Referee comments in regular font
Our responses in italics

RC1: 'Comment on egusphere-2023-3126', Anonymous Referee #1, 06 Feb 2024
Petrenko et al. explore the potential of 14CO measurements in ice cores as a means to investigate the stability of the galactic cosmic ray (gcr) flux outside the heliosphere (the local interstellar spectrum, LIS). The rationale behind the approach is, that 14CO production in firn/ice below ~70 m is dominated by fast muons which are produced by gcr of very high energy (>100 GeV). Such high energy gcr are nearly unaffected by the helio- and geomagnetic fields. Thus, changes in 14CO production by fast muons can inform about changes in the flux of gcr outside the heliosphere, which is of importance for all studies using cosmogenic radionuclides (e.g., solar activity reconstructions) as the constancy of the LIS is an underlying assumption to all of them.
The paper first reviews previous data and modelling results previously obtained from Greenland and Antarctic ice cores that allowed narrowing down the uncertainty of some of the required parameters for understanding 14CO-concentrations in ice. This lead up to the formulation of the method conceptualized here and to the identification of site characteristics required for testing it.
Using the site of EPICA Dome C as an example, the authors employ a firn model and an ice-only model to demonstrate the expected importance of the different 14CO production mechanisms over depth and the effect of prescribed changes in the cosmic ray flux on 14CO concentrations in the ice.
Lastly, the authors test, under which scenario a change in the LIS could be detected from measurements. Owing to the large temporal averaging of the big samples and the large penetration depth of fast muons, these results indicate that short term changes in the LIS are unlikely to be detected using this method (or at least the changes have to be so big that they would also become obvious from simpler methods). But the method may be able to detect a linear increase of 4% of the GCR flux over the Holocene.
This paper is building upon the work of the same group of authors and it is another great addition to the portfolio of scientific questions that may be asked through gas-specific 14C-analyses in ice. The possibility to test the stability of the LIS over time is intriguing and the paper is well written and scientifically excellent.
Hence, I only have some minor comments that I will outline below.
We thank the referee for their helpful review and address the individual comments below.

Minor Comments:
14CO can only provide constraints on the stability of the LIS above 100 GeV (the energy required for deep production by fast muons). The production of 10Be on the other hand is mainly caused by primary protons below 10 GeV (because there are so much more). With respect to the possibility to use 14CO as a constraint for the assumption of a constant LIS in 10Be-based solar activity reconstructions: Over which energy range can changes in the LIS be assumed to be proportional?
This is a good question. The answer depends on what we hypothesize as the origin of any time-dependent changes in the GCR/LIS flux. If a point-source transient such as a supernova produces a local enhancement in the GCR flux, then the time-dependent effect should be more pronounced at higher energies. This is because the diffusion length of cosmic rays in the galactic magnetic field scales with energy. A simple way to understand this is by considering the

gyroradii of protons in the galactic magnetic field; at 10 GeV, it is ten times smaller than at 100 GeV, and is much smaller than the distance to the nearest star.

Thus, at lower energies it is likely that magnetic fields in the local interstellar medium will dampen time-dependent effects observed above 100 GeV. The extent to which that occurs is difficult to estimate a priori, as it could depend strongly on random fluctuations in the turbulent component of the galactic magnetic field as well as the position of the source of GCRs. To answer the question, we would need to model several scenarios using the largest and smallest reasonable values of the galactic field. That could be the subject of a future analysis but would be outside the scope of this study.

On the other hand, there may be scenarios where an enhancement of the local GCR flux is not due to a single point source, but due to our entry into or exit from a region with an enhanced and isotropized GCR flux, such as a local bubble produced by many sources surrounding the Solar System. In that case, the overall normalization of the flux could be affected with less energy dependence than expected from a single point source of cosmic rays.

We will add some discussion in the revised manuscript to indicate that constraints on the stability of the GCR flux / LIS depend on the origin of a possible time-dependent signal and would need to be evaluated carefully in light of several origin hypotheses. In general, however, it is true that a constant LIS/GCR flux at high energy is very likely to imply a constant flux below 10 GeV, while a time-dependent flux above 100 GeV could still be consistent with a constant flux at 10 GeV.

L19: “GCR flux”: I would replace this with the term “local interstellar spectrum (LIS)” as this is clearly defined to be outside the heliosphere and thus outside the influence of helio- or geomagnetic modulation. Please also check this for the remainder of the manuscript, as I think in most instances, it is the LIS you’re referring to and not e.g., the GCR-flux into the atmosphere.
The use of the term “local interstellar spectrum (LIS)” is not one we have often seen used to refer to cosmic rays beyond the influence of the heliosphere, but we acknowledge this may be due to differences in the literature on low-energy and high-energy cosmic rays. When referring to galactic particles above several hundred GeV, the terms “GCR flux” and “GCR spectrum” are often used interchangeably in the literature, with the phrase “solar-modulated flux” referring to heliospheric effects on the spectrum (and observed flux at Earth) below 100 GeV/nucleon.

While we appreciate the referee’s constructive suggestion to improve the clarity of the paper, we feel that “GCR flux” is the more standard term used for cosmic rays beyond the heliosphere at the energy range relevant to this study, and thus we prefer to keep that term.

L27-28: “linear change/step increase”: define for which duration
We will clarify this in the revised manuscript

L37: “14C abundance”: Replace with 14C/12C
We will make this change in the revised manuscript

L45: “solar GCR flux modulation”: Consider changing to “solar modulation of the GCR flux”, as I was for a second thinking you’re referring to solar cosmic rays.
We will make this change in the revised manuscript

L52: “suggest”: replace with “assume” – I don’t think the mentioned studies provide any results to suggest this
We will make the suggested change in the revised manuscript

L143: The 14C half-life has been revised (https://doi.org/10.1016/j.nuclphysa.2003.11.001)
We will use the slightly updated value (5700 years) in the revised manuscript

L275-280 (& figure 4): where does the increase in 14CO from shallow processes (dashed blue) come from? Is this only an increase in closed porosity?
Yes, this is due to increase in closed porosity and 14CO in porosity being trapped into bubbles. Most of the 14CO that is produced in the shallow firn leaks out into open porosity, and a fraction of this 14CO diffuses down to the lock-in zone, where it is then trapped in closed porosity (bubbles). We will clarify this in the revised manuscript.

Figure 4: I suggest to add a panel to illustrate the applied production changes. These are now only mentioned in the text, described by age, while the 14CO is plotted on depth. It would be nice to get a visual overview over all of it.
In the revised manuscript, we will add a panel showing the production rates vs time in the different plotted scenarios

L402: “the assumption of GCR flux constancy”: add “during the Holocene” (and change to LIS)
We will add “during the Holocene” in the revised manuscript; please see above regarding “LIS” vs “GCR”