Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

PPS004-02 会場:101 時間:5 月 27 日 14:30-14:45

磁気乱流が駆動する原始惑星系円盤における加熱および冷却機構
Heating and cooling in protoplanetary disks driven by magnetic turbulent stresses

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We examine heating and cooling in protostellar disks that are driven by magnetic turbulent stress, contrasting them with those in protostellar disks based on the alpha model. We use 3D radiation-MHD calculations of a small patch of the Solar nebula at 1 AU, employing the shearing-box and flux-limited radiation diffusion approximations. The disk atmosphere is ionized by the stellar X-rays, well-coupled to magnetic fields, and sustains a turbulent accretion flow driven by the magneto-rotational instability, while the disk interior is highly resistive and magnetically dead. The turbulent layers are optically-thin to their own radiation, and cool inefficiently. They heat by absorbing the light from the central star, and by dissipating the turbulent magnetic fields. The location of the starlight absorption is 0.1AU higher than that in the alpha model due to an extra support of the gas by magnetic forces. Another contrast with the alpha model is that the accretion heating occurs higher in the atmosphere than the accretion stresses due to magnetic buoyancy. In the atmosphere, the irradiation heating is 33 times greater than the magnetic dissipation when averaged over time and space, and thus the averaged temperature, 410K, is the same as that in the alpha model. However, owing to the fluctuations in the turbulent fields, the local temperature reaches at least 600K, and a small fraction of the volume becomes hotter still, considering that a similar power should dissipate in a current sheet thinner than the grid spacing. The optically-thick, magnetically-dead interior is weakly heated by Silk damping of compressive disturbances, and is almost isothermal at a temperature of 130 K. In contrast, in the alpha model, there is a temperature bump of 20K near the midplane due to concentration of the accretion heating there.

キーワード: 原始惑星系円盤, 輻射輸送, 磁気乱流
Keywords: protoplanetary disk, radiative transfer, magnetic turbulence