

Ground motion attenuation of $M_S8.0$ Wenchuan earthquake*

Dawei Lu^{1,†} Jianwen Cui² Xiaojun Li³ and Weiping Lian¹

¹ National Earthquake Infrastructure Service, China Earthquake Administration, Beijing 100036, China

² Earthquake Administration of Yunnan Province, Kunming 650224, China

³ Institute of Engineering Mechanics, China Earthquake Administration, Harbin 150080, China

Abstract The great $M_S8.0$ Wenchuan earthquake has been the most destructive earthquake since 1949 in China. The earthquake occurred no more than half a year after the establishment of the National Strong Motion Observation Network System (NSMONS) of China; what is more, the epicenter was located in the area with dense strong motion observation stations so that a large number of strong motion records of the main shock were obtained. In this paper, 501 strong motion records from 167 observation stations are utilized to establish the ground motion attenuation relations in three directions in the range of fault distance less than 600 km. The result shows the difference of seismic motion attenuation in two horizontal directions is insignificant. It is the first time that strong-motion records are used to establish the ground motion attenuation relations of the $M_S8.0$ earthquake in China.

Key words: Wenchuan earthquake; strong motion record; ground motion attenuation; response spectrum

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1 Introduction

According to the China Earthquake Network Center, at 14:28 on May 12, 2008 (Beijing time), the great $M_S8.0$ Wenchuan earthquake occurred in Sichuan province of China. The epicenter was located at latitude 31.021°N , longitude 103.367°E , with a focal depth of 14 km. Except for Heilongjiang, Jilin and Xinjiang, the earthquake was felt in almost all provinces of China; and Sichuan, Gansu, Shaanxi, Chongqing, Yunnan, and Ningxia were seriously damaged. The Wenchuan earthquake caused huge casualties, economic loss, and engineering infrastructure damage. The epicentral intensity was XI, and Yingxiu, Beichuan and Chenjiaba were destructively damaged. The X- and XI-intensity region is about 230 km long and about 30 km wide along the Beichuan-Yingxiu fault. The affected area is an oval shape following the fault line, the area with the intensity greater than VI is about $440\,442\text{ km}^2$, and the area with intensity greater than VIII is about $41\,087\text{ km}^2$. The in-

tensity attenuation map is fully asymmetric. The intensity attenuates rapidly in the south-east direction but more slowly in the north-west direction.

The construction of the National Strong Motion Observation Network System (NSMONS) began in 2002 with five years of construction, trial operation and inspection, and was put into formal operation in March of 2008, which is composed of 1 600 permanent free-field strong motion observation stations (Zhou, 2006). During the great earthquake, more than 400 stations captured the main shock records. These records reflect propagation of the strong ground motion.

Ground motion attenuation relation based on sufficient recording data is important in seismic hazard analysis. Although China is a country with high seismic activity, there are few strong motion data, especially in near field of large earthquakes, before establishment of the NSMONS of China. Many researchers proposed ground motion attenuation relations (Huo et al, 1992; Xiang and Gao, 1992; Cui et al, 2006; Lei et al, 2007) basing on strong motion records from other countries, e.g., western USA and Japan, or basing on the earthquake intensity documents (Huo et al, 1992; Hu et al, 1996; Hu, 1999; Wang et al, 2000; Yu and Wang, 2004,

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† Corresponding author. e-mail: dwlu@neis.gov.cn

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2006). Therefore, a lot of strong motion records captured in the Wenchuan earthquake have a significant impact on establishing a more suitable ground motion attenuation relation for focal mechanism and geological feature of China.

Based on the strong motion records from the main shock of the Wenchuan earthquake, this paper analyzes the attenuation relations of the acceleration response spectrum in three directions by the statistical regression analysis.

2 Focal tectonic feature and observation data

The Wenchuan earthquake is large in magnitude, and its focal depth is shallow. The rupture process was unilateral and the source mechanism is quite complex. The maximal vertical displacement is 6.2 m, and dextral displacement is 4.9 m. The rupture zone is in NE225° (Zhang et al, 2009), about 300 km long. The epicenter of the Wenchuan earthquake is located in the Longmenshan thrust fault zone, which is a transitional zone between the Tibet plateau and western Sichuan foreland basin. Topography, geomorphology, and geologic features on both sides of the fault zone are very different. In no more than 50 km of horizontal distance, altitude ascends rapidly to 6 500 m from nearly 600 m in southern Sichuan basin (Zhou et al, 2006; Kirby, 2002); while crustal thickness increases to 70 km from about 40 km (Wang et al, 2005).

During the Wenchuan earthquake, the NSMONS of China obtained a large number of mainshock records from 455 stations (Department of Earthquake Disaster Prevention of China Earthquake Administration, 2008). Among these stations, Wolong station is the closest to the epicenter with epicentral distance 22 km and captured $957.7 \text{ cm}\cdot\text{s}^{-2}$ PGA; and Dongtan station of Shanghai is the farthest to the epicenter with epicentral distance 1 761 km and captured $2.4 \text{ cm}\cdot\text{s}^{-2}$ PGA. Figure 1 shows distribution of most stations that recorded the main shock. As shown in the figure, the stations are divided into four groups, i.e., rupture backward (I), footwall (II), rupture forward (III), and hanging wall (IV). For such a great earthquake with a nearly 300 km surface rupture, fault distance is regarded as more suitable for ground motion attenuation analysis (Campbell, 1981, 1997). For illustrating the influence of the fault rupture on the ground motion, the two horizontal records are rotated to fault-parallel and fault-normal directions.

The intact records with high signal to noise ratio from free sites are suitable to analyze strong motion attenuation relations. And more, with fault distance increasing, earthquake will have less influence on the structure. Therefore, this paper only analyzes the ground motions with fault distance less than 600 km. So, according to the above conditions, 501 reliable strong motion records from 167 stations are selected to analyze the ground motion attenuation of the main shock, and these records have been corrected by China Strong Motion Network Center.

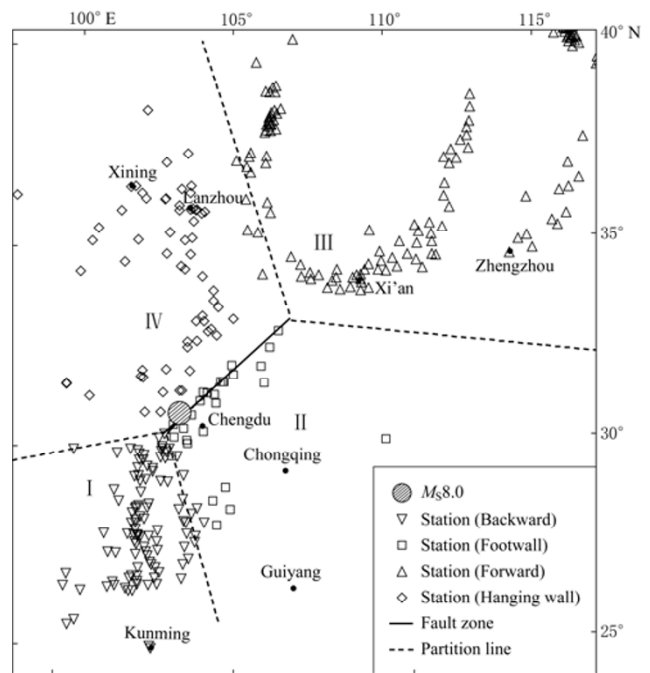


Figure 1 Distribution of the strong motion stations that recorded the main shock of the Wenchuan earthquake.

Figure 2 provides the distribution of PGAs in the east-west direction with fault distance increasing. Table 1 gives the spatial distribution of the stations with better continuity. Table 1 shows fault distance of most stations is more than 100 km. The stations with fault distance ranging from 10 km to 100 km accounts for about 13%.

Table 1 Spatial distribution of the strong motion stations

Distance/km	Number of stations	Ratio*
0–10	2	0.86%
10–30	8	3.45%
30–60	9	3.88%
60–100	14	6.03%
100–200	37	15.95%
200–400	77	33.19%
400–600	85	36.64%

* Ratio denotes the percentage of stations in this distance to all stations that are used in this paper.

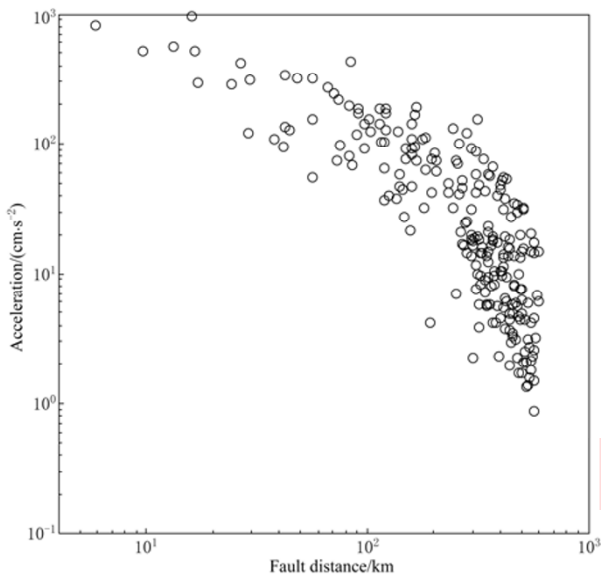


Figure 2 Distribution of PGAs in east-west direction with fault distance.

3 Ground motion attenuation

3.1 Attenuation model

According to the selected strong motion data, statistical regression is used to analyze the change of acceleration response spectra with fault distance. The attenuation model is as follows:

$$\lg S_a(T) = c_1 + c_2 \lg(R + h), \quad (1)$$

where T and S_a are the period of ground motion and corresponding acceleration response spectrum value, R is fault distance ($R \leq 600$ km), while c_1 and c_2 are attenuation coefficients to be determined. h is a parameter that reflects the influence due to focal depth between 10 km and 30 km.

3.2 Results

Based on the above attenuation model, the results of statistical analysis on observation data are shown in Table 2. Figure 3 also shows the normalized standard deviations of attenuation relations and h are correlated. That is, the standard deviations of three components all change with h . But the standard deviations are minimum for fault-parallel and UD components while h is 25 km and for fault-normal component while h is 28 km. Here only discussing the situation while $T=0$, because h should be invariable for an earthquake, so for other periods, still let $h=25$. Figure 4 shows attenuation of PGA ($T=0$). Figure 5 displays attenuation of response spectrum in three directions with damping ratio 5% in some periods.

In Table 2, for different periods, the standard deviation of attenuation relations changes from 0.246 to 0.437, which reflects the inherent discrete difference of strong motion in different periods. In general, the PGA ($T=0$) should be affected by the local site condition, but in Table 2, the standard deviation is relatively smaller. So in all factors influencing on strong motions, the influence of local site condition is not the largest.

Table 2 The attenuation coefficients of acceleration response spectrum ($h=25$)

T/s	E-W			N-S			U-D		
	c_1	c_2	δ	c_1	c_2	δ	c_1	c_2	δ
0	4.718 154	-1.284 48	0.286	4.787 383	-1.314 35	0.289	4.844 023	-1.446 5	0.303
0.1	5.748 352	-1.626 57	0.316	5.857 134	-1.668 11	0.324	5.846 355	-1.770 7	0.333
0.125	5.873 937	-1.659 61	0.315	5.871 099	-1.656 48	0.318	5.580 292	-1.650 27	0.340
0.2	5.521 355	-1.493 08	0.317	5.513 336	-1.488 39	0.304	5.121 73	-1.449 74	0.331
0.25	5.344 498	-1.409 35	0.318	5.249 738	-1.378 34	0.306	4.778 894	-1.317 36	0.315
0.5	4.424 642	-1.060 54	0.319	4.400 846	-1.059 63	0.329	4.091 544	-1.057 51	0.287
1	3.281 6	-0.662 02	0.343	3.245 091	-0.649 58	0.348	3.258 825	-0.740 25	0.312
1.5	2.688 945	-0.476 09	0.365	2.654 001	-0.460 49	0.375	2.927 037	-0.641 69	0.334
2	2.324 802	-0.378 57	0.416	2.285 484	-0.352 44	0.388	2.515 599	-0.521 71	0.344
2.5	2.324 802	-0.378 57	0.416	2.285 484	-0.352 44	0.388	2.515 599	-0.521 71	0.344
3	2.205 903	-0.421 29	0.424	2.082 184	-0.365 11	0.421	2.572 508	-0.637 45	0.358
4	2.046 022	-0.401 47	0.412	2.196 831	-0.453 86	0.414	2.746 453	-0.743 69	0.385
5	2.102 688	-0.446 17	0.433	1.955 009	-0.380 14	0.434	2.579 523	-0.673 07	0.386
6	1.930 468	-0.392 78	0.437	1.853 629	-0.353 97	0.429	2.432 163	-0.619 99	0.380
8	1.754 695	-0.377 72	0.434	1.894 243	-0.439 42	0.410	2.099 708	-0.552 51	0.373
10	1.477 818	-0.310 47	0.402	1.691 263	-0.404 03	0.384	1.983 618	-0.560 09	0.347
12	1.543 532	-0.390 3	0.382	1.634 223	-0.424 57	0.346	1.952 097	-0.606 4	0.326
14	1.418 107	-0.391 51	0.343	1.594 205	-0.454 08	0.339	1.700 531	-0.535 15	0.262
16	1.366 478	-0.423 22	0.331	1.513 23	-0.475 18	0.346	1.531 385	-0.515 67	0.258
18	1.351 104	-0.462 45	0.345	1.403 492	-0.477 71	0.361	1.419 989	-0.526 33	0.261
20	1.413 19	-0.525 92	0.347	1.316 348	-0.475 05	0.361	1.334 756	-0.535 02	0.246

Note: δ is standard deviation of attenuation relations.

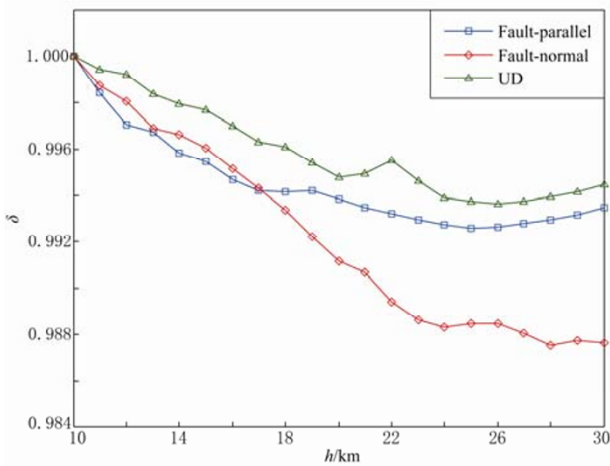


Figure 3 Relationship between normalized standard deviation (δ) of attenuation relations and parameter h .

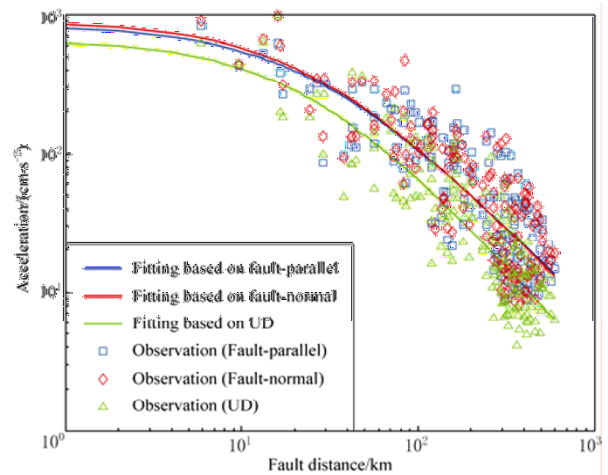


Figure 4 Attenuation of PGA with fault distance for period $T=0$.

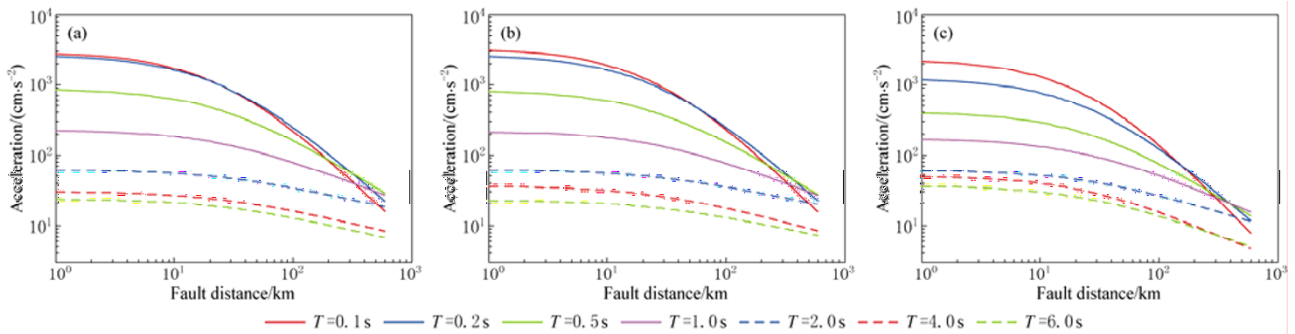


Figure 5 Attenuation of acceleration response spectrum in the fault-parallel direction (a), fault-normal direction (b) and up-down direction (c) with damping ratio 5%.

4 Discussion and conclusions

The epicenter of the Wenchuan earthquake is located in the Longmenshan thrust fault zone, which is a transitional zone between the Tibet plateau and western Sichuan foreland basin. Topography, geomorphology and geologic features on both sides of the fault zone are very different. Early research has shown that ground motion attenuation is faster in mountains than in plains, so it could be expected that characteristics of ground motion attenuation are different between two sides of the rupture zone, especially between the Tibet plateau and western Sichuan foreland basin. The above trend is shown in the recording data. Figure 6 shows the variation of the EW component of accelerations in both east and west sides of the Longmenshan fault, in the fault orientation and in the opposite direction of fault orientation, respectively. From Figure 7, we can see that the

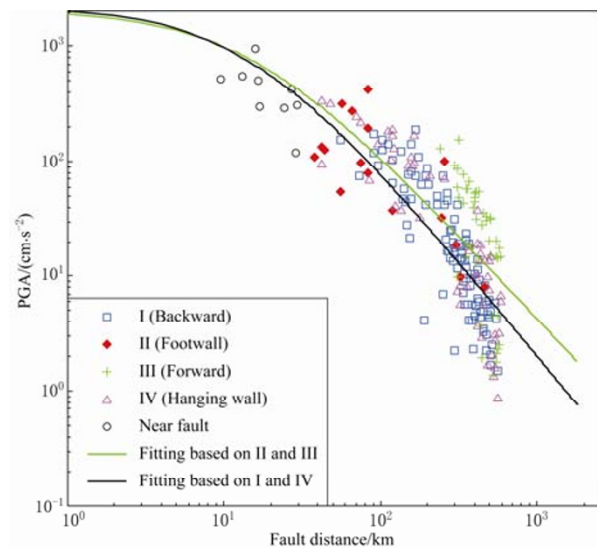


Figure 6 Variation of the EW components of ground accelerations along the four directions of the Longmenshan fault.

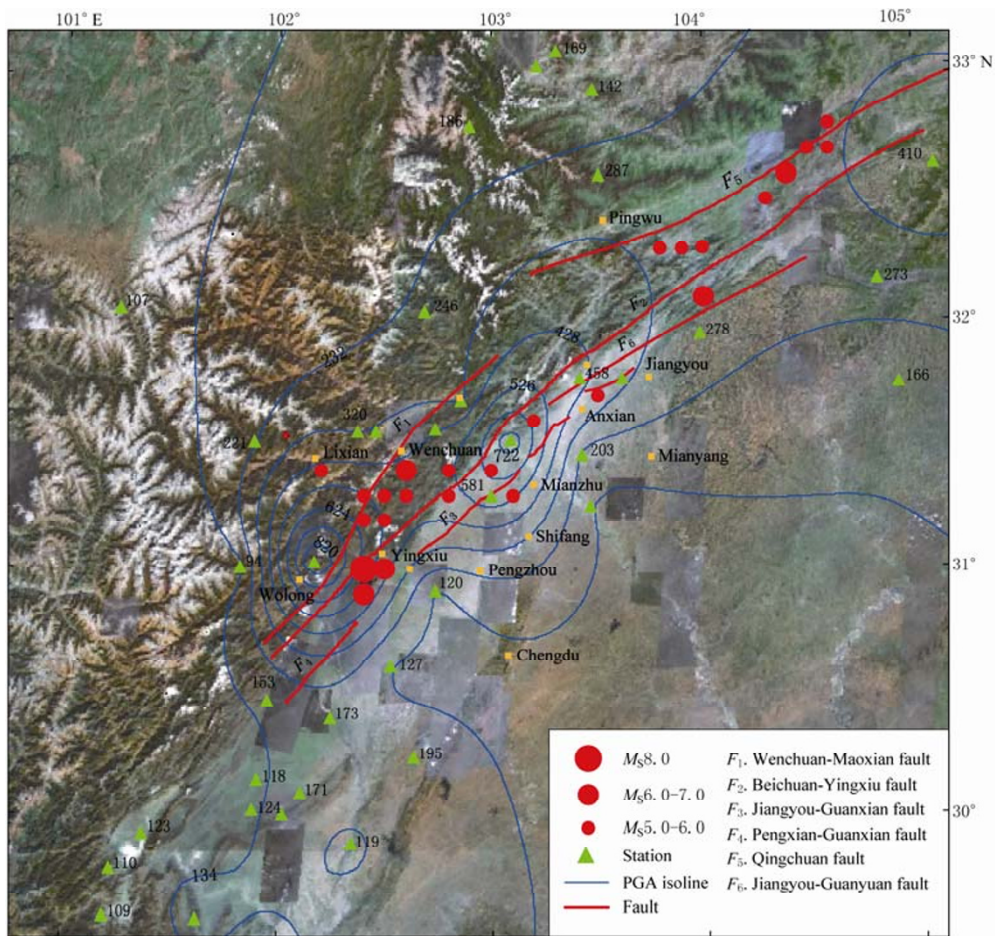


Figure 7 Isolines of the PGAs in EW direction around the fault rupture where the figure near the station denotes EW component of PGA in unit of $\text{cm}\cdot\text{s}^{-2}$.

variation of ground motions varies from each other in the four directions, and the most different ground motion lies in the fault orientation and its opposite direction. As a result, ground motion attenuation of the Wenchuan earthquake should be studied in the four directions separately; however, if the ground motion attenuation is studied separately, the recording data of the main shock are obviously insufficient.

It can be seen from Figure 4 that the peak ground accelerations of two horizontal components vary closely for $T=0$. But Figure 8 shows, they are different with the change of period. It demonstrates the characteristics of two horizontal components vary with frequency, but the difference is small, which reveals the characteristics of the strong motion attenuation in fault-parallel direction are similar to that in fault-normal direction.

This paper establishes the ground motion attenuation relations of the main shock of the $M_S 8.0$ Wenchuan

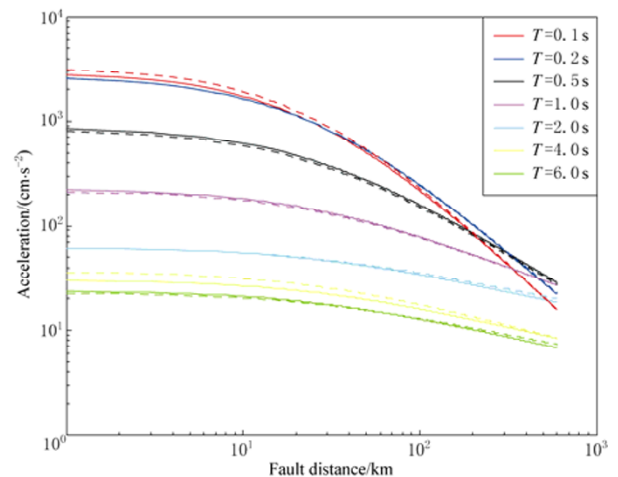


Figure 8 Comparison of attenuation of acceleration response spectrum in fault-parallel (solid line) and fault-normal (dashed line) directions with damping ratio 5%.

earthquake, which could be used to estimate the near field ground motion parameters. The result shows the difference of the seismic motion attenuation in two horizontal (fault-parallel and fault-normal) directions is insignificant.

There are many fault zones with the possibility for occurrence of about $M_S8.0$ earthquake, such as Xiaojiang fault zone, Tanlu fault zone. Therefore, it is significant to establish ground motion attenuation relations of $M_S8.0$ earthquake according to the records. The attenuation relations in this paper only are preliminary results. After the main shock, a lot of mobile instruments were deployed in the hardest-hit areas. A large number of near-field aftershock records had been obtained from these instruments, which will provide the basic data for researchers on more perfect attenuation relations.

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