

Chapter 1

Introduction

In order to gain a better understanding of Solar-Terrestrial relations, the European Space Agency (ESA), the National Aeronautics and Space Administration (NASA) and the Institute of Space and Astronautical Science (ISAS) agreed to a joint research project called the International Solar-Terrestrial Physics programme. This coordinated project aims to make simultaneous observations and measurements of the solar-terrestrial environment, over an extended period, by using five separate space satellite missions. These are SOHO, Cluster, Geotail, Polar and Wind. With Ulysses and Yohkoh still in orbit, research possibilities are more wide ranging than ever before.

SOHO and Cluster together form ESA and NASA's Solar-Terrestrial Science Programme which is the first cornerstone of ESA's longer term "Space Science Horizon 2000" programme. Cluster consisted of four identical spacecrafts which were to have taken simultaneous measurements of the plasma environment in the immediate vicinity of the Earth in order to map the 3-dimensional geometry and plasma distribution of the magnetosphere. Unfortunately, the satellites were destroyed by the failure of Ariane-5 due to an onboard software error in May 1996. However, it may be possible to realise the original goals of the mission as ESA intend to relaunch aboard Russian launchers under the new name of "Cluster 2".

SOHO was launched successfully aboard AC-121, an Atlas-IIAS rocket, from Cape Canaveral Air Force Station in Florida on December 2nd 1995. After a two and a half

month cruise phase it was inserted into an halo orbit, on February 14th 1996, around the gravitational equilibrium L1 Lagrangian point ($\sim 1.5 \times 10^6$ km from the Earth on the sunward side). Since then it has been taking helioseismology measurements and making continuous observations of the solar atmosphere and solar wind for 24 hours each day. The data is telemetered to the ground via NASA's Deep Space Network and there is now a wealth of observations available to support the original objectives of the mission. These are,

1. To study the solar interior.
2. To study the solar corona and explain how it is heated.
3. To investigate the acceleration process of the solar wind.

Observations throughout the '70s and '80s have clearly shown that changes in solar plasma conditions take place on spatial and temporal scales smaller and shorter than previous spaceborne instrumentation has been able to track. A deeper insight into the connection between radiating and dynamic properties of the solar plasma is essential for determination of the mechanisms responsible for its non-radiative heating. The state of the art equipment on SOHO provides a unique opportunity to examine these and other issues in greater detail than before (Fleck, Domingo & Poland (1995)).

Any analysis of spectroscopic data requires to adopt the best available atomic data to assist in interpretation. The problems of standard solar and atomic models in accounting correctly for the solar radiation emission have however suggested the requirements for an improved atomic basis of analysis. The importance of a unified approach to the modelling of atomic processes in plasmas cannot be understressed. To this end, a great deal of work has been done in recent years integrating and extending the quality of atomic modelling for laboratory and astrophysical plasmas. Chief amongst the concerns is the ability to handle the dynamic nature of the plasmas under investigation. At the forefront of this research field is the Atomic Data and Analysis Structure (ADAS). Originally developed at JET Joint Undertaking it has been adopted as the principal spectral analysis software package for the coronal spectrometers on board the SOHO satellite. Due attention is paid to the influence of

metastable states, finite density plasma and the competition of atomic processes in a full collisional-radiative model.

We wish to improve the quality, accuracy and flexibility of atomic modelling to gain new insight into the physical mechanisms of the solar upper atmosphere. The dynamic nature of the solar atmosphere leads us to believe that the assumption of ionisation equilibrium introduces a variability factor that limits the success of commonly used approaches such as differential emission measure analysis (DEM). One of our main objectives is to assess, execute and validate the DEM technique and to identify and quantify the sources of error associated with it.

In this chapter, a brief overview of the coronal instruments is given. Then, an outline of the principles behind the ADAS project is presented. This serves as background and an introduction to the main work of the thesis.

1.1 Outline of Capabilities of CDS and SUMER Spectrometers on SOHO

Details of all the instrumentation on board the SOHO satellite are presented by Fleck, Domingo & Poland(1995). In particular, Harrison et al.(1995) and Harrison & Fludra (1995) present details of the Coronal Diagnostic Spectrometer (CDS) while Wilhelm et al.(1995) and Wilhelm (1993) present details of the Solar Ultraviolet Measurements of Emitted Radiation (SUMER) spectrometer. These instruments deal with the provision of diagnostic information concerning dynamic behaviour such as explosive events and flows, and also the density & temperature structure of the solar atmosphere from the upper chromosphere through to the low corona. Other instruments available for coronal remote sensing are, e.g the Large Angle Spectroscopic COronagraph (LASCO, Brueckner et al.(1995)) and the UltraViolet Coronagraph Spectrometer (UVCS, Kohl et al.(1995)); however these are principally for investigating energy transport, velocities etc. in the upper corona (i.e. $1.1R_{\odot} \rightarrow 30R_{\odot}$). In addition, there is an Extreme-ultraviolet Imaging Telescope (EIT, Delaboudiniere et al. (1995)) on board but this is mainly for feature location and full disc images. Thus

CDS & SUMER are the two principal coronal instruments with which we will be concerned. Here we briefly outline the ‘state of the art’ capabilities of the two instruments with a comparison to previous and other current spaceborne instrumentation.

1.1.1 Coronal Diagnostic Spectrometer

CDS consists of a Wolter-Schwartzchild type 2 telescope and dual spectrometers fed by an entrance slit behind a scan mirror. The telescope is a full revolution system but only utilises two apertures in front of and light stops behind the telescope to select two components of the telescope beam to illuminate each of the spectrometers. One spectrometer is in normal incidence (NIS) and the other in grazing incidence (GIS). This is because reflection efficiency in normal incidence reduces at decreasing EUV wavelengths (Phillips(1992)). Thus the grazing incidence spectrometer was introduced to make wavelengths below $\sim 300\text{\AA}$ accessible. The optical layout of the instrument is given in fig.1 of Harrison et al.(1995). The spatial resolution of the telescope is defined by the full width at half intensity maximum (FWHM) of the point spread function. The point spread function is the intensity distribution obtained from observing an infinitely distant point source. For the CDS telescope, the FWHM was measured for both the NIS and GIS apertures in both the direction of wavelength dispersion and the direction perpendicular to it (Harrison et al.(1995)). The results are given in table.1.1.

For NIS the beam is focussed on a pair of toroidal gratings which diffract the image of the entrance slit onto a two-dimensional detector called the Viewfinder Detector Subsystem (VDS). This is an intensified CCD detector (Thompson et al.(1992)). The two gratings are slightly tilted to allow both spectra to be recorded at the same time. The entrance slit is usually aligned North-South during flight unless the spacecraft attitude is changed by a roll manoeuvre. Thus images can be built up by moving the scan mirror in the East-West direction through a small angle in ~ 2 arcsecond steps.

For GIS the beam hits a spherical grating placed at grazing incidence which disperses the light onto four microchannel plate (MCP) one-dimensional detectors placed

Telescope	Aperture Size Spatial Resolution	34.3cm ² -NIS, 47cm ² -GIS 1.2" GIS-wd, 1.7" GIS-pwd 1.2" NIS-wd, 1.5" NIS-pwd
NIS	Wavelength Coverage Prime Slits(4,5,6) Spectral Resolution	308-381, 513-633Å 2×240, 4×240, 90×240 arcsec. ² 0.08Å-NIS1, 0.14Å-NIS2
GIS	Wavelength Coverage Prime Slits(1,2,3) Spectral Resolution	151-221, 256-338, 393-493, 656-785Å 2×2, 4×4, 8×50 arcsec. ² 0.21Å

Table 1.1: CDS Relevant characteristics. pwd denotes the direction perpendicular to the wavelength dispersion plane and wd denotes the direction of wavelength dispersion.

around the Rowland circle. The resulting spectra are astigmatic (i.e. a focussed image of the slit is not produced on the detector) and so ‘pinhole’ slits are used. By rastering E-W using the scan mirror and N-S using the slits, images may be formed.

The field of view of the instrument is 4' by 4' and it can be repointed to anywhere on the solar disc. The wavelength coverage of the instrument is from 151Å to 785Å in the different bands as given in table.1.1. There are 6 slits available for use, nominally three for the GIS and three for the NIS, and these are also given in table.1.1. For NIS the spatial information is retained by the 2-d detector so it utilises slits which are long in the direction perpendicular to that of wavelength dispersion (i.e. 2" by 240", 4" by 240" & 90" by 240"). The 90" by 240" slit is provided to act as a feature locater. For GIS the ‘pinhole’ slits are square apertures and thus have a spatial extent limited to their size. The 8" by 50" slit can be used to provide a larger throughput. The spectral resolution of the two spectrometers can be obtained from the grating equation,

$$n\lambda = d (\sin \theta + \sin \alpha) \quad (1.1)$$

where n is the order, d is the grating spacing, θ is the angle of incidence on the grating and α is the angle of reflection off the grating. On assuming that the angle of incidence is fixed and making use of a trigonometric expansion of $\sin(\alpha + \delta\alpha)$ we

obtain,

$$\frac{\lambda}{\delta\lambda} = \frac{2\lambda R}{dx \cos \alpha} \quad (1.2)$$

which defines the spectral resolving power dependent on wavelength, with R the radius of the Rowland circle and dx the resolution scale. The spectral resolution ($\delta\lambda$) is given in table.1.1. As pointed out by Harrison & Fludra (1995) this argument is also valid for NIS. Finally, the temporal resolution, dictated by engineering capability, is of the order 1s or less.

1.1.2 Solar Ultraviolet Measurements of Emitted Radiation

The SUMER instrument optical layout is presented in fig.2 of Wilhelm et al.(1995). It consists of a telescope containing a parabolic mirror and an enclosed spectrometer utilising another parabolic mirror, a plane mirror and a spherical concave grating. The telescope mirror images the sun into the entrance slit of the spectrometer where the beam is directed onto the second parabolic mirror which collimates the light. The collimated beam is directed onto the plane mirror which deflects it onto the grating. Two two-dimensional detectors are positioned in the focal plane of the grating to collect images of the slit. Spatial information is retained as the images are stigmatic. Two spectral orders are recorded simultaneously over short wavelength ranges. To build a complete spectrum (such as that obtained with CDS) the plane mirror is rotated to scan wavelength ranges. The spatial resolution is close to 1 arcsec. but dependent on wavelength (see table.1.2).

The SUMER field of view covers 64' by 64' and is scanned using the telescope mirror which manoeuvres in 0.38" steps. This can attain a fastest rate of 300 steps s^{-1} . The wavelength coverage is from 660Å to 1610Å in first order and 330Å to 805Å in second order. The precise detector ranges are given in table.1.2. Since the instrument uses three normal incidence reflections its sensitivity is very low below $\sim 500\text{Å}$. This principally affects the detection of lines in second order. Four slits are available and they are narrow in the dimension of wavelength dispersion to provide good wavelength resolution (see table.1.2). As for CDS-NIS the spectrometer is stigmatic so long slits are used to provide spatial information. These are oriented N-S and centred on the

Wavelength Coverage	Detector A : 390-805Å (2nd order), 780-1610Å (1st order) Detector B : 330-750Å (2nd order), 660-1500Å (1st order)
Prime Slits(2,4,7,1)	1×300, 1×120, 0.3×120, 4×300 arcsec. ²
Spatial Resolution	1.03 arcsec. px ⁻¹ at 800Å 0.95 arcsec. px ⁻¹ at 1600Å
Spectral Resolution	0.0228Å px ⁻¹ at 500Å (2nd order) 0.0209Å px ⁻¹ at 800Å 0.0450Å px ⁻¹ at 800Å (1st order) 0.0418Å px ⁻¹ at 1600Å

Table 1.2: SUMER Relevant characteristics.

detector spatial dimension. Slit 1 is wide in order to increase counts and was intended for off-limb observations. Slit 4 & 7 are available for more intense lines to cut the count rates from both the line and the continuum. Slit 2 is for standard use as it maps larger areas, perpendicular to the spatial dimension, than the others in a set time. A number of other refined slit positions are available and are referred to by separate slit numbers but these are only available to authorised SUMER team members (Wilhelm et al.(1995)).

The spectral resolution is again obtained from the grating equation and is given in table.1.2. The temporal resolution is of the order 1 second but can be as little as 60ms for specific observations of intense lines using the appropriate slit.

1.1.3 Discussion

Previous solar EUV instrumentation has improved our understanding of the solar upper atmosphere and has allowed us to define what exactly is needed to make greater advances. It is clear that the atmosphere is highly dynamic and that attempts to discover the coronal heating mechanism along with a comprehensive description of the atmospheric energy balance and radiating characteristics requires observations on much finer scales than have been available here-to-fore. In addition, measurements are required over a broader wavelength range, especially to shorter wavelengths (below $\sim 300\text{\AA}$) which include emission lines from some of the hottest non-flare coronal

plasmas.

In recent years great advances have been made in instrumentation development and engineering. For example, the spatial resolution of an instrument such as the soft x-ray telescope on YOHKOH, launched in 1991, is about a factor of three better than that available to scientists involved with the Solar Maximum Mission satellite launched in 1980. Missions prior to SOHO have been limited in their impact due to project and instrumentation design. As discussed by Harrison & Fludra (1995), in the context of EUV experiments, observations have been made since the early '60s. The Orbiting Solar Observatory (OSO) series (I-VII) ran from 1962-72 but in many cases used integrated solar disc images or integrated spectral bands. For those that did not, the spatial, spectral and temporal resolution was at least, and usually more than, an order of magnitude coarser than the instruments on SOHO e.g. $20''$, 0.8\AA and 120s respectively for the best (e.g. OSO VII in 1972). Certainly also, the wavelength coverage was much less ($120\text{-}400\text{\AA}$ for OSO-VII) and usually did not extend adequately to the shorter wavelengths ($\sim 300\text{\AA}$ being typical). Skylab (1973-74) improved the situation with regard to spectral coverage ($171\text{-}630\text{\AA}$) and resolution (0.13\AA). However, the spectral and spatial information could not be separated unambiguously as the spatial resolution was dependent on the location and brightness of the feature on the disc and in the spectrum. Since Skylab there have been five short duration solar EUV missions flown on the space shuttle and sounding rockets. Of these only the Coronal Helium Abundance Spacelab Experiment (CHASE) and the Solar Extreme ultraviolet Rocket Telescope and Spectrograph (SERTS) have characteristics comparable with CDS & SUMER. CHASE flew on the space shuttle for nine days in 1985 and SERTS typically observes for ~ 6 mins. during its rocket flight. In addition, the spectral and spatial resolution of CHASE were $0.25\text{-}0.4\text{\AA}$ and $15''$ respectively, which is worse than the SOHO instruments. SERTS has spectral and spatial capabilities close to that of CDS but prior to the SOHO launch only used photographic film and thus limited its temporal resolution. Also, its wavelength range is more restricted ($170\text{-}450\text{\AA}$). SOHO-CDS & SOHO-SUMER thus provide the first opportunity for a complete investigation of the EUV sun.

CDS and SUMER together provide a wavelength coverage (from 150\AA to 1600\AA)

which encompasses spectral emission lines produced by ions formed at temperatures from 10^4 to 2×10^6 K. These temperatures are appropriate for investigation of the upper chromosphere through to the corona. The shorter wavelengths accessible by CDS allow measurement of the valuable hotter lines.

It has been usual, in solar physics, to assume that the solar atmosphere from the chromosphere through the *transition zone* to the corona is all one continuous structure. However, Feldman(1983) and Feldman(1987) argued that most of the observed solar emission between temperatures of $\sim 40,000$ – $\sim 500,000$ K originates from plasma structures magnetically isolated from the chromosphere and corona. In this model, the true *transition zone* is only responsible for a small part of the emission within these temperature ranges. These structures, which Feldman(1983) named *unresolved fine structures*, should be extremely small and as yet unobserved by spaceborne instrumentation. CDS, and particularly SUMER, have a spatial resolution that will allow investigation of some of the smaller scale structures of the solar atmosphere and will investigate such issues. From the L_1 Lagrangian point, 1 arcsecond corresponds to ~ 715 km on the solar surface (Wilhelm (1993)). Typically compact loop structures have a radius of the order of 7 or 8 thousand km (Woodgate et al.(1983)). Therefore, the spatial resolution of an instrument such as SUMER is fine enough to resolve these small structures into $\sim 10 - 20$ segments. Thus due account should be taken of the spectrometer line of sight, for example, when estimating emitting plasma volumes for comparison with models. This has not been necessary for previous missions as the resolution was adequate only for total loop observations e.g. for CHASE the spatial resolution was $15''$ equivalent to $\sim 11,000$ km (see also Doschek et al.(1982)).

The temporal resolution of CDS & SUMER is critical in assessing whether dynamics in the transition region and corona are rapid enough to cast doubt on the assumption of ionisation equilibrium. The implications of this are widespread for determination of solar atmospheric structure and predictive studies and are addressed in chap.5 of this thesis. The resolution will also allow investigation of dynamical plasma events such as jets etc. The positioning of SOHO at L_1 , conversely, permits long duration studies that can help in the interpretation of measurements of, for example,

growth and decay rates of active region loops and prominences.

Finally, the available spectral resolution of the two instruments is high enough to separate a large number of lines of prime interest for density and temperature diagnosis and also to determine line-of-sight velocities from doppler shifts with an accuracy of $\sim 1km s^{-1}$. Such accuracy will facilitate the determination of plasma flow characteristics and velocity field fluctuations around sunspots and prominences, for example.

1.2 Overview of ADAS

1.2.1 The ADAS Project and its Principles

The Atomic Data and Analysis Structure (ADAS) originated at JET Joint Undertaking and is now developed jointly with Strathclyde University, and the sponsoring laboratories, under the direction of Prof. H.P.Summers. ADAS provides an interactive set of computer codes for accessing and displaying important plasma quantities. It is possible to look at large amounts of fundamental atomic collision data and also model dependent derived data more closely linked to the experimental plasma spectroscopy data reduction. In addition, ADAS provides a powerful capability for exploring parameter dependencies, for calculation of original data and for tailoring output to the specific requirements of a particular set of spectral observations.

ADAS draws together the experience and abilities of scientists working in different areas of plasma research. Theorists who calculate detailed reaction cross-sections to spectroscopists at the forefront of plasma experimental research are involved. With the large amounts of atomic data produced presently, and the differing quality standards, it is essential that some record of data sources is used for ease of comparison. In addition, an integrated approach to the atomic modelling of plasmas can only be beneficial to the overall goals of plasma fusion and astrophysical research. ADAS provides this integrated structure by having a centrally managed atomic database where every result is traceable to its source. The adoption of a common modelling approach also provides consistent source functions, for entry to plasma transport

models, with validation through widespread use. Thus leading fusion and solar astrophysical laboratories have sponsored the ADAS project to provide themselves with this capability. The sponsoring laboratories include both of the Principal Investigator Institutes for the European coronal spectrometers on SOHO i.e. Rutherford Appleton Laboratory, Oxford, UK (CDS Team) and Max Planck Institut für Aeronomie, Katlenberg-Lindau, Germany (SUMER Team). The involvement of a Consortium of worldwide research laboratories ensures that it is possible to fill the needs of the database by separating the local atomic tasks, thus avoiding needless duplication of effort.

ADAS was originally written in FORTRAN for the IBM mainframe at JET (Summers (1994)). However, it was decided at an early stage that the future of the project lay with a workstation environment and IDL was chosen to provide the interactive window interface to the subroutines and database. Due to requirements to support the project at JET it was decided that all the processing routines would remain in FORTRAN and that the interface and process management would be written in IDL. For the past two years contracted programmers and research assistants have made the conversion to UNIX-IDL on workstations. ADAS now has three main parts.

1. Centrally controlled Interactive user display.
2. Atomic database.
3. Library of Subroutines.

The user interface helps the informed user to run through the ADAS routines. It adopts central defaults which guide the user to the correctly formatted data types. A description of how to use each routine is generally provided with each updated release of ADAS and for solar astrophysical applications a user manual has been written (Summers et al.(1996)). Individual users' own application software can draw from the database and also the library of subroutines that ADAS has built up during the course of the conversion and development. Again, this avoids duplication of effort. ADAS provides a great deal of data but there are also 'off-line' codes that can be activated for specific gaps that need filled.

Participating Organisations	Contact
JET Joint Undertaking, England	H.P.Summers
IPP Garching, Germany	K.H.Behringer
KFA Juelich, Germany	J.Hey
Oak Ridge Cont. Fusion Atom. Data Centre, USA	D.Schulz
IPF Stuttgart, Germany	K.Hirsch
RAL (SOHO-CDS), England	J.Lang
MPAe Lindau, Germany	D.Innes
INEA Frascati, Italy	R.de Angelis
CEA Cadarache, France	W.Mandl
Tokamak de Varennes, Canada	E.Haddad

Table 1.3: Members of the ADAS consortium

The Consortium

A number of research laboratories worldwide are sponsors of the ADAS project. These make up the ADAS consortium and are listed in table 1.3.

The Database

The ADAS database is strictly controlled according to various classes each of which have their own ADAS data format number. There are 24 *adf*s in the database and some examples useful for solar astrophysical applications are shown in table 1.4. These formats must be strictly adhered to and a sample specification of each is given in Summers(1994). These are still valid for the UNIX-IDL version. Further examples of *adf*04 files are given in chap.3. Although there is some provision for inputting default values, if for example particular data is not available, there is generally not much protection against a faulty dataset. The data comes from a variety of sources. JET has contractual arrangements with Douglas Sampson and co-workers, at Pennsylvania State University, and Queen's University Belfast to name two. There is also a great deal of data taken from the general literature. Lang et al.(1994) compiled a comprehensive critical review of the available atomic data which is generally referred to as the 'green book'. This document includes contributions from many distinguished

Data Class	Description
adf04	Specific ion data
adf07	Direct resolved electron impact ionisation data
adf11	CR ionisation, recombination and power data
adf15	Photon emissivity coefficient data
adf20	$G(T_e)$ functions

Table 1.4: Key ADAS data format numbers for solar applications

Series No.	Title	Description
ADAS1	Atomic Data Entry and Verification	Graphing/Interpolation of individual reaction data & subsequent evaluation of rate coeffs.
ADAS2	General Z data and Population Processing	Coefft. preparation for and evaluation of excited populations of specific ions in a plasma. Calculation of line emission.
ADAS3	Charge Exchange processing	Graphing/processing of charge exchange related data (special interest to fusion).
ADAS4	Recombination and Ionisation Processing	Coefft. preparation for and evaluation of ground and metastable populations in plasma models (dynamic or steady state).
ADAS5	Supplementary Programs	Graphing/fitting of derived data & preparation of $G(T_e)$ DEM precursor files.
ADAS6	Data Analysis Programs	Differential emission measure analysis.

Table 1.5: Summary of ADAS organisation

authors and represents a good ‘benchmark’ opinion of the best available data. It includes reviews of atomic data for H-like to F-like ions and also SiII-SiIV, SII-SIV and FeI-XVII. The ‘green book’ developed from an atomic data assessment meeting held at Cosener’s House in Abingdon in 1992. Since its publication there have been many improved calculations and it is important to keep aware of these. Lang & Summers (1996) have prepared an ADAS document outlining the data needed to complete the adf04 database for the requirements of SOHO-CDS & SOHO-SUMER.

The Modelling Codes

This thesis is primarily concerned with solar radiation modelling so it is worthwhile to mention the ADAS codes which are of interest here. There are currently six ADAS series and not all are relevant to this topic. Table 1.5 provides a list and brief summary of the purpose of each of them. The modelling approach adopted for ADAS is that of generalised collisional-radiative theory (sec.2.2.2). Most ADAS codes draw from the fundamental database, perform some collisional-radiative modelling appropriate to the study in question, and output derived data that can be confronted with the experimental results. Alternatively, they provide for examination of fundamental or generated derived data. Output data from each program is formatted so it can be passed to other relevant ADAS routines for further investigative studies. Text and graphical output is also provided for the users’ convenience. The codes of special relevance to solar astrophysics are listed in table 1.6 and described in great detail by Summers et al.(1996). Some of these are also described in chap.3, with examples of use, and many have been used in the study of oxygen (chap.4). Each of the codes in table 1.6 was completed with the release of ADAS v.1.6 in June 1996, so ADAS now has a fully functioning capability for solar physics. Many studies and analysis of spectroscopic data in the past have been questionable due to uncertainties in the atomic modelling calculations. For example, the ionisation balance, line emission functions and line ratio diagnostic techniques can often be a weakness in the final results. ADAS has a powerful capability for examining such issues and it is hoped that its use will validate certain approaches and eliminate many of these problems. Although many of the codes are complex and can only be handled with practice,

Program	Use
ADAS205	Calculation of metastable & excited state populations
ADAS207	Calculation & display of line emissivities and ratios
ADAS208	Advanced version of ADAS205
ADAS209	Combines rate coefft. data from LSJ coupling to LS
ADAS210	Separates rate coefft. data from LS coupling to LSJ
ADAS405	Calculation of ionisation equilibrium fractions, radiated power & $G(T_e)$'s-can be metastable resolved
ADAS502	Interrogates ionisation rate coefficients
ADAS503	Interrogates photon emissivity coefficients
ADAS506	Interrogates $G(T_e)$ functions, sets up collection file for DEM analysis
ADAS601	Executes DEM analysis

Table 1.6: Key ADAS routines for solar applications

the tutorial manual used together with the release bulletins should alleviate any difficulties. In addition, it is hoped that the study of oxygen in ch.4 will provide a useful demonstration of the analysis path for solar applications.

ADAS is currently only applicable to optically thin plasmas. However, it is hoped that its success in modelling the radiating properties of such plasmas will encourage a similar structured approach to the investigation of optically thick plasmas. Indeed the flexibility, organisation and modelling approach of ADAS is such that it is well suited to developing new methods for dealing with these and other circumstances. The incorporation of a complete treatment of radiative transfer by simultaneous solution with the equations of statistical equilibrium, the integration of simpler *escape factor* models (McWhirter (1965)) and non-maxwellian electron distributions, are some of the ideas for future development.