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PEM31-03 Room:503 Time:May 1 16:15-16:30

Observation of Lightning in Protoplanetary Disks by Ion Lines

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Lightning in protoplanetary disks is an important elementary process in protoplanetary disk science. It has been studied as a candidate mechanism for chondrule formation, and it provides unique window to probe the electromagnetic state of the protoplanetary disks. As a consequence, multiple lightning models has proposed for protoplanetary disks, and it is important for protoplanetary disk astrophysics to observationally distinguish which model is correct. Here we study the possibility of observationally distinguishing lightning models in protoplanetary disks.

Lightning on Earth is discharge phenomenon in the air, and the gas discharge physics in air has been studied for centuries and is well understood process. But it has been observed that lightning takes place under electric field amplitude well below the dielectric strength of the air, the fact that has been a long standing mystery. Here, dielectric strength of an insulating material is the maximum amplitude of the electric field the subject material does not cause the electric breakdown. It is physical property of central importance for discharge physics.

In attempt to solve the mystery, traditional Townsend breakdown model has been challenged by new discharge models such as Druyversteyn-Penning breakdown model and runaway breakdown model. The values of the dielectric strength according to the latter two model are much smaller than it by Townsend breakdown model.

We can distinguish the breakdown models by their dielectric strength. Dielectric strength is the point where the electrons accelerated by the electric field reaches certain ionization energy. The electric field also accelerates the positively-charged ion species to the energy comparable to the electrons. Because the ionization energy is a universal constant, the accelerated ion energies are also constant. Observationally, this means that we will observe ion velocities much faster than the thermal velocity, and the observed velocities will be independent of the local density nor temperature among the lightning regions. This will be unique observational feature to detect and distinguish breakdown models in protoplanetary disks. For example, under disk gas that consists of 92% H_2 and 8% He, the characteristic ion speed of HCO^+ is 7.1km/s, 2.9km/s and 0.49km/s, respectively, for Townsend breakdown model, Druyversteyn-Penning breakdown model, and runaway breakdown model.

We have calculated the velocity distribution of the three ion species HCO^+, DCO^+ and N_2H^+, taking the lightning models into consideration. We have simulated the line profile and two-dimensional position-velocity images. We found lightning features of 10-100mJy appear in line profile. Recent ALMA observations e.g. by Mathews et al. (2013) and Qi et al. (2013) achives ~10mJy sensitivity. Therefore we can reject some of the lightning models based on ALMA archive data, and distinguish lightning models by future ALMA observations.

Keywords: Protoplanetary disks, Discharge phenomena, Lightning, Weakly-ionized plasma, astrophysical plasma

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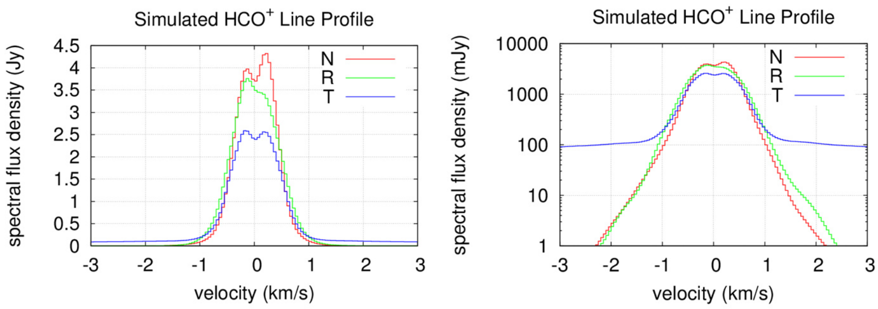

Simulated HCO^+ line profile of an MMSN disk located at distance d=56pc, inclination i = 7(deg). The three curves indicate disk without lightning (N), disk with runaway breakdown model (R), and with Townsend breakdown model (T), respectively.