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Side discharges on positively charged lightning leaders

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Recent observations unveiled two types of side discharges associated with positive leaders: needle discharges and nearby bidirectional leaders. The formation mechanism and connections of two phenomena remained unclear due to the lack of synchronous optical detection and radio mapping data. Here we present the first high-speed video and low-frequency lightning mapping results. Negative branches of nearby bidirectional leaders can propagate after connecting to the parent positive channel, and needle discharges act as positive connecting leaders. Our research shows that positive leaders exhibit unconventional channel extensions, maintained by frequent recoil leaders, sharing characteristics with streamer discharges. Notably, when two approaching positive leaders develop in this manner, they can eventually collide. These findings significantly advance our understanding of side discharges on positive leaders, offering fresh insights into these intriguing phenomena.