Tandem Planetary Formation Theory

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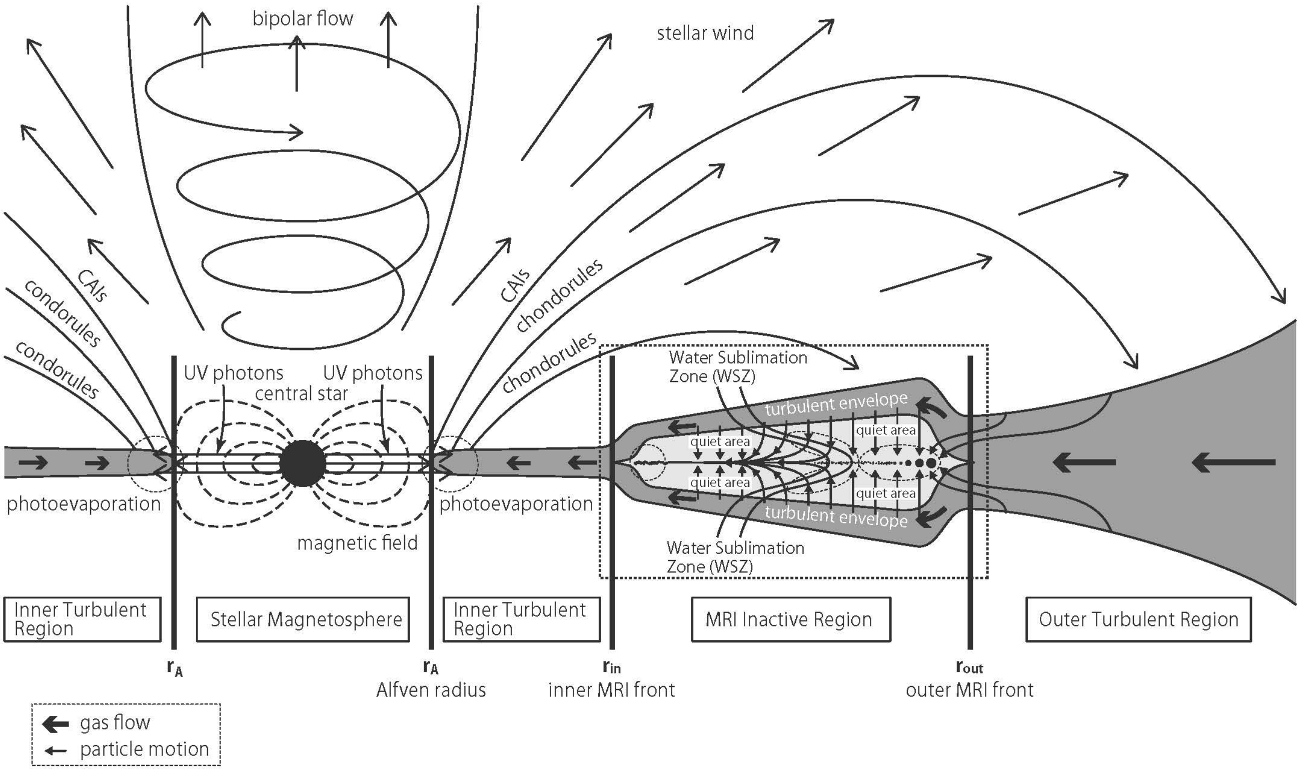
We have obtained a steady-state, 1-D model of the accretion disk of a protostar taking into account the magneto-rotational instability (MRI). We find that the disk is divided into an outer turbulent region (OTR), a MRI suppressed region (MSR), and an inner turbulent region (ITR). The outer turbulent region is fully turbulent because of MRI. However, in the range, r_{out} (= 8 - 60 AU) from the central star, MRI is suppressed around the midplane of the gas disk and a quiet area without turbulence appears, because the degree of ionization of gas becomes low enough. The disk becomes fully turbulent again in the range r in (= 0.2 - 1 AU), which is called the inner turbulent region, because the midplane temperature become high enough (\gt 1000 K) due to gravitational energy release.
Planetesimals are formed through gravitational instability at the two distinct sites, outer and inner MRI fronts (the boundaries between the MRI suppressed region (MSR) and the outer and inner turbulent regions), because of the radial concentration of the solid particles. At the outer MRI front, icy particles grow through low-velocity collisions into porous aggregates with low densities. They eventually undergo gravitational instability to form icy planetesimals. On the other hand, rocky particles accumulate at the inner MRI front, since their drift velocities turn outward due to the local maximum in gas pressure. They undergo gravitational instability in a sub-disk of pebbles to form rocky planetesimals at the inner MRI front.
The tandem regime is consistent with the ABEL model, in which the Earth was initially formed as a completely volatile-free planet. The water and other volatile elements came later through the accretion of icy particles by the occasional scatterings in the outer regions.

Keywords: Planetary Formation, Accretion Disk, Magneto-Rotational Instability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magnetic field
Water Sublimation Zone (WSZ)
turbulent envelope
quiet area
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turbulent envelope
Water Sublimation Zone (WSZ)
Inner Turbulent Region
Stellar Magnetosphere
Inner Turbulent Region
MRI Inactive Region
Outer Turbulent Region
r_A
r_A
Alfven radius
r_{in}
inner MRI front
r_{out}
outer MRI front
gas flow
particle motion

