The Impact of Ancient Mantle Xe Archives on Geodynamic Evolution Models

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Introduction

The mantle volatile budget reflects primordial volatiles delivered during accretion, radiogenic ingrowth of isotopic species, volcanic outgassing of the mantle, and regassing of atmospheric volatiles through subduction. Xe isotopic compositions are powerful tools for tracing the evolution of Earth's volatile budget because they are sensitive to volatile exchange between terrestrial reservoirs [*e.g.,* 1]. The evolution of the mantle volatile budget is coupled with the atmosphere through continuous degassing and regassing of the mantle (via subduction) over Earth history.

Here we present new isotopic evolution models that can explore a range of past geodynamic scenarios (i.e., rates of mantle degassing and regassing). In addition, we present Ne and Xe isotopic data from a 2.9 Gyr old Greenland anorthosite, an ancient mantle derived rock. We present a new model to explore non-monotonic mantle processing rate histories. We investigate how large magmatic events (e.g., Large Igneous Province (LIP) volumes or greater) at different points in time would impact mantle Xe isotopic evolution. Past mantle compositions are not well constrained. Establishing precise constraints on past mantle Xe has the potential to tell us about fundamental geodynamic processes and how they have shaped the Earth over its history.

Numerical modeling of Xe isotopes: Does episodic outgassing have a measurable effect on mantle Xe?

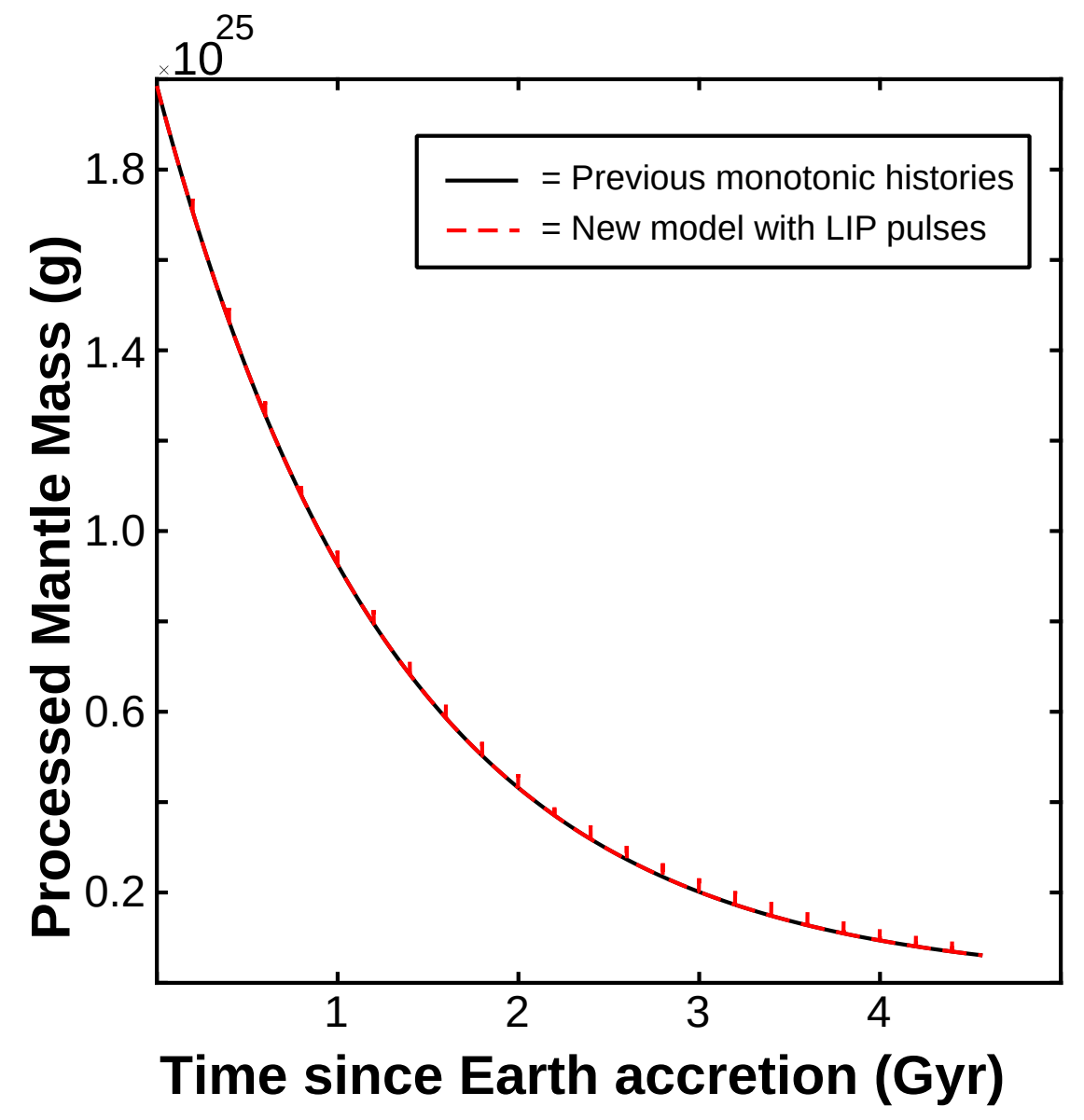


Figure 1. Modeled mantle processing rate over time. Prior models [1] have assumed a smoothly decreasing monotonic processing history (black line). However, we know that episodic outgassing has occured (e.g., LIP events). Here we investigate episodic outgassing corresponding to LIP eruptions (red dashed line) and compare the results to prior models with exponentially decreasing processing rates. LIP volume estimates are taken from [2] and we assume an eruption interval of 200 Myr and duration of 1 Myr.

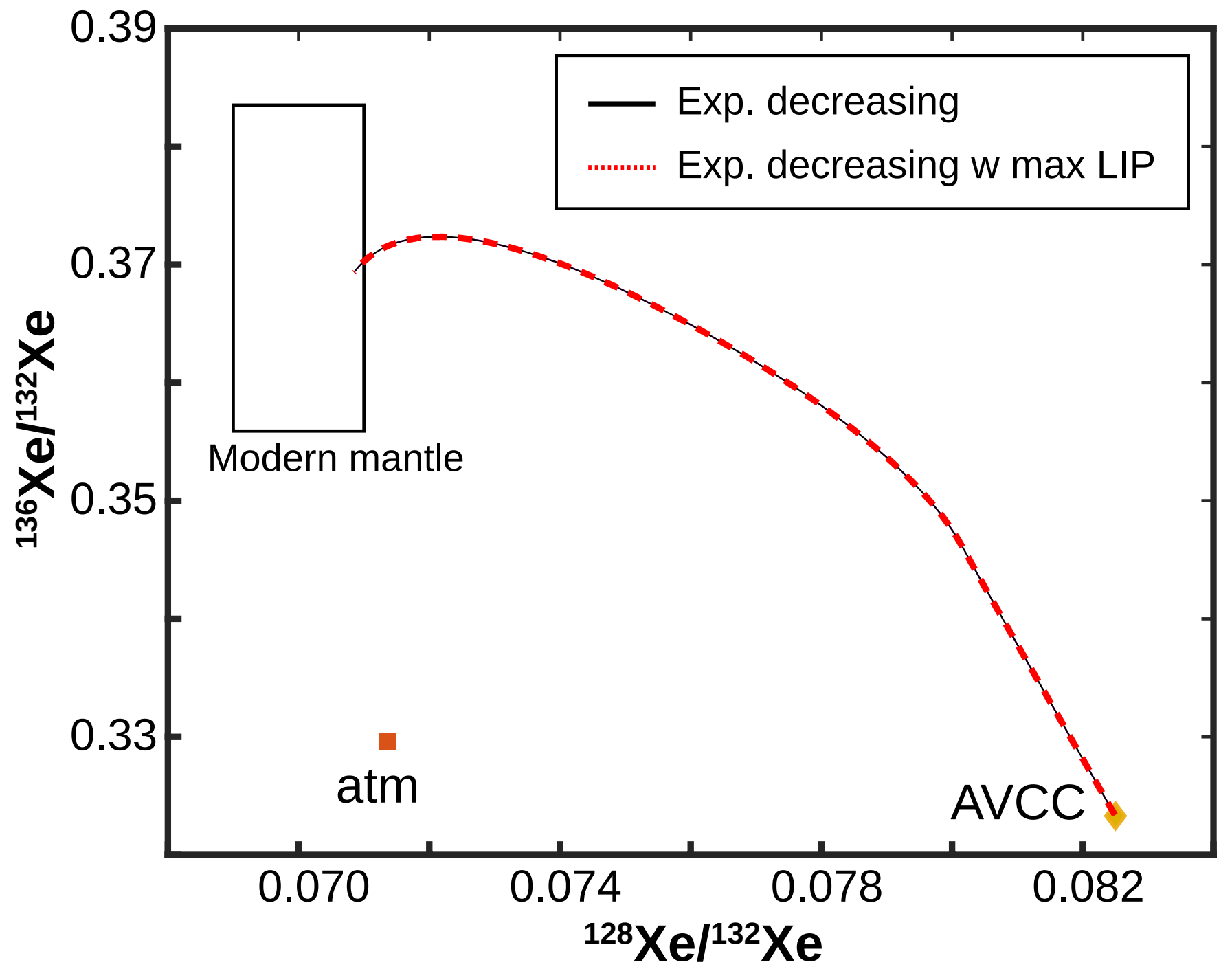


Figure 2. Time evolution model of Xe isotopes in a mantle reservoir. We assume an initial composition of average carbonaceous chondrites (AVCC) and compute evolution due to mantle degassing, fissiogenic ingrowth, and regassing (via subduction processes) towards the modern mantle compositions. Episodic outgassing through LIPs has no distinguishable effect on Xe isotopic evolution.

How large does a single outgassing event need to be to affect mantle Xe?

Investigation of large single outgassing events. We investigated how large of a magmatic event would be required to produce a resolvable difference in modern mantle Xe composition, given a certain time of outgassing.

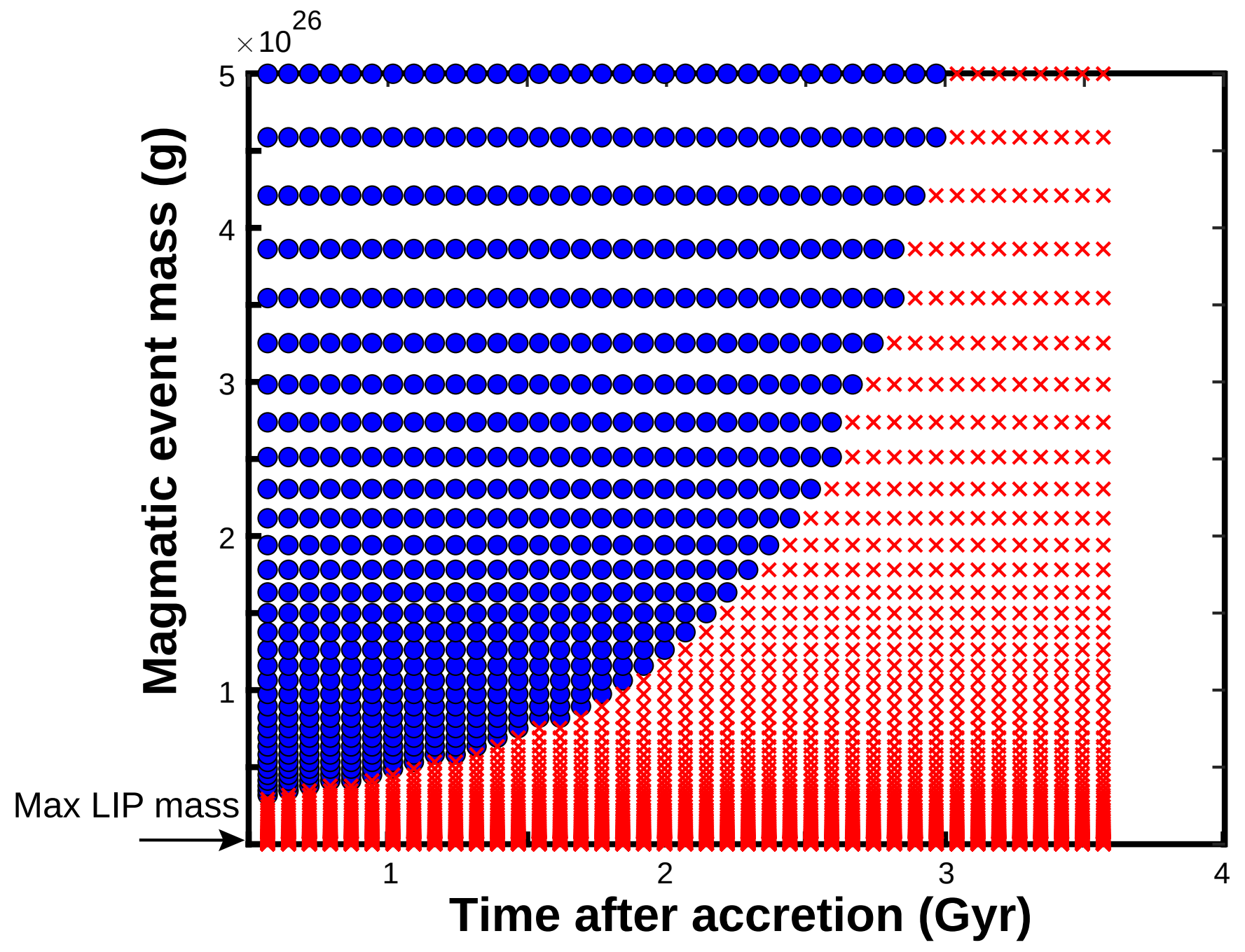


Figure 4. Parameter space tested for resolvable modern mantle Xe difference. Each data point reflects a single magmatic event at its corresponding time and mass. Blue circles indicate pairings where a single outgassing event generates resolvable differences in six Xe isotope ratios that are routinely measured with better than 5 per mil precision and red Xs indicate that at least one isotope ratio has <5 permil difference compared to the exponentially decreasing case. The max volume of LIPs is also marked with a black arrow. Magmatic events that occured farther in the past would have a larger effect on modern mantle compositions but the required volumes are too large to be realistic.

Ne and Xe isotopes in a 2.9 Gyr old Greenland Anorthosite

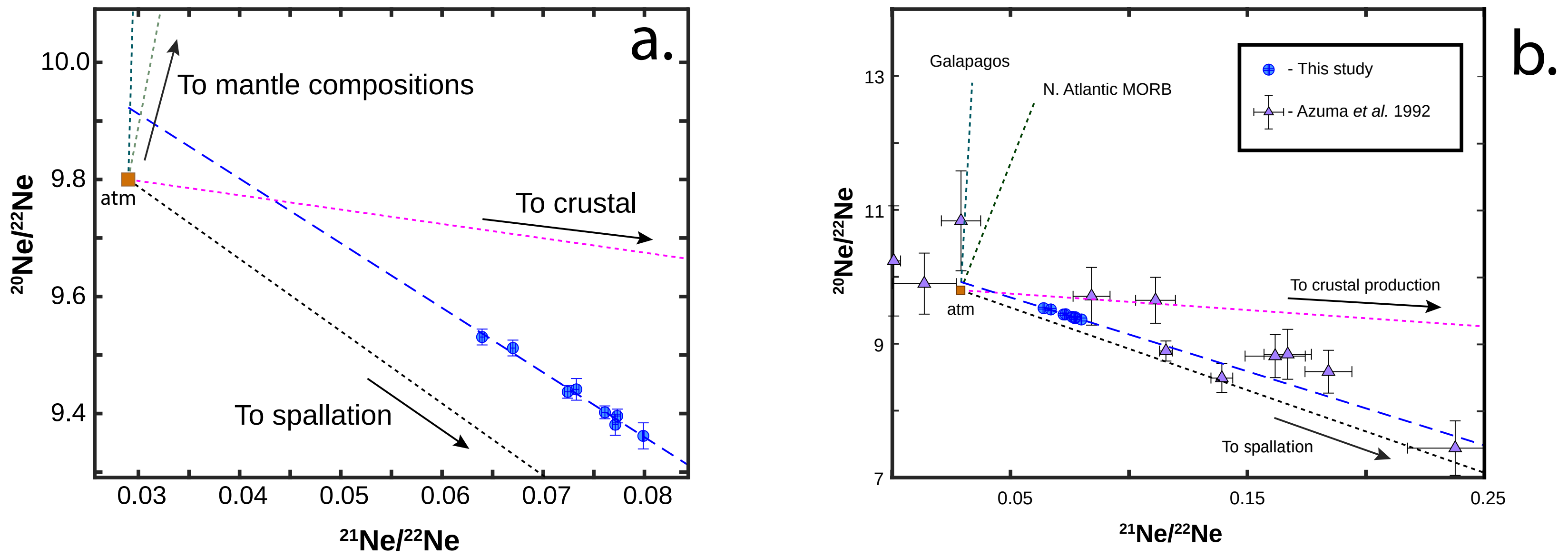
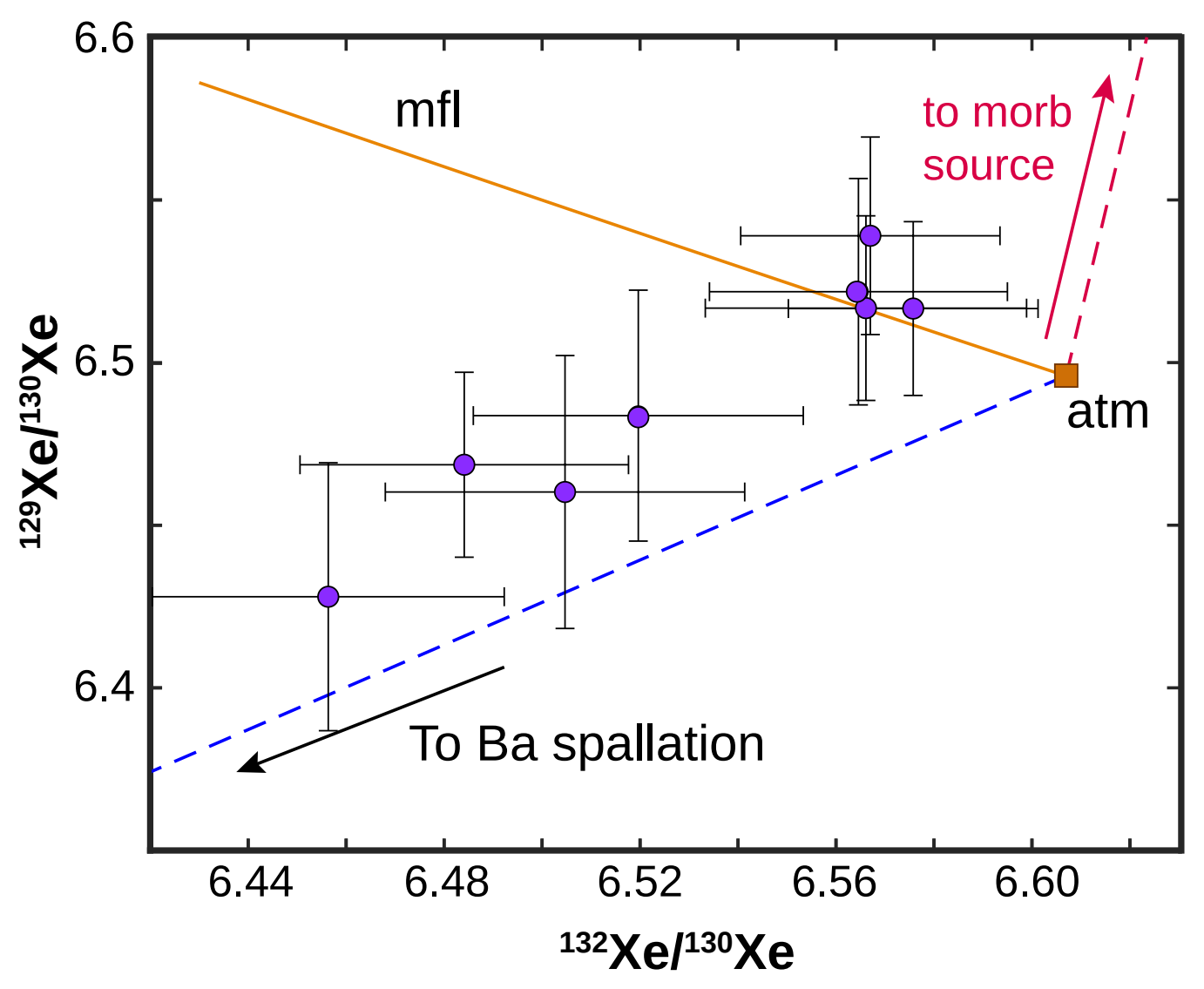


Figure 5. 3 isotope plot of neon data. a) Our data have low ^{20}Ne/^{22}Ne and high ^{21}Ne/^{22}Ne ratios compared to atmosphere and define a mixing trend within the crustal-spallation wedge. Modern mantle compositions [3,4] fall within the wedge with elevated ratios compared to atmosphere. We apply a total least squares fit to the data and find that our sample requires mixing with a component distinct from modern atmosphere. Atmospheric ^{20}Ne/^{22}Ne was likely lower in the past and increased due to mantle outgassing over Earth history [5,6]. Our data would be consistent with a contribution from mantle gas with elevated ^{20}Ne/^{22}Ne ratios, or a mixture of atmosphere, crustal, and spallogenic Ne. b) a previous study [7] on ancient Greenland anorthosites reported compositions consistent with air mixing with crustal/spallogenic Ne. Our data showcase improvements in Ne multicollector mass spectrometry. While the mixing trend seen in our data clearly requires a spallation component, a potential mantle contribution can be tested with Xe isotopes.

Xe isotopes suggest non-crustal component

Figure 6. ^{132}Xe/^{130}Xe vs ^{129}Xe/^{130}Xe data compared to atmosphere, Ba spallation production, and mass fractionated air. Data trends parallel to mixing between atmosphere and Ba spallation, but is offset to higher ^{129}Xe/^{130}Xe. Similar to our Ne data, our Xe data shows possible mixtures of a source with elevated ^{129}Xe (possibly ancient mantle) and Ba spallation, or mass fractionated air (ancient atmosphere, enriched in light isotopes) and Ba spallation. An excess in ^{129}Xe is in agreement with a prior study of Greenland anorthosites [8].



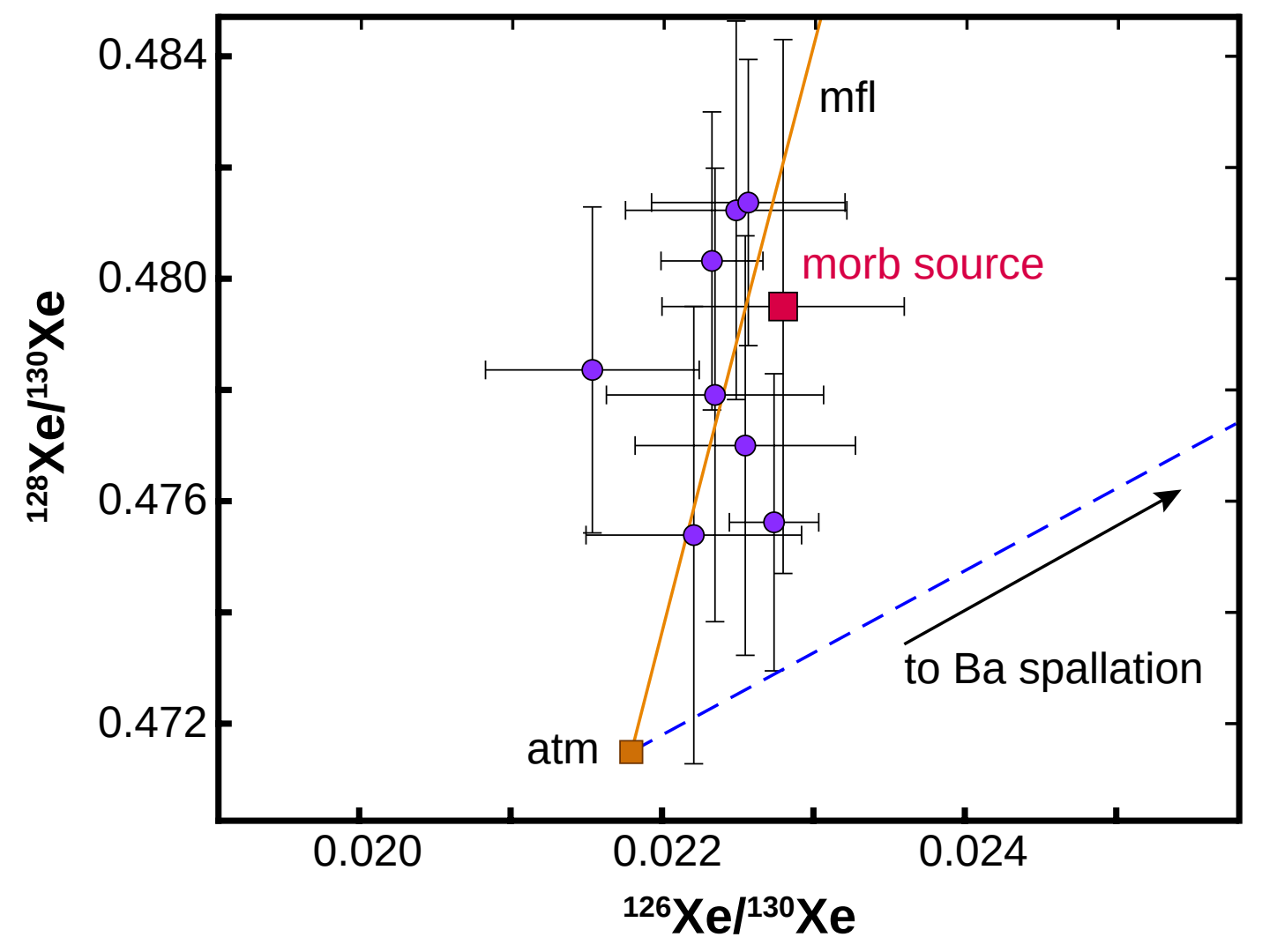


Figure 7. ^{126}Xe/^{130}Xe vs ^{128}Xe/^{130}Xe compared to atmosphere, mass fractionated atmosphere, Ba spallation, and the modern MORB mantle [9]. There is no obvious trend to this data but the grouping is not consistent with modern air mixing with ba spallation. If Xe in this sample is affected by spallation [10] (Fig. 6), then a component with lower ^{126}Xe/^{130}Xe than modern atmosphere must be involved.

Conclusions

Numerical modeling results

- Episodic outgassing produces mantle evolution plots that are not distinguishable from smoothly decreasing processing histories.
- Extremely voluminous single magmatic events are required to obtain detectable deviations from smoothly decreasing processing rates.

Noble gas isotope data for a 2.9 Gyr old Greenland anorthosite

- **Neon data suggests possible mantle component** with implications from a mixing trend with an elevated ^{20}Ne/^{22}Ne source.
- Xenon data shows potential mixing with **an elevated ^{129}Xe source (ancient mantle)**
- Light Xe isotopes do not show an excess in ^{126}Xe as prior studies have suggested. The role of spallation Xe requires further investigation.

Future work will result in additional NG analysis of this sample and additional anorthosites ranging in age.

References:

[1] Parai and Mukhopadhyay, 2018 *Nature*; [2] Bryan and Ernst, 2008 *Earth-Science Reviews*; [3] Peron et al., 2021 *Nature;* [4] Parai and Mukhopadhyay, 2021 *GCA*; [5] Marty, 2012 *EPSL*; [6] Zhang et al., In review; [7] Azuma et al., 1992 *EPSL*; [8] Jeffrey, 1971 *Nature*; [9] Peron and Moreira, 2018 *GPL*; [10] Hennecke, E.W., 1975. PhD Thesis, University of Missouri, Rolla.