

# Stochastic description of UHECR interactions

Leonel Morejon\*, Julian Rautenberg\*

\*Bergische Universität Wuppertal, Germany

## UHECR-24

### Analytic probability distributions for UHECR nuclear cascades along the propagation trajectory: Source to Earth

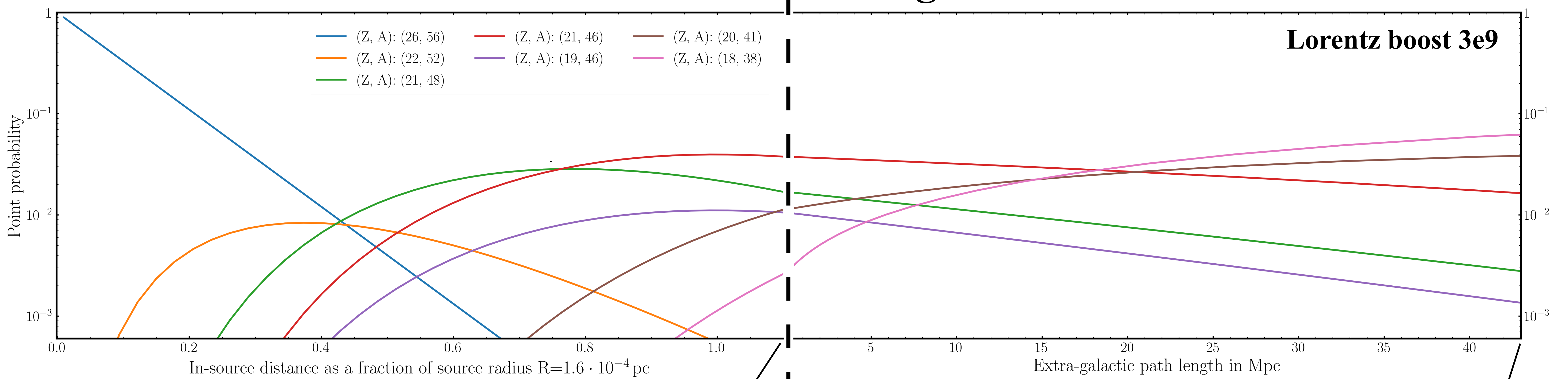


Source modeling based on GRB170817A assuming a fireball model with source parameters from (B. P. Abbott et al 2017 ApJL 848 L13)

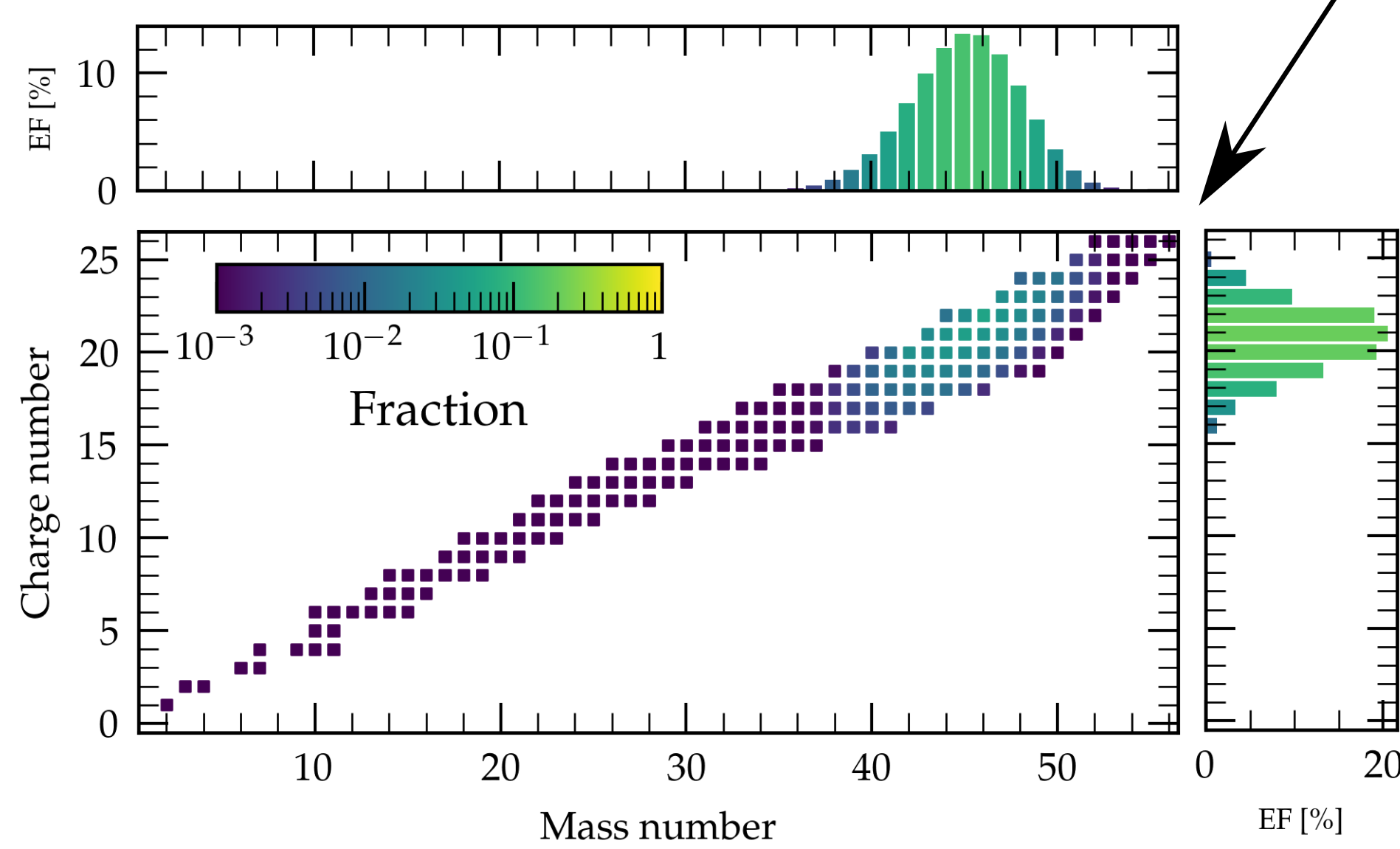
**in-source medium**

Propagation distance of about 40 Mpc as estimated for GRB170817A. Photodisintegration of nuclei with the cosmic microwave background and extra-galactic background light based on cross sections and nuclear tables taken from CRPropa (Rafael Alves Batista et al JCAP09(2022)035)

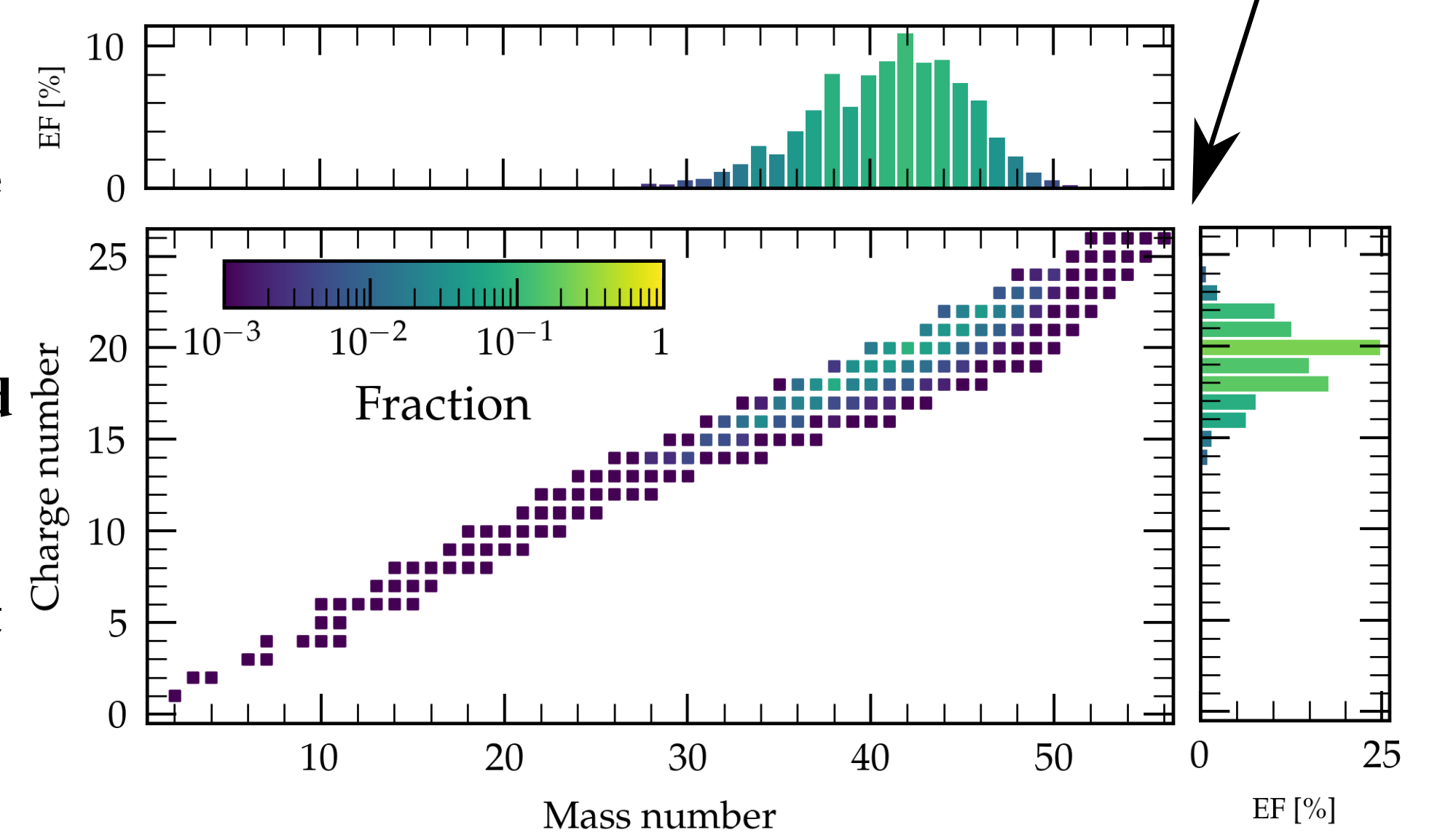
**extra-galactic medium**



Escaping fractions from the source are given for each of 184 nuclear species. Starting Fe nuclei disintegrate and produces a range of masses due to photodisintegration and photomeson interactions in the source.



Escaping fraction from the source cascades further due to photodisintegration and photomeson interactions with the cosmic background photon fields. Arrival fractions are given by the point probabilities at the last position (Earth).



### Details of the method

Probability distributions based on theory of Markov Jump Processes see "Matrix-Exponential Distributions in Applied Probability" by Mogens Bladt & Bo Friis Nielsen (2017)

$$f(L) = \pi \exp(\Lambda L) \Lambda e \rightarrow \text{distribution function}$$

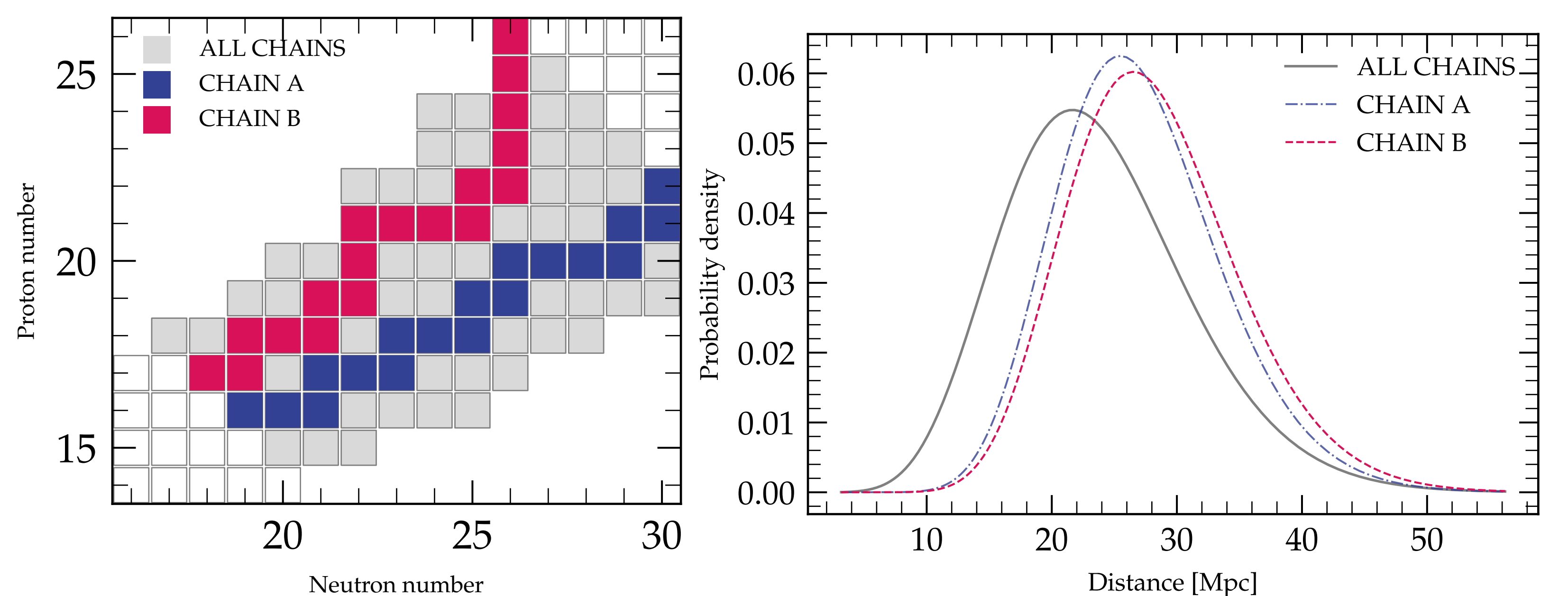
starting vector of fractions of each species

matrix of interaction rates as a function of boost

$$\Lambda(\gamma) = \begin{pmatrix} -\lambda_{S_1}^{\text{tot}} & \lambda_{S_1 \rightarrow S_2} & \lambda_{S_1 \rightarrow S_3} & \lambda_{S_1 \rightarrow S_4} & \lambda_{S_1 \rightarrow S_5} & \dots & \lambda_{S_1 \rightarrow S_N} \\ 0 & -\lambda_{S_2}^{\text{tot}} & \lambda_{S_2 \rightarrow S_2} & \lambda_{S_2 \rightarrow S_3} & \lambda_{S_2 \rightarrow S_4} & \dots & \lambda_{S_2 \rightarrow S_N} \\ 0 & 0 & -\lambda_{S_3}^{\text{tot}} & \lambda_{S_3 \rightarrow S_3} & \lambda_{S_3 \rightarrow S_3} & \dots & \lambda_{S_3 \rightarrow S_N} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & 0 & 0 & \dots & -\lambda_{S_N}^{\text{tot}} \end{pmatrix}$$

interaction rates for each possible transition between a pair of species in the nuclear table

The probability distribution is made up of all the individual possible chains of jumps with set starting and ending states. Below, the individual distributions for two different chains are shown. The distributions (right) describe the chains (left) and the combination of all distributions (grey) includes all chains between A=52 and A=34.



More details...

\* L. Morejon PoS ICRC2023 (2023) 284  
\* L. Morejon ECRS-2024 proceedings (in preparation)  
\* L. Morejon journal publication (in preparation)

