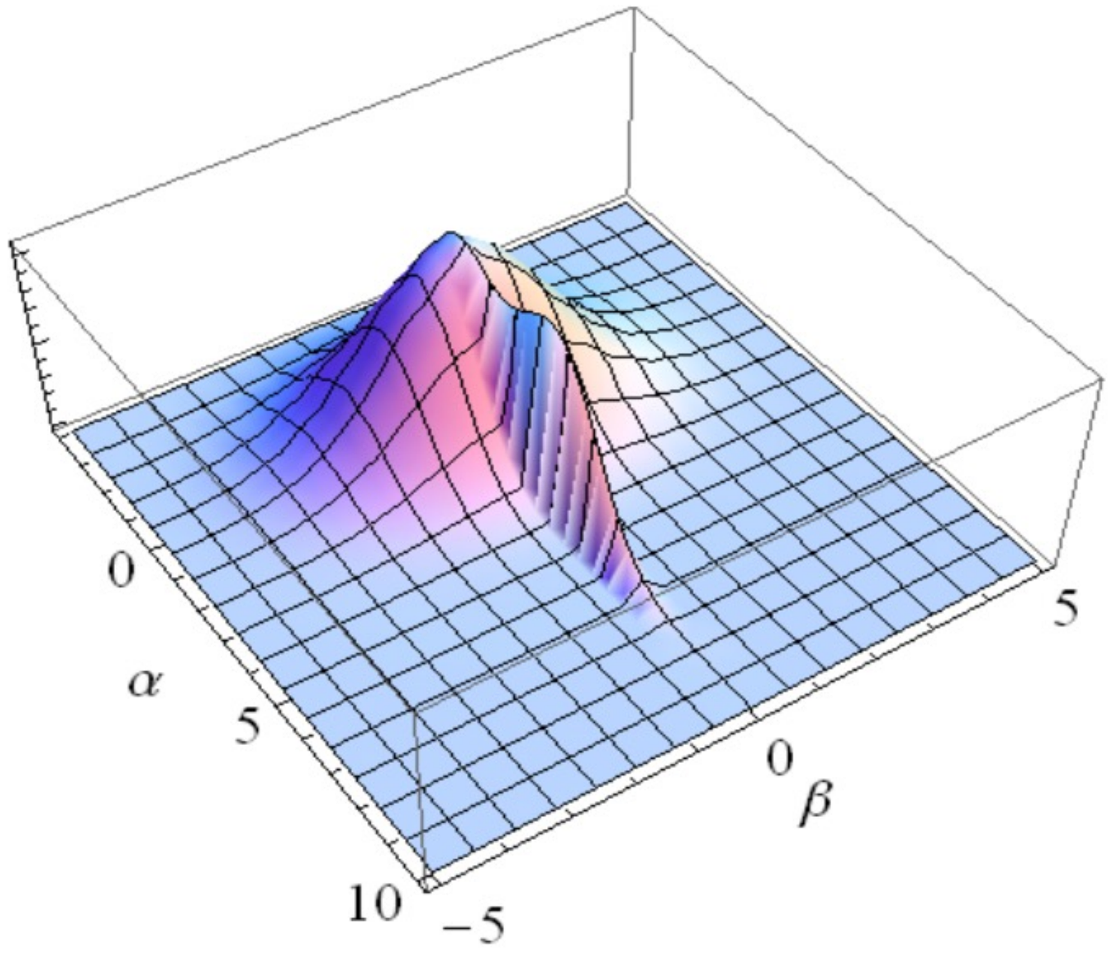
BASED ON ARXIV:2211.01935



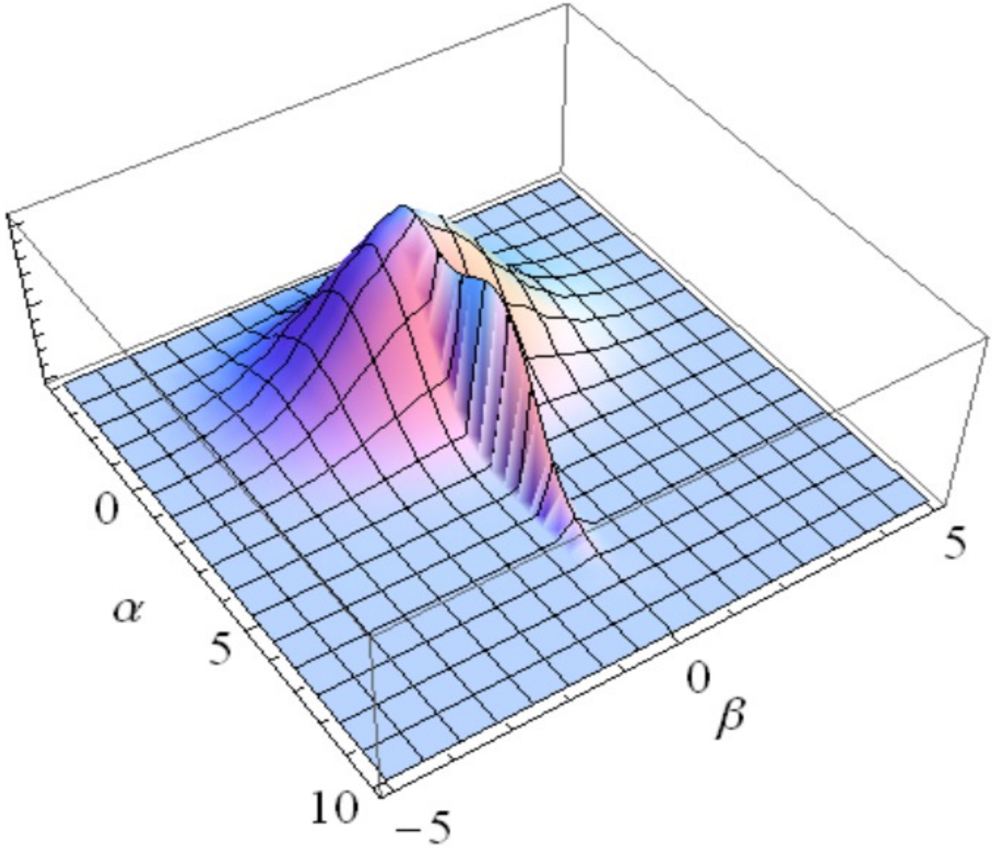
EMIL BRINCH HOLM

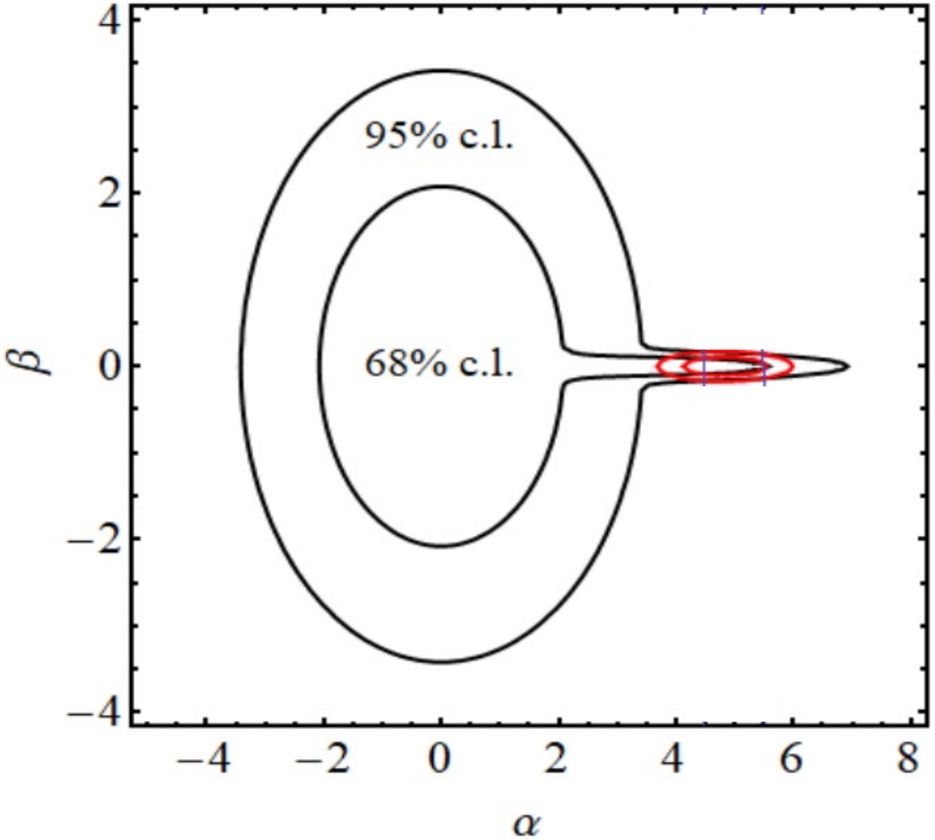
Dark Side of the Universe 2020

December 6, Sydney, Australia



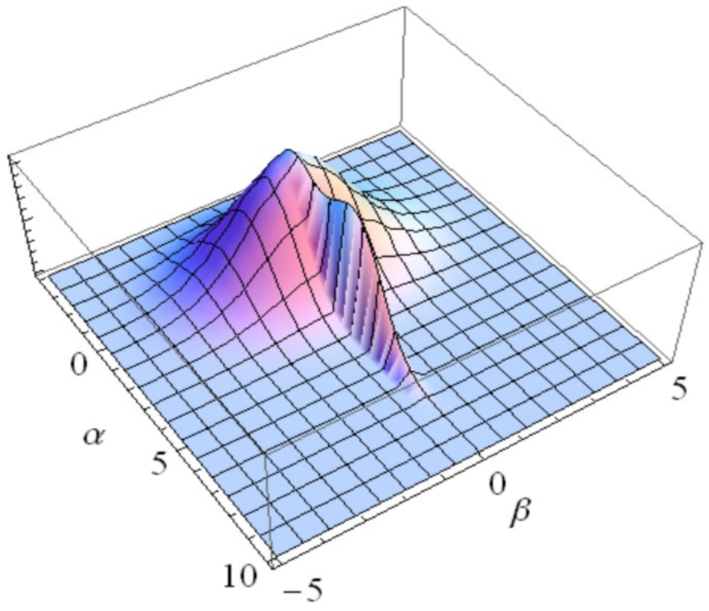
A. Gomez-Valent 2022 (arXiv:2203.16285)

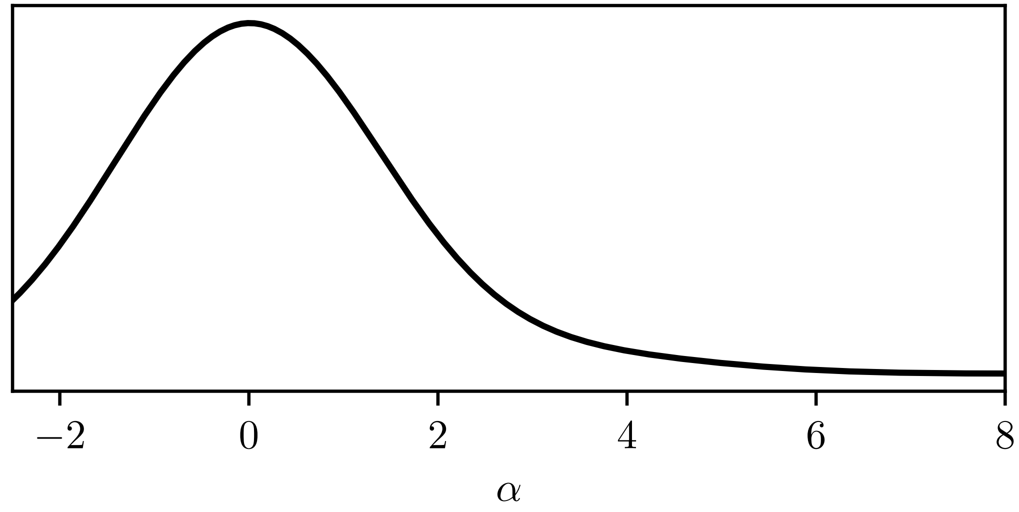


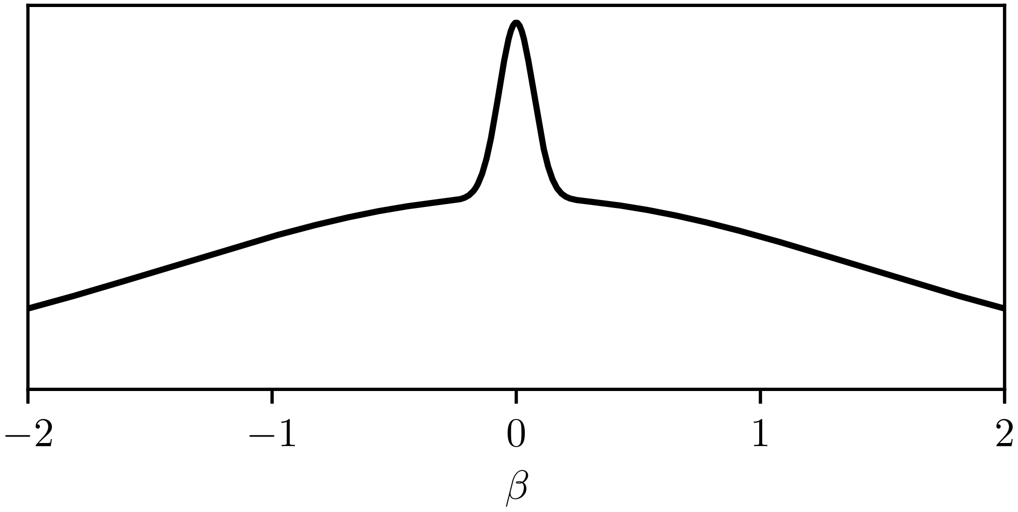


A. Gomez-Valent 2022 (arXiv:2203.16285)

$\int d\beta\ L(\alpha,\beta)$



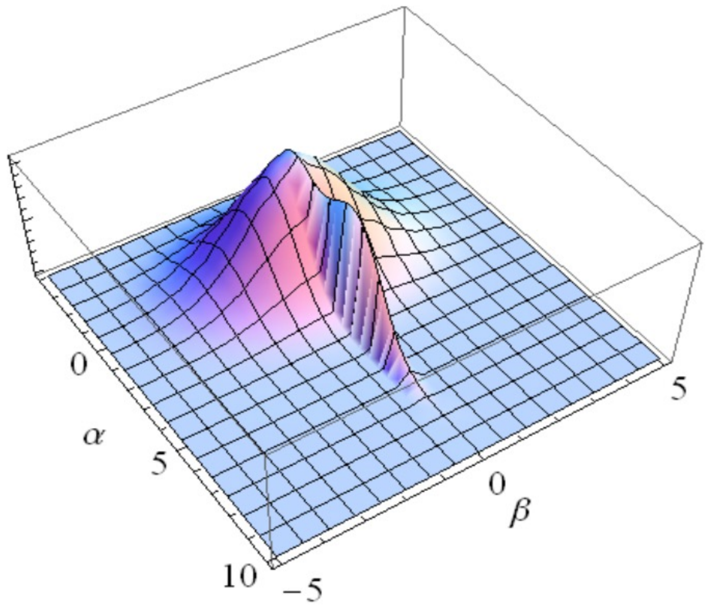


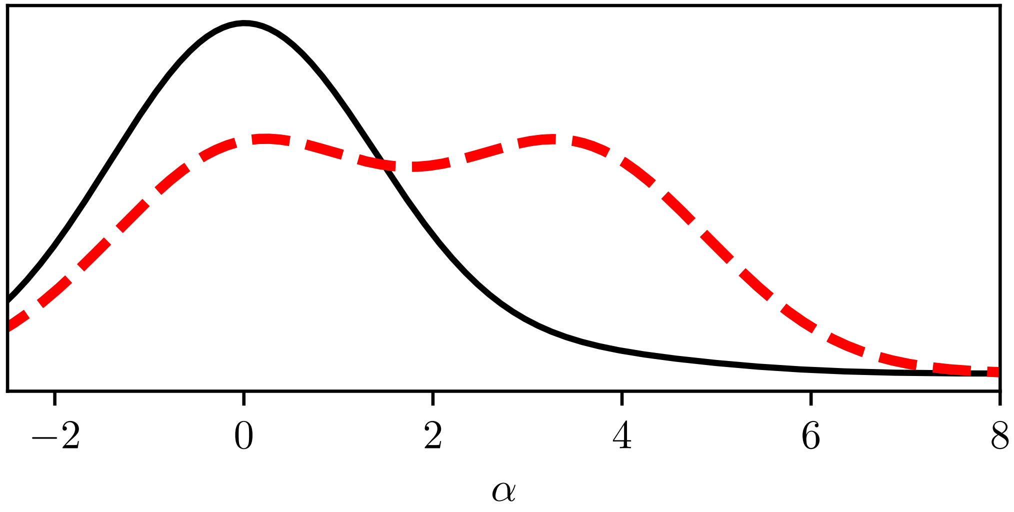


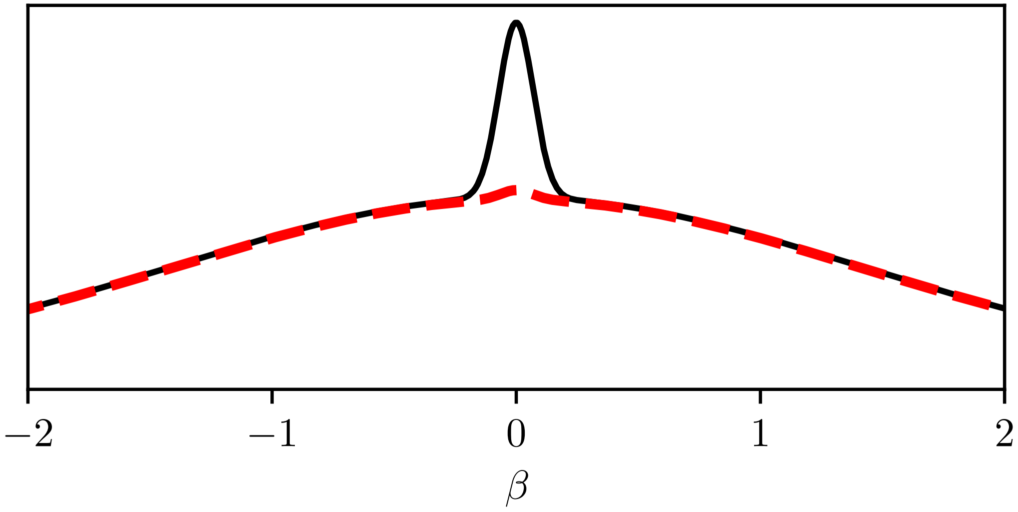
A. Gomez-Valent 2022 (arXiv:2203.16285)

$$\int \mathrm{d}\beta \;\; L(\alpha, \beta)$$

$$\max_\beta L(\alpha, \beta)$$





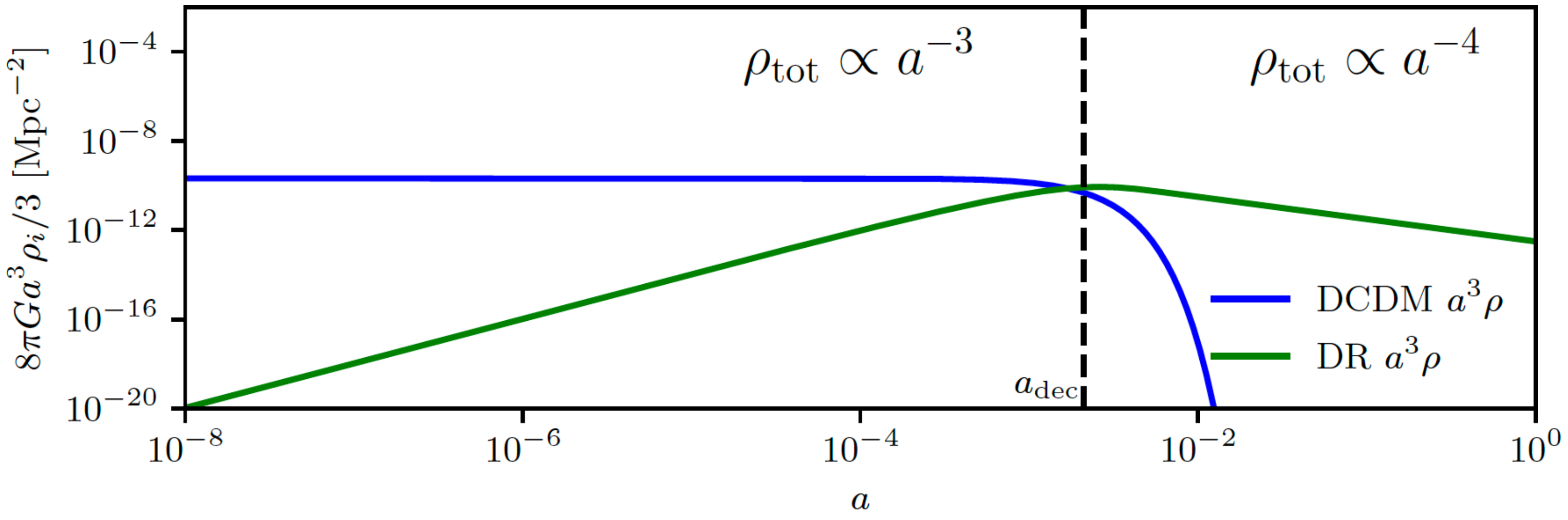


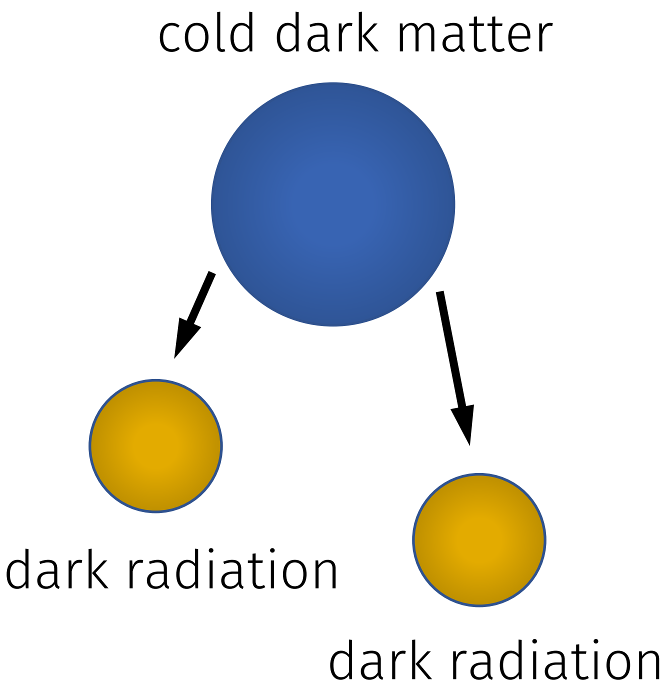
A. Gomez-Valent 2022 (arXiv:2203.16285)

Invisibly decaying dark matter

model:

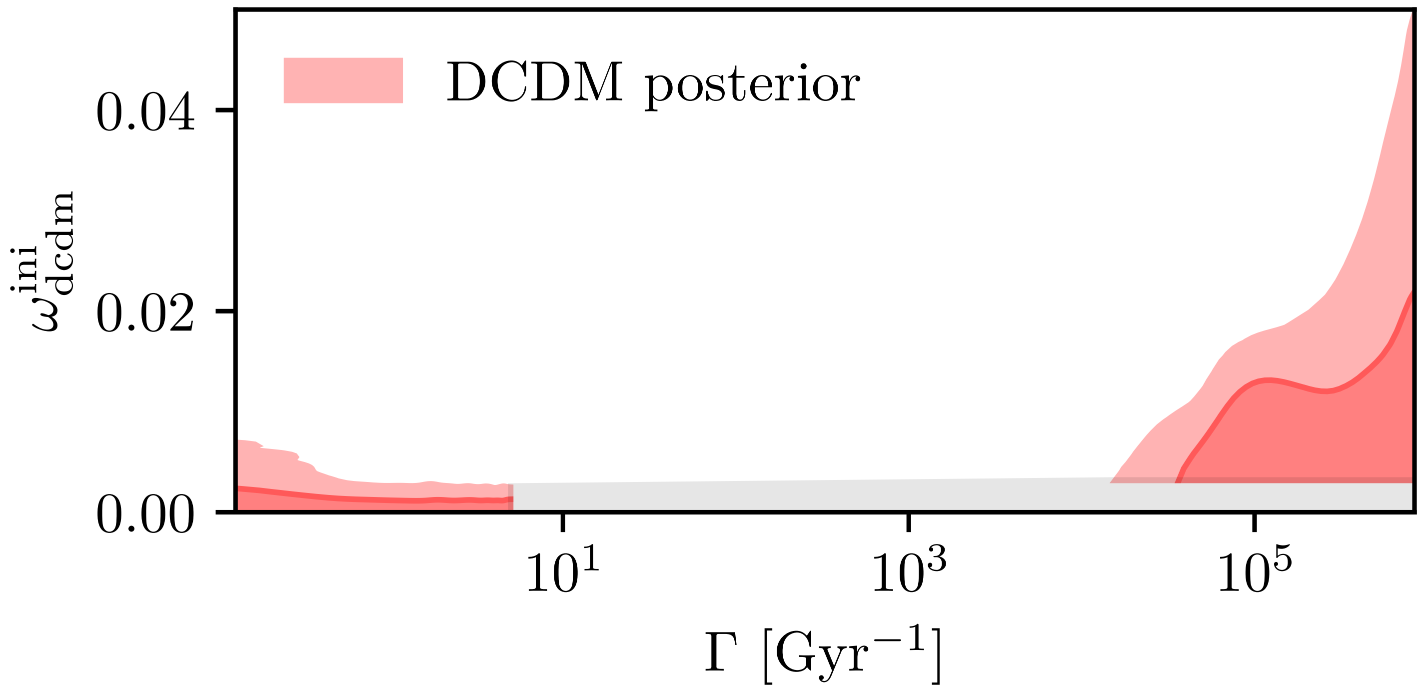
fraction f_{DCDM} of **cold dark matter**
decaying to **dark radiation**





Earlier constraints on DCDM

$f_{\mathrm{DCDM}} < 0.0216$ from Planck, BAO, LSS (arXiv:2203.07440)



adapted from (arXiv:2011.01732)

Profile likelihoods

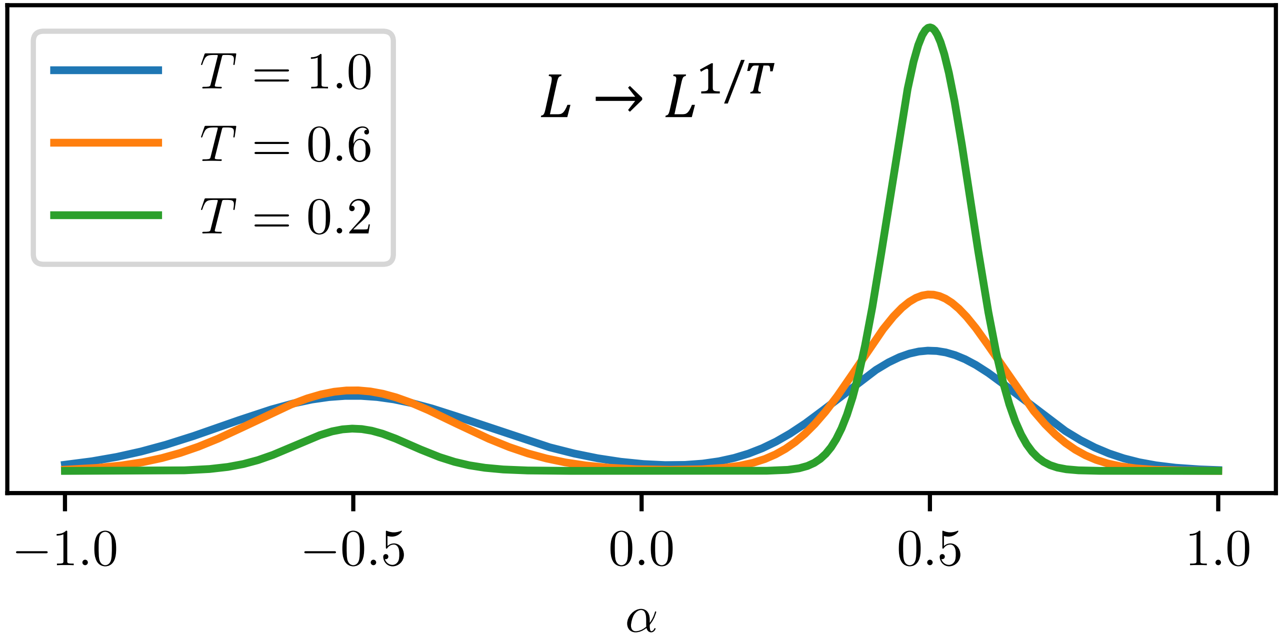
- Profile likelihood (PL):

$$\mathrm{PL}(\alpha) = -2\ln\left(\max_{\beta}\frac{L(\alpha,\beta)}{L_{\mathrm{max}}}\right) \stackrel{\mathrm{def}}{=} \min_{\beta}\Delta\chi^2(\alpha,\beta) \quad \sim \quad \chi^2(1\ \mathrm{DoF})$$

- Parabolic PL:
  - 68 % CI: $\mathrm{PL}(\alpha) < 1$
  - 95 % CI: $\mathrm{PL}(\alpha) < 3.84$

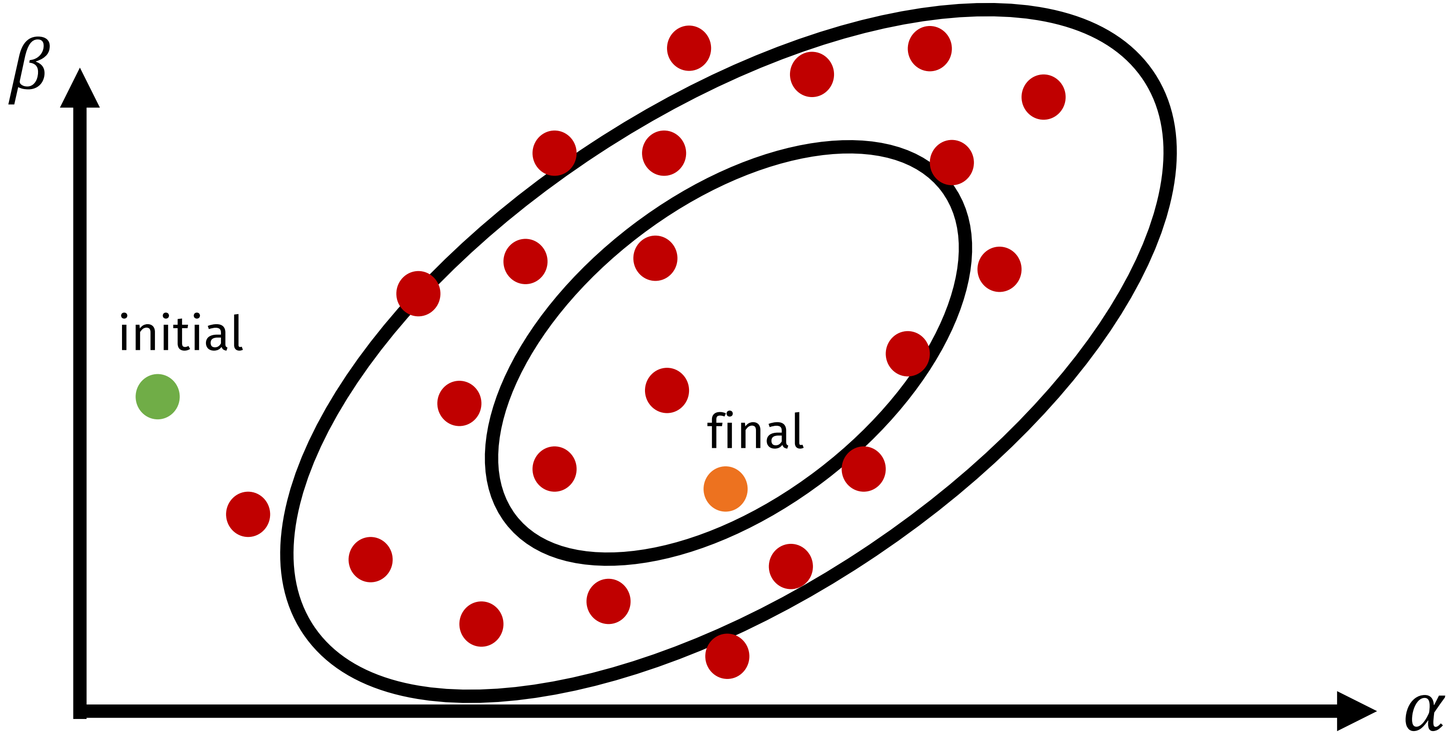
(but holds approximately even if not parabolic…)

Profile likelihoods: Simulated annealing



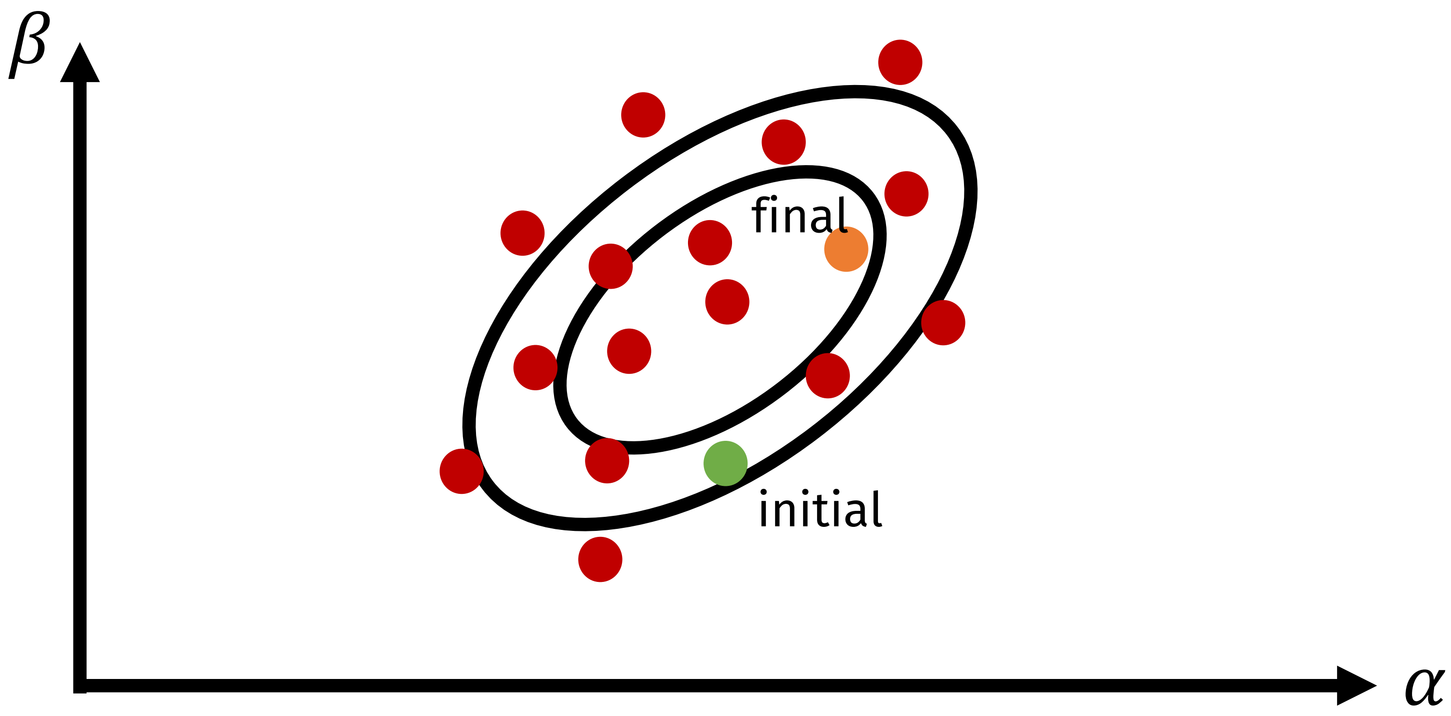
Simulated annealing

Iteration 1



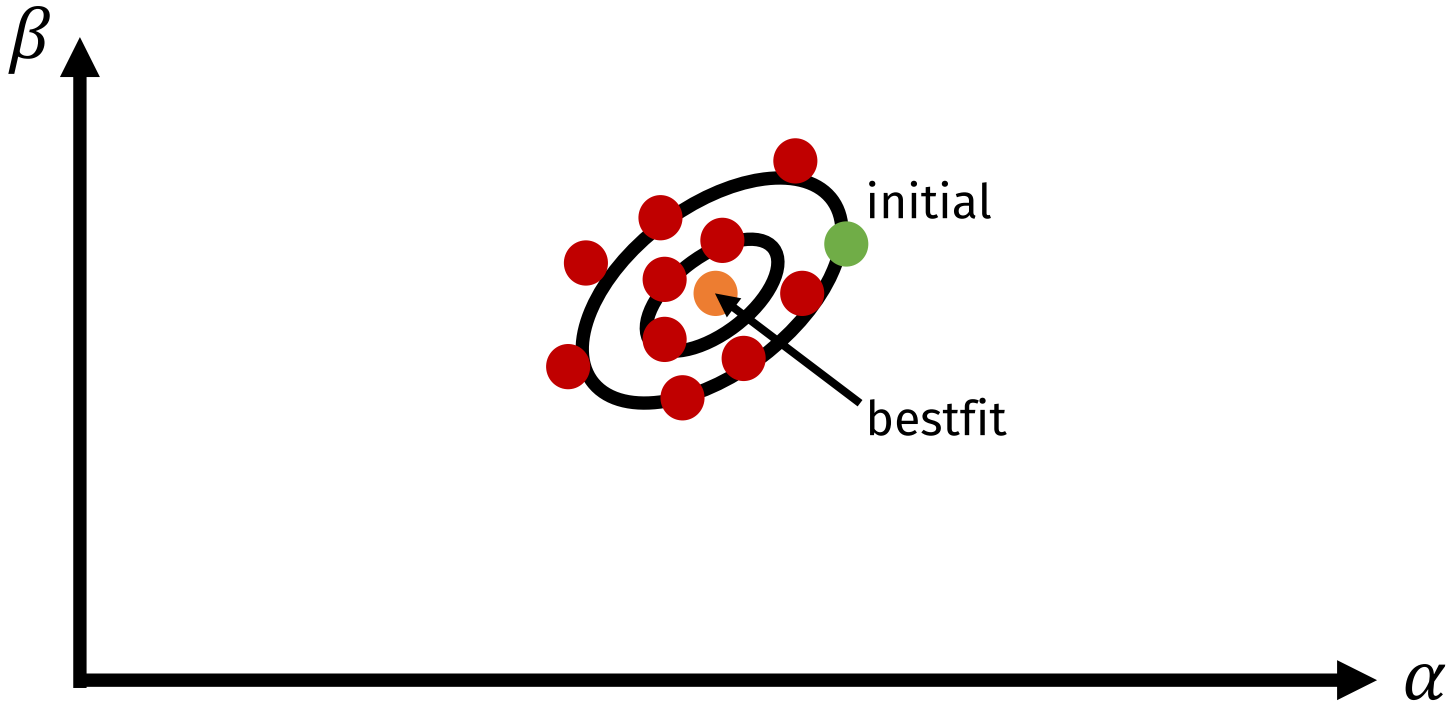
Simulated annealing

Iteration 2

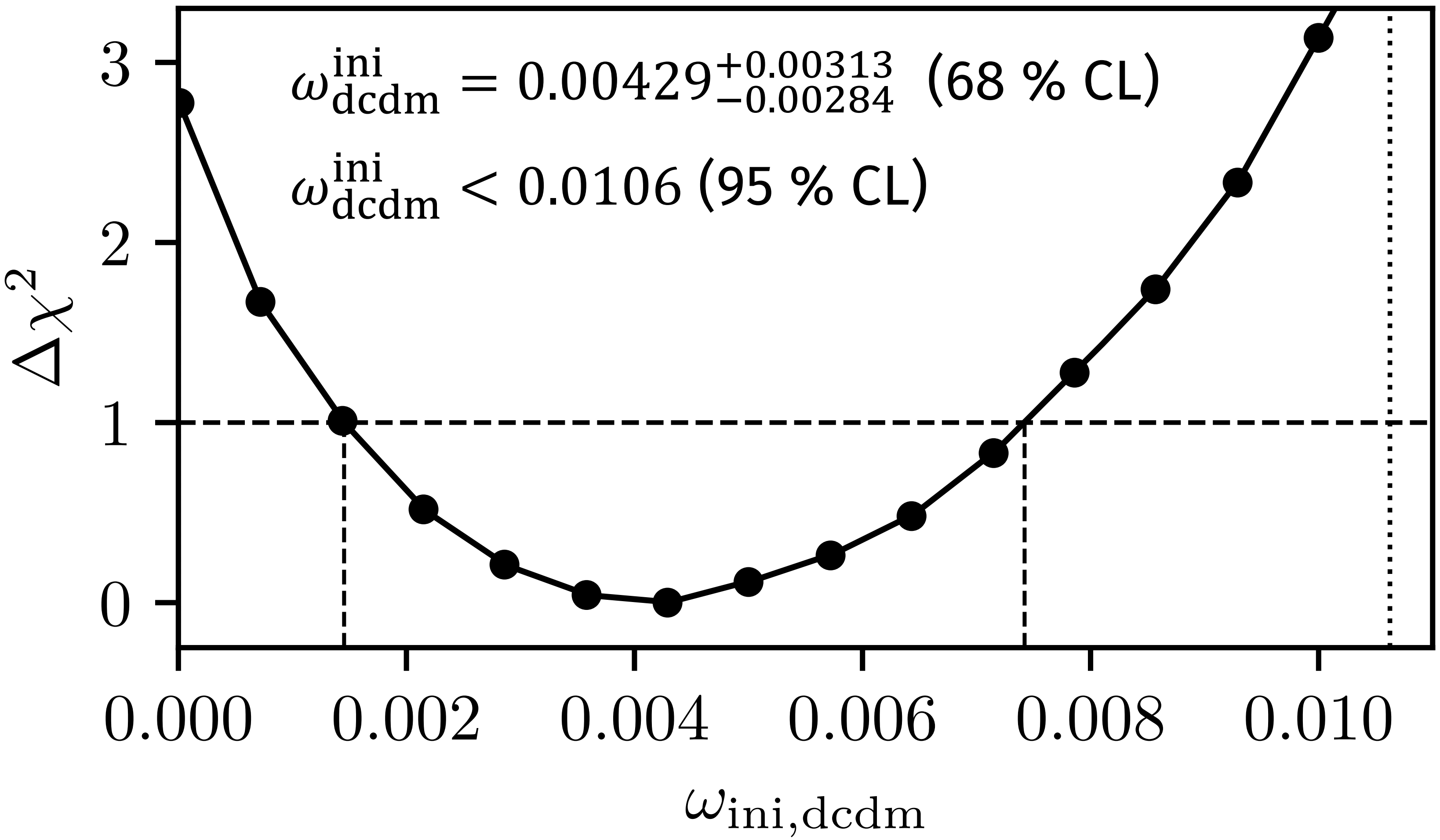


Simulated annealing

Iteration 3

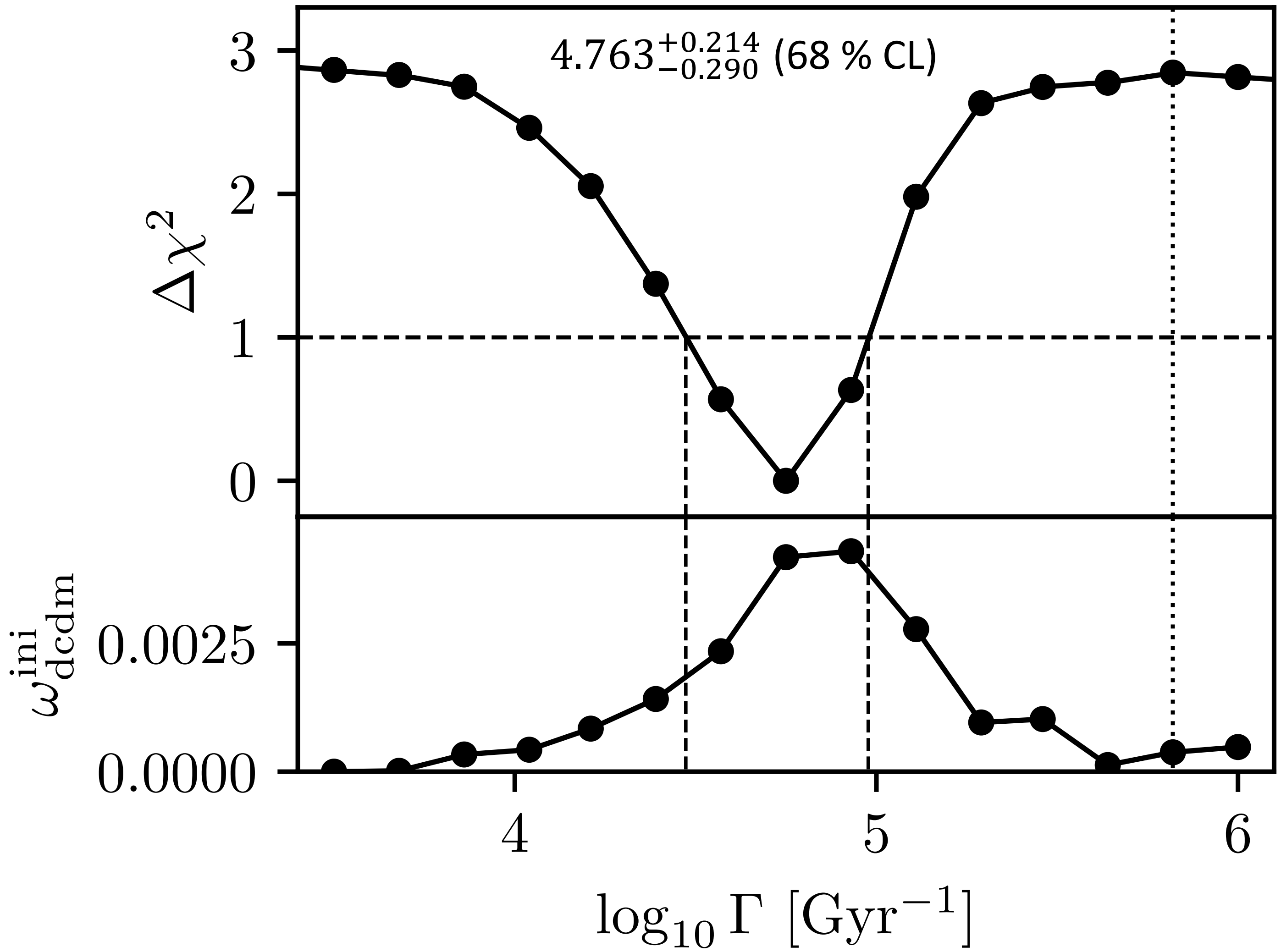


Results

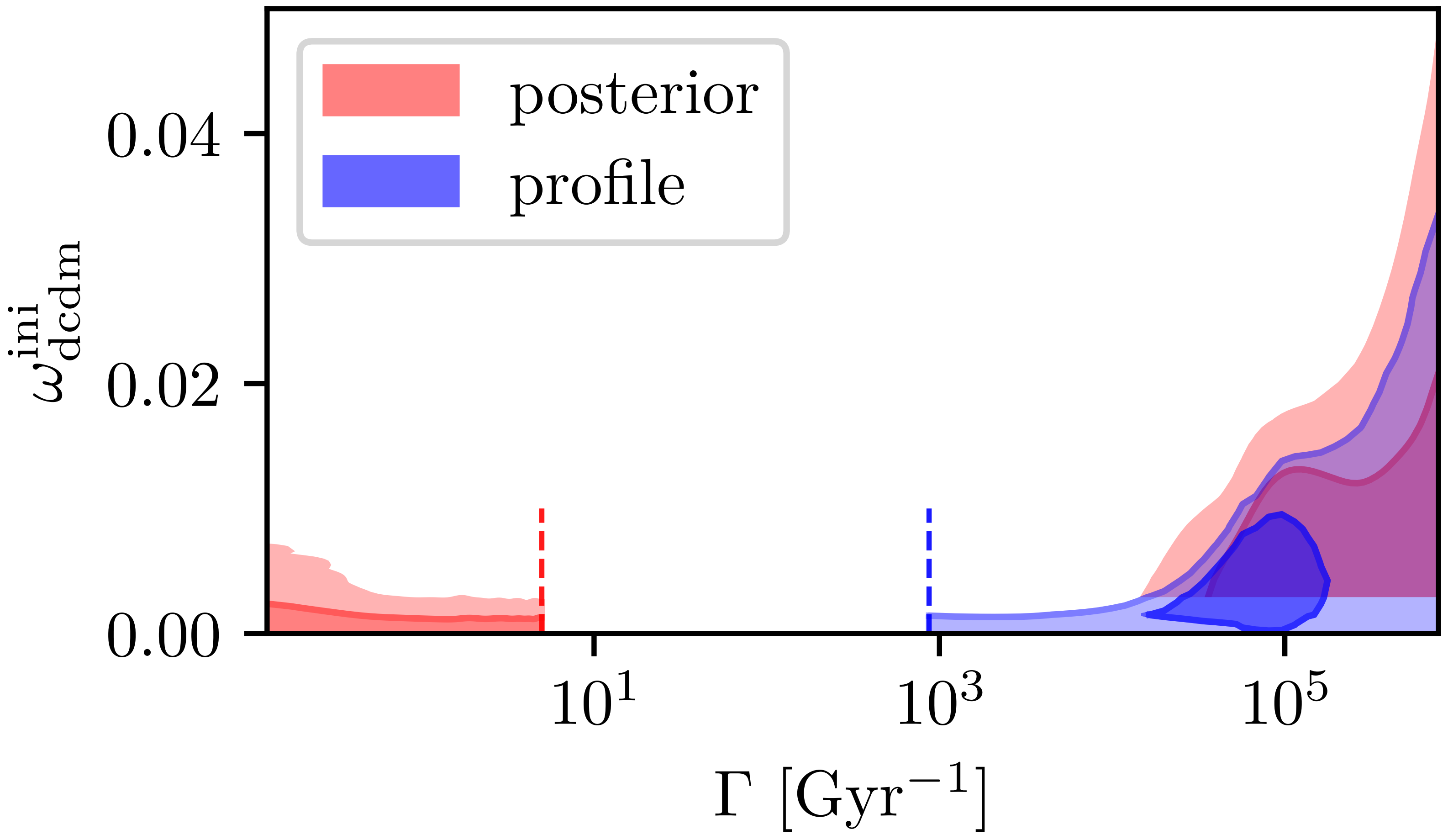


$\omega_{\rm dcdm}^{\rm ini} = 0.00429^{+0.00313}_{-0.00284}$ (68 % CL)
$\omega_{\rm dcdm}^{\rm ini} < 0.0106$ (95 % CL)
$\Delta\chi^2$
3
2
1
0
0.000
0.002
0.004
0.006
0.008
0.010
$\omega_{\rm ini,dcdm}$

Results

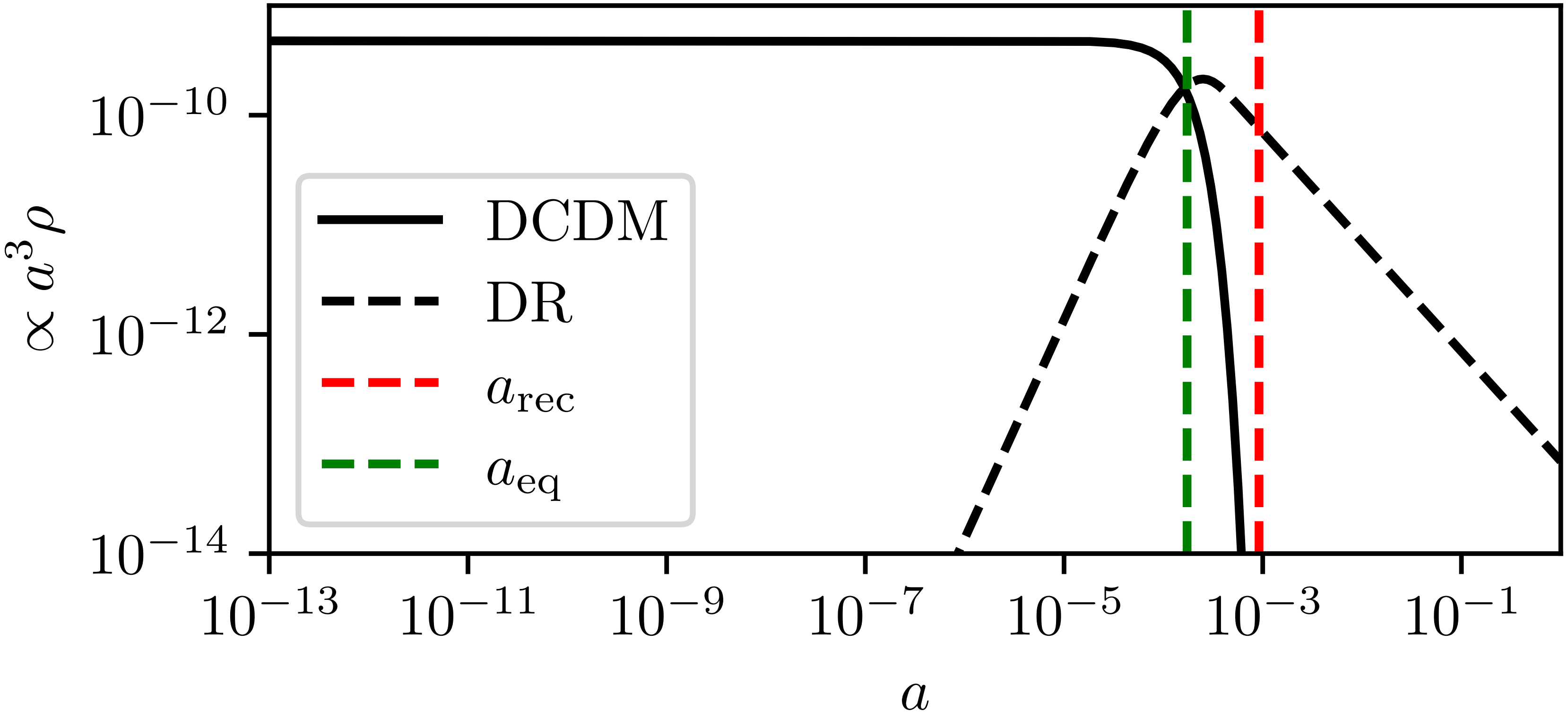

$4.763^{+0.214}_{-0.290}$ (68 % CL)
$\Delta\chi^2$
3
2
1
0
$\omega_{\rm dcdm}^{\rm ini}$
0.0025
0.0000
4
5
6
$\log_{10}\Gamma$ [Gyr^{-1}]

Results

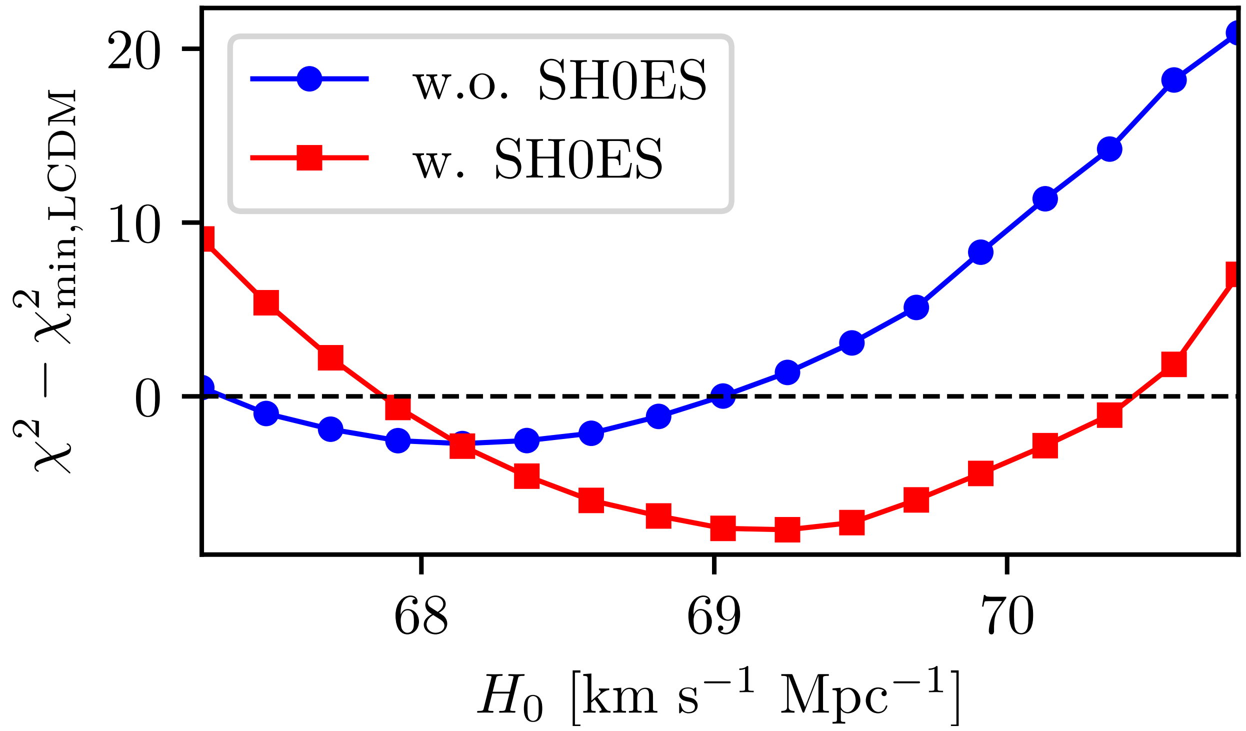


posterior
profile
0.04
0.02
0.00
$\omega_{\rm dcdm}^{\rm ini}$
10^1
10^3
10^5
Γ [Gyr^{-1}]

Bestfit decays around recombination



Still does not solve H_0



At 68 % CL:

$H_0 = 68.14^{+0.54}_{-0.49}$ km s^{-1} Mpc^{-1} *(Without SH0ES)*

$H_0 = 69.25^{+0.32}_{-0.49}$ km s^{-1} Mpc^{-1} *(With SH0ES)*

H_0 tension: 4.1σ to 3.6 σ

Conclusions

- Bayesian constraints on DCDM are **highly prior-dependent** and **strongly driven by volume effects**
- Bestfit DCDM is not LCDM, but 1.6σ significant intermediate regime with ~3 % of CDM decaying around recombination
- Even without volume effects, DCDM doesn't solve H_0

Outlook

- Expect volume effects in LCDM extensions with *abundances* or *coupling constants*

  → PLs are important!

- Main PL disadvantage (computation) solved in the future:
  - emulators
  - gradient-based optimization

  → PLs accessible in the future!

- Both MCMC and PL are “correct”

  → Use together!

Discovering a new well: Decaying dark matter with profile likelihoods

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(Dated: November 4, 2022)

A large number of studies, all using Bayesian parameter inference from Markov Chain Monte Carlo methods, have constrained the presence of a decaying dark matter component. All such studies find a strong preference for either very long-lived or very short-lived dark matter. However, in this letter, we demonstrate that this preference is due to parameter volume effects that drive the model towards the standard ΛCDM model, which is known to provide a good fit to most observational data.

Using profile likelihoods, which are free from volume effects, we instead find that the best-fitting parameters are associated with an intermediate regime where around 3% of cold dark matter decays just prior to recombination. With two additional parameters, the model yields an overall preference over the ΛCDM model of $\Delta\chi^2 \approx -2.8$ with *Planck* and BAO and $\Delta\chi^2 \approx -7.8$ with the SH0ES H_0 measurement, while only slightly alleviating the H_0 tension. Ultimately, our results reveal that decaying dark matter is more viable than previously assumed, and illustrate the dangers of relying exclusively on Bayesian parameter inference when analysing extensions to the ΛCDM model.

arXiv:2211.01935v1

Code available at
https://github.com/AarhusCosmology/montepython_public/tree/2211.01935