# Chapter 7

# Thesis Summary and Discussion

This thesis addresses the problems associated with deriving information about the structure and dynamical nature of the solar upper atmosphere. We wish to extract as much information as possible from the spectral observations. In general, we require either an inversion or prediction approach. In the case of inversion, we must ensure that minimal errors are introduced by the observational and experimental techniques if we are to use the spectral intensities with confidence. Even if we can there are questions regarding the validity of the assumptions we make and in the interpretation of the results we obtain. The problems with this approach have been outlined throughout this thesis. For the predictive approach we are limited with the knowledge that even an exact match with our simulations does not definately tell us that the model is correct. It is only one possible solution. Despite these difficulties we hope to make substantial progress with improved instrumentation on SOHO, improvements to models and to numerical techniques. Of necessity we require a more accurate description of the radiating characteristics of atoms and ions in plasmas than has previously been applied in astrophysics.

Throughout the last decade extensive work has been done to define the difficulties with commonly used approaches and to attempt to address them in order to gain maximum output from the SOHO satellite. In the late eighties, Summers and co-workers began developing the ADAS package to provide the improved atomic model required. Harrison & Thompson (1992) reviewed the quality of differential emission measure codes and that of Thompson(1991) was recommended and subsequently integrated with ADAS. Lang et al.(1994) reviewed the quality of fundamental data and made recommendations which have been used to expand the ADAS database. Lang et al.(1990) undertook a critical review of the differential emission measure technique and provided suggestions of how to test the various assumptions involved. Judge et al.(1995) revisited their work and attempted to narrow the choice of likely explanations for problems using data from the SOLar-STellar Irradiance Comparison Experiment (SOLSTICE) on the Upper Atmosphere Research Satellite (UARS), and the EUV Grating Spectrograph (EGS) which was flown on a sounding rocket on October 4th 1993. We are in the process of revisiting these questions again with the improved data from SOHO. Thus many workers have addressed each area of the subject and the results are only now starting to come to fruition.

Clearly the task is on going and it is unrealistic to expect this thesis to conclude the work. However, we have methodically set about the task and made significant inprovements at each stage of the work. We review these here.

Data handling utilities were introduced to ADAS to allow flexibility in the use of fundamental data between astrophysical and fusion applications. The ability to 'work at different resolution levels' within excited population structure allows us to avoid the duplication of effort in atomic collision calculations. In addition, the inclusion of a proper treatment of recombining ion metastables paves the way for a more realistic approach to ionisation-recombination models in transiently ionising plasmas (see sec.3.1.1).

The development of a numerical method for calculating a metastable resolved equilibrium ionisation balance was introduced (see sec.3.2.1). This allowed investigation of the effects of such states in line emissivities, contribution functions, radiated power etc. In addition, the explicit treatment of metastables allows use of the most sophisticated dielectronic recombination and ionisation data which is now becoming readily available for the first time. An in-depth analysis of this type was undertaken in chap.4 for oxygen. This included a critical review and upgrade of the existing fundamental database and production of results for solar targeted studies. This provides an example of the analysis methods for solar astrophysical applications which were previously tested successfully in the fusion environment. It was shown there that a generalised collisional radiative model is essential for maintaining accuracy in the atomic modelling underlying the spectral reduction. This requires the inclusion of the substantial effects of finite density plasma and the influence of metastable states. If we are to attempt to improve on the two dimensional differential emission measure work of Judge et al.(1997), density dependent contribution functions will be required (see discussion of sec.4.6). Further, if we are to aim at the type of precision he requires in the 'kernel' functions metastable states must be included.

Although the effects of a dynamic ionisation were not included in the analysis of oxygen, it was shown in sec.3.2.1 and sec.5.3.1 that this effect is clearly important in the solar atmosphere. As mentioned in sec.4.7 it is clear that metastable states will play a significant role in this too. This is an area that has not been fully investigated.

Again nonequilibrium ionisation is clearly relevant for analysis of spectral intensities by differential emission measure. It is likely that at least this assumption in the formulation of the intensity integral equation is invalid. Its incorporation is an area we intend to investigate and the influence of metastables will be included.

Before improvement however we have to be sure of the limitations of the current approach. Hence the reason for our definitive differential emission measure study. To limit the observational and experimental inaccuracies a critical analysis was presented (chap.5) of the effects of instrumental problems (e.g. cosmic rays, fixed patterning etc.) and analysis methods (e.g. line fitting). We developed the maximum likelihood line profile fitting procedure of Lang et al.(1990) to ensure awareness of the magnitude of the errors associated with the line fitting. We developed further the methods of Lang et al.(1990) to quantify the observational accuracies of the measurements to produce meaningful errors for our differential emission measure analysis. In the course of this we made a statistical analysis of the variation of spectral line intensities and revisited the interesting point of variability pattern changes mentioned by Lang et al.(1990).

We developed an archiving scheme and set of analysis procedures to draw the CDS and SUMER data from their respective archives and link the data to the ADAS differential emission measure code via the line profile fitting procedure. The routines and system were thoroughly tested and a demonstration DEM for CDS-NIS data was presented. The spread of observed to predicted intensities was then examined to constrain the variability of the DEM with temperature and also to investigate closely the normal incidence spectrometer calibration question. These results are preliminary but are proving helpful for the CDS team investigating the calibration issue. Atomic data was found to be lacking for some important lines, especially Iron in NIS1, and there appeared to be problems associated with the imperfect separation of badly blended lines and multiplets. These issues are under investigation for the final study. However, the number of strong identified lines available is encouraging for an extensive study which we also hope will include the grazing incidence spectrometer and SUMER in due course.

Finally, in chap.6 we initiated some work on predictive modelling using the hydrodynamic code of MacNeice (1983). This consisted mainly of a test run of the code to help in our understanding but some initial thoughts and investigations were presented in sec.6.4.

Many of the results presented here will be re-examined more comprehensively for the differential emission measure study, but the identification of lines, analysis of variability etc. is part of a larger work to be presented on the CDS spectrum. This presents the EUV spectrum comprehensively for the first time, as observed by CDS, and is analogous to the work of Feldman et al.(1997) on SUMER.

Associated with this work is an investigation of the role of opacity to help in exclusion of optically thick lines for the DEM study. An additional output from this has been investigation of the extension of ADAS to the optically thick case by integration of simple 'escape factor' models of radiation transfer. Further to this we intend to integrate opacity and differential emission measure studies with the aim of moving towards a more complete radiative transfer description of the radiation emission of ions such as SiII. Studies of photoabsorption and radiative transfer are essential for preparation for the upcoming deep space satellites AXAF (Advanced X-ray Astrophysics Facility) and XMM (X-ray Multiple Mirror satellite).

**References**


Abu-Salbi, N., Callaway, J.: 1981, *Physical Review A*, **24**, 237

Aggarwal, K.A.: 1983, *Astrophys. Journal Supp.Ser.*, **52**, 387

Aggarwal, K.A.: 1985, *Astronomy & Astrophysics*, **146**, 149

Aggarwal, K.A.: 1993, *Astrophys. Journal Supp.Ser.*, **85**, 197

Aitken, K.L., Harrison, M.F.A.: 1971, *Journal Physics B*, **4**, 1176

Allard, N.: 1990, *Astronomy & Astrophysics Supp.Ser.*, **84**, 563

Antiochos, S.K., Noci, G.: 1986, *Astrophys. Journal*, **301**, 440

Antiochos, S.K., Klimchuk, J.A.: 1990, *Astrophys. Journal*, **378**, 372

Arnaud, M., Rothenflug, R.: 1985, *Astronomy & Astrophysics Supp.Ser.*, **60**, 425

Athay, R.G.: 1981, *Astrophys. Journal*, **249**, 340

Badnell, N.R., Pindzola, M.S., Dickson, W.J., Summers, H.P.: 1993, *Astrophys. Journal Letters*, **407**, L91

Badnell, N.R., Gorczyca, T.W, Pindzola, M.S., Summers, H.P.: 1996, *Journal Physics B*, **29**, 3683

Bates, D.R, Kingston, A.E., McWhirter, R.W.P.: 1962, *Proc. Royal Society London*, **267A**, 297

Bell, K.L., Hibbert, A., Stafford, R.P., McLaughlin, B.: 1994, *Physica Scripta*, **50**, 343

Berrington, K.A.: 1994, *Atomic Data Nuclear Data Tables*, **57**, 71

Berrington, K.A., Eissner, W.B., Norrington, P.H.: 1995, *Computer Physics Comms.*, **92**, 290

Berrington, K.A. et al: 1979, *Journal Physics B*, **12**, L275

Berrington, K.A. et al: 1985, *Journal Physics B*, **33**, 195

Bhadra, K., Henry, R.J.W.: 1982, *Physical Review A*, **26**, 1848

Bhatia, A.K., Doschek, G.A., Feldman, U.: 1979, *Astronomy & Astrophysics*, **76**, 359

Bittencourt, J.A.: 1986, *Fundamentals of Plasma Physics, Pergamon, Oxford.*

Blum R.D., Pradhan, A.: 1992, *Astrophys. Journal Supp.Ser.*, **80**, 425

Braginskii, S.I.: 1965, *Reviews of Plasma Physics (Leontovich ed.)*, **205**

Bransden, B.H., Joachin, C.J.: 1992, *'Physics of Atoms and Molecules', Longman*

Breeveld, A.A., Edgar, M.L., Smith, A., Lappington, J.S., Thomas, P.D.: 1992, *Reviews Sci. Inst.*, **63**, 1

Brook, E., Harrison, M.F.A., Smith, A.C.H.: 1978, *Journal Physics B*, **11**, 17

Brooks, D.H., Badnell, N.R., lang, J., Summers, H.P.: 1997, *In Preparation*

Brosius, J.W., Davila, J.M., Thomas, R.J., Monsignori-Fossi, B.C.: 1996, *Astrophys. Journal Supp.Ser.*, **106**, 143

Brown, J.C.: 1973, *Solar Physics*, **31**, 143

Brown, J.C., Dwivedi, B.N., Sweet, P.A., Almleaky, Y.M.: 1991, *Astronomy & Astrophysics*, **249**, 277

Brown, J.C., Thompson, A.M.: 1991, *Rutherford Appleton Laboratory Report*, RAL-91-092

Brueckner, G.E., and 14 other authors.: 1995, *Solar Physics*, **162**, 357

Burgess, A.: 1964, *Astrophys. Journal*, **139**, 776

Burgess, A.: 1965, *Astrophys. Journal*, **141**, 1588

Burgess, A., Seaton, M.J.: 1964, *Mon. Not. R. Ast. Soc.*, **127**, 355

Burgess, A., Summers, H.P.: 1969, *Astrophys. Journal*, **157**, 1007

Burgess, A., Summers, H.P.: 1976, *Mon. Not. R. Ast. Soc.*, **174**, 345

Burgess, A., Tully, J.: 1992, *Astronomy & Astrophysics*, **254**, 436

Burgess, A., Summers, H.P., McWhirter, R.W.P., Cochrane, D.M.: 1977, *Mon. Not. R. Ast. Soc.*, **179**, 275

Burke, Burke, Scott.: 1992, *Computer Physics Comms.*, **69**, 76

Callaway, J.: 1994, *Atomic Data Nuclear Data Tables*, **57**, 9

Cheng, C.C., et al.: 1983, *Astrophys. Journal*, **265**, 1090

Christensen, R.B., Norcross, D.W., Pradhan, A.K.: 1985, *Physical Review A*, **32**, 93

Cowan, R.D.: 1981, *'The Theory of Atomic Structure and Spectra'.*

Craig, I.J.D., Brown, J.C.: 1976, *Astronomy & Astrophysics*, **49**, 239

Culhane, J.L., and 27 other authors.: 1991, *Solar Physics*, **136**, 89

Cuperman, S., Weiss, I., Dryer, M.: 1981, *Astrophys. Journal*, **239**, 345

Dere, K.P., Landi, E., Mason, H.E., Monsignori-Fossi, B.C., Young, P.R.: 1996, *Astronomy & Astrophysics Supp.Ser.*, *In press*

Dickson, W.J.D.: 1993, *Ph.D. Thesis, Univ. of Strathclyde*

Domingo, V., Fleck, B., Poland, A.I.: 1992, *Space Science Reviews*, **70**, 7

Doschek, G.A., Bohlin, J.D., Feldman, U.: 1976, *Astrophys. Journal*, **205**, L177

Doschek, G.A, Boris, J.P., Cheng, C.C., Mariska, J.T., Oran, E.S.: 1982, *Astrophys. Journal*, **258**, 373

Doyle, J.G., McWhirter, R.W.P.: 1980, *Mon. Not. R. Ast. Soc.*, **193**, 947

Dubau, J. : 1994, *Atomic Data Nuclear Data Tables*, **57**, 21

Elliot, J.A.: 1993, *'Plasma Physics' (Dendy Ed.), C.U.P.*

Emslie, A.G.: 1987, *Solar Physics*, **113**, 175

Fawcett, B., Mason, H.E.: 1989, *Atomic Data Nuclear Data Tables*, **43**, 245

Fleck, B., Domingo, V., Poland, A.: 1995, *Solar Physics - Special Edition*, **162**

Feldman, U., Behring, W.E., Curdt, W., Schuele, U., Wilhelm, K., Lemaire, P.: 1997, *Astronomy & Astrophysics Supp. Ser.*, *Accepted*

Feldman, U.: 1983, *Astrophys. Journal*, **275**, 367

Feldman, U.: 1987, *Astrophys. Journal*, **320**, 426

Feldman, U., Laming, M.: 1994, *Astrophys. Journal*, **434**, 370

Fisher, G.H., Canfield, R.C., McLymont, A.N.: 1985, *Astrophys. Journal*, **289**, 414

Gabriel, A.H.: 1976, *Phil. Trans. R. Soc. London A*, **281**, 339

Gan, W.Q., Fang, C., Zhang, H.Q.: 1991, *Astronomy & Astrophysics*, **241**, 618

Gan, W.Q., Reiger, E., Fang, C., Zhang, H.Q.: 1993, *Solar Physics*, **143**, 141

Geesman, H., Hanne, G.F., Stauffer, A.D., Stauffer, J.A.: 1991, *Nucl. Inst. Methods in Phys. Res.*, **A307**, 413

Grevesse, N., Anders, E.: 1991, *Solar Interior and Atmosphere. Univ. Arizona Press*, **A92-36201 14-92**, 1227

Hahn, Y.: 1985, *Adv. Atomic Mol. Phys.*, **21**, 123

Harrison, R.A., Fludra, A.: 1995, *Rutherford Appleton Laboratory Report*, **SC-CDS-RAL-SN-95-0001**

Harrison, R.A., Insley, J.E.: 1997, *Solar Physics Special Edition, , In Press*

Harrison, R.A., Thompson, A.M.: 1992, *Rutherford Appleton Laboratory Report*, **RAL-91-092**

Harrision, R.A., and 38 other authors.: 1995, *Solar Physics*, **162**, 233

Hayes, M.A.: 1983, *Journal Physics B*, **16**, 285

Hayes, M.A., Nussbaumer, H.: 1983, *Astronomy & Astrophysics*, **134**, 193

Henry, R.J.W.: 1981, *Physics Reports*, **68**, 1

Ho, Y.K., Henry, R.J.W.: 1983, *Astrophys. Journal*, **264**, 733

Hubeny, V., Judge, P.G.: 1995, *Astrophys. Journal Lett.*, **448**, L61

Hutchison, I.H.: 1987, *'Principles of Plasma Diagnostics', C.U.P.*

Innes, D., Inhester, B., Axford, W.I., Wilhelm, K.: 1997, *Nature*, *Submitted*

Janev, R.K., Winter, H.: 1985, *State Selective Electron Capture in Atom - Highly Charged Ion Collisions*, *Physics Reports*, **117**, 265

Jordan, C.: 1969, *Mon. Not. R. Ast. Soc.*, **142**, 499

Judge, P.G., Hubeny, V., Brown, J.C.: 1997, *Astrophys. Journal*, **475**, 275

Judge, P.G., Woods , Brekke, Rottman : 1997, *Astrophys. Journal*, **475**, 275

Karlicky, M., Henoux, J.C.: 1992, *Astronomy & Astrophysics*, **264**, 679

Kato, T.: 1994, *Private Communication*

Kato, T., Lang, J., Berrington, K.: 1990, *Atomic Data Nuclear Data Tables*, **44**, 133

Kato, T., Nakazaki, S.: 1989, *Atomic Data Nuclear Data Tables*, **42**, 313

Kent, B.J., Breeveld, A.A., Bromage, B.J., Hollandt, J., Lang, J., Pike, C.D., Thompson, W.T.: 1997, *In Preparation*

Kingsburgh, R.L., English, J.: 1992, *Mon. Not. R. Ast. Soc.*, **259**, 635

Kohl, J.L. and 38 other authors: 1995, *Solar Physics*, **162**, 313

Kopp, R.A., Fisher, G.A., MacNeice, P., McWhirter, R.W.P., Peres, G.: 1986, *Proc. of SMM Flare Workshop*, *NASA-CP-2439*,

Laher, R.R., Gilmore, F.K.: 1990, *Journal Phys. Chem. ref. Data*, **19**, 277

Laming, J.M., Drake, J.J., Widing, K.G.: 1995, *Astrophys. Journal*, **443**, 416

Lang, J. (Special Editor): 1994, *Atomic Data Nuclear Data Tables*, vol.57

Lang, J., Payne, J.: 1987, *Rutherford Appleton Laboratory Report*

Lang, J., Summers, H.P.: 1994, *Atomic Data Nuclear Data Tables*, **57**, 215

Lang, J., Summers, H.P.: 1996, *ADAS Document*

Lang, J., Mason, H.E., McWhirter, R.W.P.: 1990, *Solar Physics*, **129**, 31

Lang, J., and 13 other authors.: 1992, *PASJ*, **44**, L55

Lanzafame, A.C., Brooks, D.H., Lang, J., Summers, H.P., Thompson, A.M.: 1997, *In Preparation*

Lennon, D.J., Burke, V.M.: 1994, *Astronomy & Astrophysics Supp.Ser.*, **103**, 273

Luken, W.L., Sinanoglu, O.: 1976, *Journal Phys. Chem. Ref. Data*, **64**, 1495

Maggi, C.F.: 1996, *Ph.D. Thesis, Univ. of Strathclyde*

Mann, J.B.: 1983, *Atomic Data Nuclear Data Tables*, **29**, 407

MacNeice, P.: 1983, *Ph.D. Thesis, Univ. of Cambridge*

MacNeice, P.: 1986, *Solar Physics*, **103**, 47

MacNeice, P., McWhirter, R.W.P., Spicer, D.S., Burgess, A.: 1984, *Solar Physics*, **90**, 357

MacNeice, P., Fontenla, J., Ljepojevic, N.N.: 1991, *Astrophys. Journal*, **369**, 544

Mariska, J.T., Emslie, A.G., Li, P.: 1989, *Astrophys. Journal*, **341**, 1067

McLaughlin, B.M., Bell, K.L.: 1993, *Astrophys. Journal*, **408**, 753

McLaughlin, B.M., Bell, K.L.: 1994, *Astrophys. Journal Supp.Ser.*, **94**, 825

McWhirter, R.W.P.: 1960, *Proc. Phys. Soc.*, bf 75, 520

McWhirter, R.W.P.: 1965, in *'Plasma Diagnostic Techniques'* , 201

McWhirter, R.W.P.: 1994, *Atomic Data Nuclear Data Tables*, **57**, 139

McWhirter, R.W.P., Summers, H.P.: 1985, in *'Applied Atomic Collision Physics* , 51

Mihalas, D.: 1978, *'Stellar Atmospheres' (Freeman) & Co.*, 26

Monsignori-Fossi, B.C., Landini, M.: 1994, *Atomic Data Nuclear Data Tables*, **57**, 125

Moore, C.E.: 1993, in *'Tables of Spectra of hydrogen, carbon, nitrogen and oxygen*

Nagai, F.: 1980, *Solar Physics*, **68**, 351

Nagai, F., Emslie, A.G.: 1984, *Astrophys. Journal*, **279**, 896

Noci, G., Spadaro, D., Zappala, R.A., Antiochos, S.K.: 1989, **338**, 1131

Pallavicini, P., Peres, G., Serio, S., Vaiana, G., Acton, L., Leibacher, J., Rosner, R.: 1983, *Astrophys. Journal*, **270**, 270

Peres, G., Reale, F., Serio, S., Pallavicini, P.: 1987, *Astrophys. Journal*, **312**, 895

Phillips, K.J.H.: 1992, *'Guide to the Sun', C.U.P.*

Pike, D., Harrison, R.A.: 1997, *Solar Physics Special Edition,* , *In Press*

Poland, A.I., Mariska, J.T., Klimchuk, J.: 1986, in *'Coronal and Prominence* , 57

Pradhan, A.K.: 1976, *Mon. Not. R. Ast. Soc.*, **177**, 31

Pradhan, A.K., Norcross, D.W., Hummer, D.G.: 1981, *Astrophys. Journal*, **246**, 1031

Robb, D.: 1980, in *Informal Report LA-6220-MS (Merts et al.)*

Sampson, D.H., Goett, S.H., Clark, R.E.H.: 1983, *Atomic Data Nuclear Data Tables*, **29**, 467

Sampson, D.H., Zhang, H.L., Fontes, C.J.: 1994, *Atomic Data Nuclear Data Tables*, **57**, 97

Saraph, H.E.: 1972, *Computer Physics Comms.*, **3**, 256

Saraph, H.E.: 1978, *Computer Physics Comms.*, **15**, 247

Saraph, H.E., Seaton, M.J., Shemming, J.: 1969, *Proc. R. Soc.*, **264**, A1149

Scott, N.S., Burke, P.G.: 1980, *Journal Physics B*, **13**, 4299

Seaton, M.J., Storey, P.J.: 1976, *UCL Dept. Phys. & Ast. Report*

Somov, B.V., Sermulina, B.J., Spektor, A.R.: 1982, *Solar Physics*, **81**, 281

Spadaro, D., Noci, G., Zappala, R.A., Antiochos, S.K.: 1990, *Astrophys. Journal*, **355**, 342

Spadaro, D., Antiochos, S.K., Mariska, J.T.: 1991, *Astrophys. Journal*, **382**, 338

Spadaro, D., Lanza, A.F., Antiochos, S.K.: 1996, *Astrophys. Journal*, **462**, 1011

Spadaro, D., Lanza, A.F.: 1996, *Private Communication*

Spence, J.: 1987, *Ph.D. Thesis, Univ. of Strathclyde*

Spitzer, L.: 1956, *'Physics of Fully Ionised Gases', Interscience, NY*

Spruitt, H.C.: 1981, in *'The Sun as a Star'*, *NASA-SP 450*, 385

Summers, H.P.: 1973, *Appleton Laboratory Report*, **A1-R-5**

Summers, H.P.: 1974, *Mon. Not. R. Ast. Soc.*, **169**, 663

Summers, H.P.: 1992, *Unpublished*

Summers, H.P.: 1994, *JET Internal Report*, *JET-IR(94)-06*

Summers, H.P.: Dickson, W.J.: 1992, in *'Recombination of Atomic Ions'* , 31

Summers, H.P.: Hooper, M.B.: 1983, *Plasma Phys. Cont. Nucl. Fusion*, **25**, 1311

Summers, H.P.: McWhirter, R.W.P.: 1979, *Journal Physics B*, **12**, 2387

Summers, H.P., Brooks, D.H., Hammond, T.J., Lanzafame, A.C., Lang, J.: 1996, *Rutherford Appleton Laboratory Report*, **RAL-TR-96-017**

Tayal, S.S., Kingston, A.E.,: 1984, *Journal Physics B*, **17**, 1383

Tayal, S.S., et al: 1982, *Proc. of ICPEAC Berlin*, 192

Tayal, S.S., Henry, R.J.W., Pradhan, A.K.: 1987, *Astrophys. Journal*, **319**, 951

Thompson, W.T.: 1994, *CDS Software Note*, **13**

Thompson, W.T., Poland, A.I., Sigmund, O.W., Swartz, M., Leviton, D.B., Payne, L.J.: 1992, *SPIE Proc.*, **1743**, 464

Topping, J.: 1962, *'Errors of Observation and their Treatment'*,

Van Maanen, A.: 1982, *Unpublished*

Vernazza, J.E., Avrett, E.H., Loeser, R.: 1981, *Astrophys. Journal Supp.Ser.*, **45**, 635

Weise, W.L., Smith, M.W., Glennon, B.M.: 1966, *'Atomic Transition Probabilities 1'*, **NSRDS-NBS**, 4

Widing, K.G., Doyle, J.G., Dufton, P.C., Kingston, A.E.: 1982, *Astrophys. Journal*, **257**, 913

Wilhelm, K.: 1993, *Max Planck Institut Report*, **SUM-MPAE-RO-113000-02-00**

Wilhelm, K., and 15 other authors.: 1995, *Solar Physics*, **162**, 189

Winglee, R.M., Pritchett, P.L., Dulk, G.A.: 1988, *Astrophys. Journal*, **327**, 968

Woodgate, B.E., Shine, R.A., Poland, A.I., Orwig, L.E.: 1983, *Astrophys. Journal*, **265**, 530

Wolf, R.C.: 1993, *JET Internal Report, JET-IR(93)-08*

Zhang, H.L., Sampson, D.H.: 1994, *Atomic Data Nuclear Data Tables*, **56**, 41

Zhang, H.L., Graziana, M., Pradhan, A.K.: 1994, *Astronomy & Astrophysics*, **283**, 319

Zirker, J.B.: 1981, in *'The Sun as a Star'*, *NASA-SP-450*, 135