Chapter 6

Summary and Conclusions

In this thesis we developed a suitable Fokker-Planck equation which is used to explain the charge particle transport under an Archimedean spiral magnetic field configuration. The fluid flow model simply uses the assumption of a spherically symmetric outflow (inflow). An appropriate equation can be designed to suit our desired magnetic field configuration. Finally, we obtained an equation containing all the relevant physical processes concerning the time evolution of the distribution function $F(p, r, \mu)$, including the physical processes of spatial transport (streaming and advection), pitch angle changes (scattering and adiabatic focusing due to the magnetic field divergence) and momentum changes (adiabatic deceleration) due to the divergence of the fluid flow.

Then we developed a useful numerical methodology that we call a generalized TVD method (see Chapter 3) to improve the solution of the spatial transport. This technique allows us to run the program 10 to 100 times faster (Nutaro, Riyavong and Ruffolo, 2000). Hence, all of our simulations could be performed on only a PC-based computer under the Linux operating system.

Our main goal is to numerically solve the transport equation we developed in Chapter 2, which incorporates the effects of the adiabatic focusing and adiabatic deceleration. This is because of the spherically symmetric wind model we used. The treatment of particles crossing the shock is included in the code (Ruffolo, 1999) and has been substantially modified to suit our case. We then have the freedom to investigate the behavior of charged particles under the influence the magnetic field and the shock encountered.

The primary testing results for the generalized TVD schemes (see section 5.1), found that, for the case of no shock, we could reproduce the same results as Ruffolo (1995) when the same parameters were used. The results were slightly different from the prototype when a coarser grid size was used to improve the program running speed. Within the limit of an acceptable numerical error the program running speed can be made at least 10 to 20 times faster. The new, generalized TVD scheme also worked well under the oblique, *planar* shock circumstance (see Figures 5.4-5.5).

We then proceeded to investigate a spherical, oblique, and strong shock which has a four-fold fluid speed difference between upstream and downstream. For this study we chose an incident magnetic field angle upstream of 75° for convenience. At the beginning stage, we simply used the spectral index $\delta = 2.0$. Figures (5.9 - 5.20) show the short, sharp increase of the charged particle intensity on the upstream side. That is, the acceleration of charged particles takes place nearby the spherical shock boundary as we expected (see Chapter 1). The $\langle j \rangle_\mu$

profile when compared to the oblique, planar shock case is rather similar, giving us confidence in the accuracy of the new code.

It is obvious that the generalized TVD we have developed can play a major role for spatial transport solving as well. Hence this new scheme is applicable to a wide range of problems which incorporate an advection term, since the running speed can be improved more in the same manner as in this thesis.

Regarding shortcomings, the spherically symmetric model and the numerical technique we developed will be adjusted to suit problems of more recent interest such as space weather forecasting. The new model of a spherical shock is more realistic than the *planar shock* assumption used in previous work of this sort (e.g. Ruffolo, 1999). This is because range of ultimate interest in such events occurring at distances relatively close to the Sun where the shock geometry is still more curved. We hope that, by taking the curvature effect of the shock into account, we will obtain a more accurate numerical result than has ever been obtained before.

Further work using this computer program could lead us to investigate deeper and deeper in fine detail about the spherical shock transport and acceleration mechanism which incorporates the possible physical processes occurring nearby the shock as we explained in Chapter 2. In the long term, we might consider to improve our program to handle a moving, spherical shock, which would be useful to explain a wider range of physical phenomena occurring somewhere in deep space.