We thank the reviewer for their careful and helpful comments.

In the response, referee comments are in *italics*, our replies are in normal font, and the revised text is highlighted in light blue relative to the preprint version.

Major Comments

As the authors said, they took the accumulation rate and age depth relationship from Vostok ice core which is 700 km away from Kunlun station. It may have large difference from the real relationship at Kunlun station. Hence it may cause large uncertainty in the optimal value of parameter p and the modelled age, as it is a key function in this 1D pseudo-steady-state age model. So I am wondering how the modelled age at Kunlun station would change if another accumulation rate and age depth relationship is taken? For instance, use the accumulation rate and age depth relationship at the Dome Fuji or Dome C. I also would like to see the plot of normalized vertical velocity. Please add this plot at Kunlun station. Also, it would be interesting to compare the normalized vertical velocity with Zhao et al. (2018).

Reply: Thank you for this comment, we have now tested different ice core chronologies (age-depth relationship and accumulation history) as input (Sect 5.1.3). Based on this, we assess the sensitivity of the 1D modelled ages to different ice chronologies. We have also added a comparison of vertical velocity profiles in Section 5.1.1, where we explain the origin of the velocity differences between the 1D and 3D models, and address why these differences are particularly pronounced in the shallow ice column even within the depth interval constrained by dated isochrones.

The added text is as follow:

“

5 Discussions

5.1.1 Results at Kunlun Station

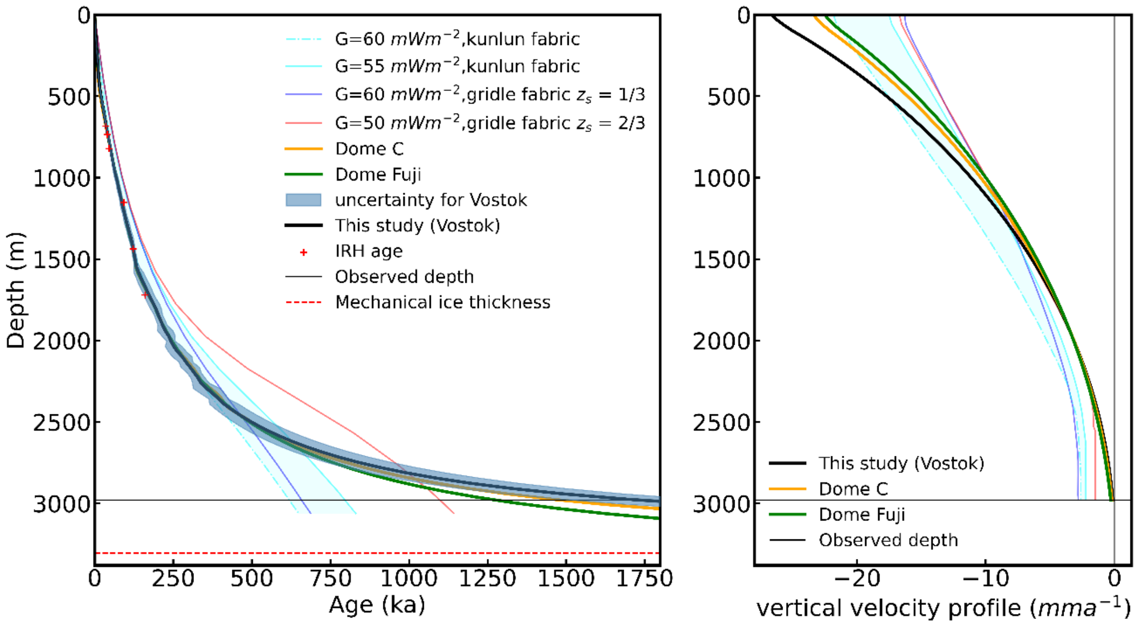

Figure 1. Modeled results at Kunlun Station. The left and right panels show the age–depth and vertical velocity profiles, respectively. Thick lines denote 1D model outputs: black thick lines are from this study, and other thick lines are sensitivity test results for different ice chronologies (Dome Fuji and Dome C), while thin lines represent those of Zhao et al. (2018). Light blue shading indicates the recommended range of age–depth estimates from Zhao et al. (2018), while dark blue shading represents uncertainty in this study (Vostok), arising from uncertainties in input dated IRHs. Black and red horizontal lines denote bedrock and mechanical ice thickness, respectively. Red crosses indicate dated IRHs.

Among existing studies of ice ages in the Dome A region, Sun et al. (2014) used a three-dimensional full-Stokes model to demonstrate that Kunlun Station provides a high-resolution ice core record of 600-700 ka. However, approximately 5 km north of Kunlun Station, an older but lower-resolution ice core record exists. Our simulations also reflect this result. Zhao et al. (2018) used the same methodology as Sun et al. (2014) to estimate the age of the Dome A region, using data from the C21 radar survey as this study within a 30 × 30 km^2 area at Dome A. By varying ice fabric and geothermal flux, their simulated basal maximum ice age ranges from 650 to 830 ka, with melt rates of 2-3 mm yr^{-1}.

Compared with the age-depth curve simulated by Zhao et al. (2018) at Kunlun Station, the age ranges of the curve (Vostok) are similar. Our simulated curve agrees well with the curve (G=60 mWm^{-2}, Kunlun fabric) at depths above 2500 m (Fig. 6). Below 2500 m depth, our simulated ages increase strongly with depth, significantly exceeding the age of the curve (G=60 mWm^{-2}, Kunlun fabric). At the bottom of Kunlun, our simulations yield an age of 1737 ± 223 ka and a relatively low melt rate of 0.14 mm yr^{-1}. This differs significantly from the simulations of Zhao et al.(2018). This discrepancy likely arises from the lack of IRH constraints at the base of the ice sheet. The best IRH is less than 60% of the ice-sheet thickness at Kunlun Station with an age of 161 ka. This is significantly shallower and younger than IRHs used in other studies with this model (Chung et al., 2023; Wang et al., 2023b). Due to basal melting, it is generally difficult to preserve old ice at the bedrock. In ice cores drilled at Dome C, the oldest ice is found 60 m above the bedrock, while in the Greenland Ice-core Project (GRIP), this value is 200m. Although our simulated age for the oldest ice at Kunlun Station differs significantly from that of Zhao et al. (2018), our simulated age of 909±113 ka at a depth of 200 m above the bedrock at Kunlun is considered a conservative estimate of the maximum ice age and is relatively consistent with the maximum ice age simulated by others (Sun et al., 2014; Zhao et al., 2018).

To provide a more comprehensive comparison of the simulation results, we further compared the vertical velocity profiles derived from the 1D and 3D models. Overall, systematic differences in vertical velocity are observed throughout the entire depth range, with substantially larger discrepancies in the shallow layers than in the deeper ice. Notably, even within the depth interval constrained by dated IRHs, the two models exhibit significant differences in vertical velocity, whereas their age–depth relationships remain largely consistent within the same interval (Fig. 6).

The apparent contradiction of significant velocity differences but consistent ages where isochrone constraints exist, can be explained by two factors. First, the two models are constrained by fundamentally different target variables. The 1D model directly fits the ages of dated isochrones, and age represents the integral of the inverse vertical velocity. Consequently, the 1D model inversion problem is inherently non-unique: different shapes of the vertical velocity profile can produce the same cumulative age within the interval constrained by isochrones. In contrast, the steady-state 3D inversion directly constrains the surface velocity field and obtains a physically self-consistent three-dimensional velocity field through solving the Stokes equations. The difference in inversion targets implies that the vertical velocity profile inferred from the 1D model may deviate from a physically self-consistent velocity field, because the inversion only requires agreement in the integrated age signal rather than in the velocity field itself. Second, the integral nature of age reduces the impact of velocity differences in the shallow layers. The shallow ice constitutes the initial segment of the age integration path, where the integration length is relatively short. As a result, the cumulative age uncertainty induced by differences in vertical velocity remains limited. Therefore, within the shallow interval constrained by dated isochrones, the 1D model can reproduce the observed ages by adjusting the shape of the vertical velocity profile without introducing substantial age discrepancies.

In the deeper ice, however, the influence of vertical velocity differences on age becomes more pronounced. Because no dated isochrone constraints are available at depth, biases in vertical velocity can no longer be compensated for through adjustments to the profile shape. Instead, these biases accumulate and amplify over the long integration path, causing the ages simulated by the 1D model to become systematically older. At 200 m above the bed at Kunlun Station, the age difference between the 1D simulation (Vostok) and the 3D simulation ($G = 60$ mW m^{-2}, Kunlun fabric) reaches approximately 261 ka. This offset reflects the structural discrepancy between the two models, which comprises two main components: (1) differences in model assumptions, particularly the neglect of horizontal advection by the 1D model; and (2) differences in parameter treatment, including the handling of GHF and ice fabric, which are discussed in Sect. 5.4.

5.1.3 Senseitivity test at Kunlun Station

In this section, we assess the sensitivity of the 1D simulated ages to two input-related factors: uncertainties in dated isochrone ages and the choice of ice chronology input. For the dated isochrones, the influence of age uncertainty on the simulated results is represented by the shaded region labelled "uncertainty for Vostok" (Fig. 6). The resulting age differences are relatively small in the upper ice column but increase with depth. At 200 m above the bed, the uncertainty range reaches 113 ka, increasing to 223 ka at the bed.

We adopted the Vostok ice chronology as the reference input and also tested other ice chronologies, shown in Fig. 6 as Dome C in yellow and Dome Fuji in green. In these tests, only the accumulation variations (Bouchet et al., 2023; Oyabu et al., 2022) applied to the age-depth profile were changed; the isochrone ages remain tied to the Vostok chronology and cannot be independently re-dated from the other ice cores. The test results show that the simulated age–depth profiles remain broadly consistent in the upper part of the ice column (Fig. 6). Below approximately 2600 m depth, however, the differences become dependent on the selected ice chronology and increase progressively toward the bed. At 200 m above the bed beneath Kunlun Station, switching the ice chronology introduces age differences of up to 104 ka, while at the bedrock the differences reach as much as 459 ka. The Vostok chronology produces older ages in deep ice than the other chronologies. This may reflect the greater uncertainty in the Vostok accumulation-rate history, as it was derived from a flank ice core that is more difficult to model than dome-site records.

In contrast to the age–depth relationship, the vertical velocity profiles are more sensitive to the choice of ice chronology in the upper ice column, while showing only minor variations in the deeper part. This opposite behaviour arises because the 1D model is constrained primarily by age rather than velocity, and because age represents the integral of the inverse vertical velocity. As discussed in Sect. 5.1.1, variations in shallow vertical velocity have only a limited influence on cumulative age, whereas age becomes highly sensitive to velocity changes at depth.

Among the above factors, the uncertainty associated with dated isochrone ages was propagated into the simulated age envelope and is therefore already included in Fig. 6. The effects associated with ice chronology input differences are not included in the envelope, but are listed here as an independent reference magnitude. For comparison, the structural discrepancy between the 1D and 3D models introduces an age difference of ~261 ka at 200 m above the bed (Sect. 5.1.1). At this depth, the relative magnitudes of the three sources are, from largest to smallest: structural differences between the 1D and 3D models (~261 ka) > isochrone-derived age uncertainty (113 ka) > ice chronology input differences (104 ka).

”

Minor Comments

Line 1, what do you mean by 'high precision'? Why do you think your model is a high precision model?

Reply: Thank you for your comment. As we believe that the 1D model performs reasonably well at Little Dome C and EDC, the previous wording may have appeared somewhat subjective. We have removed it.

-Line 19, there are two commas.

Reply: Done.

-Line 21, add 'of' after the last 'age'.

Reply: Done.

-Line 24, It need to point out the model limitation, which may bring large uncertainty to this result.

Reply: We have added a sentence to explain the model limitation. "

We have pointed out the model limitations and discussed their implications for uncertainty in several sections of the revised Discussion:

1. In Sect. 5.1.3, we compare the magnitudes of three sources of age discrepancy. The structural discrepancy between the 1D and 3D models (~261 ka) is identified as the largest single source of uncertainty, exceeding both the isochrone-derived uncertainty (113 ka) and the uncertainty associated with different ice-chronology inputs (104 ka).

2. In Sect. 5.4, we discuss the origins of this structural discrepancy, including the neglect of horizontal advection and the indirect treatment of GHF and ice fabric, whose effects are implicitly absorbed into the shape parameter p.

3. In Sect. 5.5, we adopt a conservative estimate of 909 ± 113 ka at 200 m above the bed, for which the uncertainty range still encompasses 1 Ma. By choosing this depth rather than the modelled basal age, we reduce the sensitivity to poorly constrained deep extrapolation and to the structural discrepancy discussed in Sect. 5.4. Together with the relative ranking of the three sites, these results suggest that Dome A has the greatest potential among the three candidates for preserving ice older than 1 Ma.

-Line 25, 'Isoinv1D model' is only used here. But you use '1D pseudo-steady-state model' in section 3. Use the same name.

Reply: Done.

-Line 37, change 'simulations' to 'projections'

Reply: Done.

-Line 52, what is 'NP'? Provide its full name when it first appears.

Reply: Done. NP refers to the North Patch area in Dome C (Chung et al., 2023). The revised text is "Simulated ages exceeded 2 Ma at another more promising old ice location, the North Patch (NP) (Chung et al., 2023)."

-Line 56, it is hard to understand this sentence '... the maximum ice age is defined as ice characterized by an age density of 20 kyr/m.'

Reply: We have rephrased this to "…the maximum ice age is defined as the age at the depth where the age density reaches 20 kyr m^{-1}".

-Line 65, 'a full Stokes coupled heat equation model' is wrong description. Full Stokes model includes the heat equation.

Reply: Done. We have revised it to "a Full Stokes model showed that".

-Line 70, it is not clear what do you mean by 'these factors'. The main uncertainty comes from GHF. 'greater uncertainty', why do you use 'greater', than what?

Reply: We have rewritten these sentences as this also caused confusion for Reviewer 2. We are comparing the GHF representation in the Zhao et al. (2018) with that of 1D pseudo-steady-state.

From Line 71, the new sentences are:

"Their models are constrained by surface velocity measurements and prescribed GHF. However, surface velocity observations across Dome A are sparse, and GHF exhibits strong spatial variability (Schroeder et al., 2014; Yang et al., 2014). Both ice fabric and GHF were identified as key controls on deep ice age, and the influence of fabric is comparable to uncertainties associated with GHF (Sun et al., 2014). Different GHF values (50–60 mW m^{-2}) produced basal age ranging from 650–830 ka (Zhao et al., 2018). Despite its importance, direct GHF measurements remain extremely limited in East Antarctica. Existing GHF datasets rely on indirect geophysical inversions or glaciological inferences and therefore carry substantial uncertainties (Lösing et al., 2020; Martos et al., 2017). Consequently, the treatment of GHF represents an important source of model uncertainty, which is discussed in Sect 5.4. In contrast, the approach adopted here offers three advantages: (1) the 1D pseudo-steady-state model does not explicitly include parameters for GHF and surface velocity, avoiding the uncertainties inherent in their estimation; (2) it is constrained by dated internal reflecting horizons (IRHs), which provide a stronger constraints on age-depth structure; and (3) The model has been successfully applied in multiple regions, especially at EDC and LDC where it has been validated."

-Line 71, Provide the full name of 'IRH' when it first appears.

Reply: Done.

-Line 73, 'supportf' is a typo

Reply: Done.

-Line 85-87, avoid to use 'light blue' and 'dark blue' in the main text. They should only appear in figure captions. Remove thelightm. Use C21DA and C21KL instead.

Reply: Done.

-Line 92, is it Luo et al. (2023) or Luo et al. (2022)?

Reply: Thank you for pointing out this error. It is Luo et al.(2022).

-Line 94-96, for some reason, the font size of the subscripts for the variables in the text and in the equations is too large.

Reply: Done.

-Line 120. It is not correct that '... cannot quantify the melting rate.'

Reply: We have deleted it.

-Line 126, why do you make this assumption?

Reply: The steady-state age is calculated at the radar measurement points, and the true age is calculated using the ratio r(t) between the average accumulation and the true accumulation from ice cores. We therefore assume r(t) = 1 for ages exceeding the maximum ice core age as we have no accumulation variations for ice older than this. This approach follows similar treatments in the literature (Chung et al., 2023; Wang et al., 2023).

-Eqn (4), check if you missed Hm.

Reply: Thanks, we have added H_m in the text.

-Eqn (5), use parentheses that match the formula height.

Reply: Done.

For all the equations, double check the variables if they are scalar or vector. Vectors should be in bold.

Reply: Done. We have bolded vectors in the text.

Page 6, the subscript of Hm in this page looks odd.

Reply: Done.

-Line 157-158, what do they mean by '4 km, 18 km, and 44 km'? Are they distance from somewhere? Please describe them accurately.

Reply: We have revised it and corrected the value error of "18 km". The revised sentence is "Simulated ice ages near the bedrock are relatively old at distances of 4 km, 13 km, and 44 km along the C21 KL transect from its starting point (77.44 °E,80.38 °S)".

-Line 181. I do not understand this sentence 'Near and north of Kunlun Station, a larger maximum ice age corresponds to greater ice sheet thickness. '.

Reply: We now refer to areas shown in Fig. 4A and have corrected the sentence to reflect this. "In areas B and C (Fig. 4A), the larger maximum ice age is explained by a greater ice thickness, as shown in Fig. 3 C."

-Line 184, I assume you mean Fig. 3 A?

Reply: Yes, that is Fig. 3 A. We have corrected it.

-Line 223, add 'as Sun et al., (2014)' after 'the same methodology'.

Reply: Done.

-Line 226-228, avoid to use words like 'blue curve' in the main text. Replace them with scientific description.

Reply: Done.

-Line 230-232. Rephrase this long sentence.

Reply: We have rephrased this sentence."This differs significantly from the simulations of Zhao et al.(2018). This discrepancy likely arises from the lack of IRH constraints at the base of the ice sheet. The deepest IRH is less than 60% of the ice-sheet thickness at Kunlun Station with an age of 161 ka. This is significantly shallower and younger than IRHs used in other studies with this model (Chung et al., 2023; Wang et al., 2023b).

-Line 233. There is something wrong in this sentence. 'this figure is 200 m'?

Reply: We have rephrased this to "…while in the Greenland Ice-core Project (GRIP), this value is 200 m."

-Line 248-249. I do not agree with this sentence. Do you have similar cold surface temperature and low geothermal heat flux in Dome A?

Reply: We have revised the argument and supported it with specific data in Sect 5.2:

"However, greater ice thickness does not necessarily imply increased basal melting. The thermal state of the ice sheet base depends on the competition between geothermal heating and the downward advection and diffusion of surface cold. In the East Antarctic interior plateau, where surface mean temperatures can drop below -50°C, the downward transfer of cold can effectively counteract or even exceed the effects of GHF and pressure melting. A prime example is Dome A, where the measured surface temperature is approximately −58 °C (Xiao et al., 2008) and GHF is relatively low compared to the West Antarctic average (Burton-Johnson et al., 2020). Based on different datasets, GHF at Dome A is estimated to range from 47.1 to 62.4 mW m^{-2} (Liu et al., 2026; Lösing et al., 2020; Stål et al., 2021), a level of thermal input low enough to allow the ice sheet base to remain frozen despite its significant thickness. This may explain why our simulation along the C21KL transect (Fig. 2) did not exhibit the expected trend of higher basal melt rates with increasing ice thickness.”

-Line 291, do not use subjective words such as ‘successful’.

Reply: Thank you for your comment. We have no changes due to the rewritting of Sect 5.5.

-Line 294-310. Please rephrase the conclusion paragraph. The wording needs to be improved. For instance, you cannot say “The method obtained parameters”. Is this ‘8 km south’ correct? It is said ‘8 km southwest’ in section 4.2.

Reply: Thanks for your suggestions. ‘8 km southeast’ is the correct description. We have revised the conclusion paragraph. The revised paragraph is

“

6 Conclusions

We applied the 1D pseudo-steady-state model from (Chung et al., 2023; Parrenin et al., 2006, 2017) to simulate the age-depth profile along the C21 radar lines. Using six IRHs dated from the Vostok ice core as constraints, we propagated the Vostok age-depth relationship to the Dome A radar survey lines and derived the resulting ice age and time averaged accumulation rate.

Figure 4A shows that ice exceeding 1 Ma is concentrated in three regions: Area A is ~2.5 km around the point (76.89 °E, 80.47 °S); Area B is ~3 km around the point (77.12 °E, 80.42 °S); Area C is ~8 km around the point (77.14 °E, 80.37 °S). These regions are characterized by greater ice thickness, lower basal melt rates (<1 mm yr^{-1}), and age densities below 20 kyr m^{-1}, although they also exhibit higher age uncertainty than other areas. Area C shows greater maximum ice ages but also higher age density compared to Area B. At Kunlun Station, under ideal conditions, the simulated maximum ice age is 1737 ± 223 ka, with an age density of ~8.2 kyr m^{-1} and a basal melt rate of 0.14 mm yr^{-1}. Considering basal melting and the distribution of old ice, we adopted a conservative estimate of 909 ± 113 ka at 200 m above the bedrock. This value is broadly comparable to the 650–830 ka range reported by Zhao et al. (2018), with the lower bound of our estimate overlapping the upper end of their range.

These results indicate that drilling in both the Kunlun Station region (Area B) and the northern region (Area C) could yield ice cores older than 1 Ma. This provides some guidance for prioritizing promising drilling targets near Dome A and supporting ongoing international efforts to recover ice exceeding 1 Ma.

”

-Line 305. Rephrase this sentence 'These differences are likely due to the simplified yet effective modelling framework adopted here, which allows the integration of more spatially explicit radar-derived age constraints'. Both this study and Zhao et al. (2018) used the same radar-derived age constraints. Maybe you write 'The variation in results is mainly due to different methods.'

Reply: We have now changed due to the rewritting of Conclusion.

-For the figures: There are only one or two numerical values on the longitude and latitude lines in the maps. It is not easy to read the map. For all the maps, add numerical values to all the longitude and latitude lines. Besides, for all the maps, add the scale bar. The text and numbers on the figures need to be enlarged.

Reply: Done.

-Figure 1. I would label C21DA for the dark blue line and C21KL for the dark blue line, to be consistent with what you said in the caption. It is hard to see the two intersections of AWI with C21KL. Are the two points 'S' and 'N' necessary to show? Give the reason why you need to label them. If you need to, I suggest to use other letter to represent them, because S and N can easily be confused with south and north. I do not think it is correct '...and the black lines represent surface elevation contours.' There are no surface elevation contours. You did not say anything for the inset figure. The label of 'Vostok' could be smaller. There are black lines in the inset box, what are they? Describe it in the figure caption. The sub-caption of the figure is not need, remove it. Put the unit 'm' into parentheses.

Reply: We have revised the color: light blue for C21DA and dark blue for C21KL. We have removed the 'S' and 'N' points. We have added the surface elevation contours in meters (black lines).

-Figure 2. It is hard to match this figure with figure 1. You have stretched the four triangles into a straight line. Where is your starting point? And the direction? Where is Kunlun station? Mark it.

Reply: We have corrected the color of C21DA and C21 KL. C21KL (dark blue) is stretched into a straight line, starting from the endpoint of C21 KL near the center of C21DA. We have also changed the caption for Fig. 2 to "

Figure 2. Profile along C21KL(Fig. 1). The background color denotes the modeled ice age (ka). The vertical line shows the location of Kunlun Station. The white, black and red line represent dated IRHs, bedrock and mechanical ice thickness, respectively. Distance denotes distance from the starting point near (77.44 °E,80.38 °S) along C21KL.

".

-Figure 3-6. Much of the figure domain is useless and not interesting; the spatial extent of the plot can be reduced. This legend for 'Kunlun station' is not needed. Say it in the caption and remove the red star legend. Remove the sub-captions of the figure.

Please them at the colorbar. Put the units into parentheses. Chang the units like 'mm/yr' to 'mm yr-1'. The text and numbers on the figures need to be enlarged. Circle the same optional area in Figure 4b as in Figure 4a.

Reply: Done.

-The figure 4 caption is unclear, such as 'A is the 8 km area southwest of Kunlun Station, B is the Kunlun Station area, and C is the 5 km area north of Kunlun Station.'.Please improve it, to be consistent with the main text. You may say 'Area A is 8 km southwest of Kunlun Station, ...'. You can combine figure 4 and 5 into one figure.

Reply: The sentence has been revised to be more consistent with the text. "

Figure 3. (A) Age density at 1Ma, (B) Basal melting rate, (C) Standard deviation. The dashed circle marks the potential area for preserving old ice. Area A is 2.5 km around the point (76.89 °E,80.47 °S), Area B is 3 km around the point (77.12° E,80.42° S) and Area C is 8 km around the point (77.14 °E, 80.37 °S).

"

Figure 7. Replace the legend 'Age-depth scale' with 'this study'. Add a subplot to show the vertical velocity.

Done.

Reference:

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