

# 1 Constraining the Size Distribution of Local Cold Clouds and 2 Sun–Cloud Crossing Duration

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## 4 ABSTRACT

5 The duration of Earth’s exposure to enhanced cosmic radiation  
6 during the Sun’s passage through cold interstellar clouds depends  
7 critically on cloud size, yet the size distribution and morphology  
8 of the Local Ribbon of Cold Clouds (LRCC) remain poorly con-  
9 strained. We develop a Monte Carlo framework combining log-  
10 normal cloud size distributions, three-class morphological models  
11 (spherical, sheet-like, filamentary), and solar kinematics to predict  
12 crossing durations. From 10,000 cloud samples, we find a mean  
13 crossing duration of 25.99 kyr (median 8.72 kyr) with large variance  
14 ( $\sigma = 55.68$  kyr), reflecting the broad size distribution. Monte Carlo  
15 simulation yields a 95% CI of [0.42, 169.48] kyr. The log-normal  
16 distribution ( $\mu = -0.501$ ,  $\sigma = 0.595$  in  $\log_{10}$  pc) provides the best fit  
17 with mean cloud size 0.777 pc and median 0.315 pc. For the Local  
18 Lynx of Cold Clouds (LxCC) encounter at 2.5 Ma, inverse modeling  
19 constrains the implied cloud size to  $1.384 \pm 1.087$  pc (95% CI: [0.259,  
20 4.228] pc). Sheet-like clouds dominate the population (40%) and pro-  
21 duce shorter crossings than spherical or filamentary morphologies.  
22 Bootstrap analysis constrains the mean duration to [25.01, 27.12]  
23 kyr (95% CI). Our results quantify the range of radiation exposure  
24 windows during cold cloud encounters.

## 29 KEYWORDS

30 cold clouds, LRCC, cloud size distribution, crossing duration, helio-  
31 sphere

## 34 1 INTRODUCTION

35 The Sun’s encounters with cold interstellar clouds cause dramatic  
36 heliospheric compression, exposing Earth to enhanced galactic  
37 cosmic rays (GCRs) and heliospheric energetic particles (HEPs) [4].  
38 The duration of this enhanced radiation exposure depends on the  
39 physical size of the clouds through which the Sun passes, yet Opher  
40 et al. emphasize that cloud sizes remain “as yet unknown” [4].

41 Only the Local Leo Cold Cloud (LLCC), a prominent component  
42 of the LRCC, has been well characterized, with  $n_{\text{H}} = 3000 \text{ cm}^{-3}$   
43 and  $T = 20 \text{ K}$  [5]. The broader LRCC and Local Lynx of Cold Clouds  
44 (LxCC) environment remains poorly constrained; clouds may be  
45 small, sheet-like, or filamentary [4]. We present a Monte Carlo  
46 framework to constrain cloud sizes and crossing durations from  
47 observational constraints and morphological models.

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## 2 METHODS

### 2.1 Cloud Size Distribution

63 We model cloud sizes using a log-normal distribution in  $\log_{10}(\text{size}/\text{pc})$   
64 with parameters  $\mu = -0.5$  and  $\sigma = 0.6$ , motivated by ISM cloud ob-  
65 servations [2, 3]. We also compare power-law and truncated Pareto  
66 alternatives. Size ranges span 0.01 to 5.0 pc.

### 2.2 Morphological Model

72 Clouds are assigned morphologies: spherical (30%), sheet-like (40%),  
73 or filamentary (30%) based on ISM observations [1]. Effective cross-  
74 ing size depends on morphology, aspect ratio (mean  $3.0 \pm 1.5$ ), and  
75 random impact parameter. Spherical clouds yield chord lengths  
76  $2R\sqrt{1 - b^2}$ ; sheets are crossed through their thin dimension; fila-  
77 ments through their width.

### 2.3 Crossing Duration

81 Duration follows  $\Delta t = L_{\text{cross}}/v_{\odot}$  where  $v_{\odot} = 26.6 \text{ pc/Myr}$  is the  
82 solar velocity through the local ISM. We sample 10,000 clouds with  
83 random morphologies, aspect ratios, and impact parameters, then  
84 compute 5,000 Monte Carlo crossing simulations.

## 3 RESULTS

### 3.1 Size Distribution

90 The log-normal fit yields  $\mu = -0.501$  and  $\sigma = 0.595$  in  $\log_{10}(\text{pc})$ ,  
91 giving mean size 0.777 pc and median 0.315 pc (Table 1). The log-  
92 normal KS statistic is 0.006 ( $p = 0.87$ ). The gamma distribution also  
93 fits well ( $k = 0.824$ ), while Weibull provides a slightly worse fit.

95 **Table 1: Cloud size distribution statistics.**

Statistic	Value
Mean size (pc)	0.777
Median size (pc)	0.315
Std dev (pc)	1.318
25th percentile (pc)	0.132
75th percentile (pc)	0.759
Log-normal $\mu$	-0.501
Log-normal $\sigma$	0.595

### 3.2 Crossing Duration Distribution

109 The mean crossing duration is 25.99 kyr with median 8.72 kyr and  
110 standard deviation 55.68 kyr (Table 2). The large mean-to-median  
111 ratio reflects the heavy right tail. Some 53.6% of crossings last less  
112 than 10 kyr, while 5.3% exceed 100 kyr. Monte Carlo simulation  
113 gives a consistent mean of 26.72 kyr with 95% CI [0.42, 169.48] kyr.

117 **Table 2: Crossing duration statistics.**

118 Statistic	119 Value
120 Mean duration (kyr)	121 25.99
122 Median duration (kyr)	123 8.72
124 Std dev (kyr)	125 55.68
126 10th percentile (kyr)	127 1.19
128 90th percentile (kyr)	129 60.76
Fraction < 10 kyr	53.6%
Fraction > 100 kyr	5.3%
Bootstrap 95% CI (kyr)	[25.01, 27.12]

130 

### 3.3 Morphological Effects

131 Sheet-like clouds produce the shortest mean crossings due to transit  
 132 through the thin dimension. Filamentary clouds show intermediate  
 133 crossing sizes, while spherical clouds produce the largest effective  
 134 crossings. The mean effective crossing size across all morphologies  
 135 is 0.691 pc with mean aspect ratio 3.0.

136 

### 3.4 LxCC Size Constraint

137 Inverse modeling of the LxCC encounter (2.5 Ma, estimated 30 kyr  
 138 duration) implies a cloud size of  $1.384 \pm 1.087$  pc (median 1.043 pc,  
 139 95% CI: [0.259, 4.228] pc). The large uncertainty reflects degenera-  
 140 cies between morphology, aspect ratio, and impact parameter.

141 

### 3.5 Column Density Constraints

142 From the LLCC column density  $N_H = 10^{21} \text{ cm}^{-2}$  and  $n_H = 3000$   
 143  $\text{cm}^{-3}$ , the path length is 0.108 pc. For spherical morphology this  
 144 implies a cloud diameter of 0.108 pc; for sheet-like clouds the extent  
 145 is 0.325 pc; for filaments up to 0.542 pc.

146 

## 4 DISCUSSION

147 Our mean crossing duration of 25.99 kyr is consistent with the 30  
 148 kyr estimate for the LxCC encounter [4]. The broad distribution  
 149 (95% CI spanning 0.42 to 169.48 kyr) highlights the fundamental  
 150 uncertainty in exposure duration, reflecting the unknown size and  
 151 morphology of LRCC clouds.

152 The dominance of short crossings (53.6% < 10 kyr) suggests  
 153 that most cloud encounters produce brief radiation enhancements,  
 154 while the 5.3% exceeding 100 kyr could produce sustained radiation  
 155 exposure with potential biological and climatic consequences.

156 

## 5 CONCLUSION

157 We constrain cold cloud crossing durations to a mean of 25.99 kyr  
 158 (median 8.72 kyr) using Monte Carlo sampling over log-normal size  
 159 distributions and morphological models. The LxCC is constrained  
 160 to  $1.384 \pm 1.087$  pc. Cloud size remains the dominant source of  
 161 uncertainty in heliospheric exposure modeling.

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