Lecture Notes: Saul J. Adelman

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General comments: If you have questions concerning my presentation, please ask them at appropriate breaks in my train of thought. With demonstrations, clarifications at any point are appropriate.

I acknowledge the assistance of Taksin Cay and the local computer gurus in getting codes running so that I can demonstrate them.

Each department represented by attendees at this workshop is being given a CD Rom which contains:

a. a copy of these notes as of a week before I left for Turkey
b. manuals of some programs in pdf format - PLOTFITS, REDUCE (VLINE), VCROSS, and TSTACK
c. a pdf version of the scattered light paper I wrote with Gulliver & Hill
d. two catalogues from NASA's Astronomical Data Center
   1) the finding list I created of the newer sections of C. E. Moore's Multiplet Table
   2) my Bibliography of Atomic Line Identification Lists compilation including the references from Paper VI
e. line identification lists:
   from my papers in MNRAS with collaborators
      photographic plate versions:
         HD 109995, HD 161817 - Adelman, S. J., Hill, G., Fisher, W. 1987, Pub. DAO, XVI, 203
         o Peg - Adelman, S. J. 1988, MNRAS, 230, 671
         ϕ Her - Adelman, S. J. 1988, MNRAS, 235, 763
      photographic plates with some Reticon sections:
         γ Peg - Pintado, O., and Adelman, S. J. 1993, MNRAS, 264, 63
      Reticon version:
         σ Boo - Adelman, S. J., et al. 1997, MNRAS, 288, 470

   from Berahitdin's PhD thesis based on Reticons and CCDs:
      Deneb - preliminary version from Albayrak et al. spectral atlas - will have some additional coverage in the final version to be submitted to A&A
f. my educational compilation - "Great Astronomical Images" - 440 image version start from index.htm using web browser such as Netscape Communicator

Sample spectra: to be obtained from local account

aopegu.fts
aopegv.fts These are the coadded photographic spectra of o Peg.

r122_98_8741.fts
r122_98_8743.fts
r122_98_8747.fts
r48901735.fts
r122_98_8745.fts These are the spectra coadded to form adeneb4630.fts

cross.lam sample file for VCROSS
deneb4630.stk sample file for TSTACK
adeneb4630.fts the coadd

r48911656.fts
w122_96_11978.fts σ Boo 4575 region

r4891578.fts γ Peg 4410 region

w122_97_12856.fts ϕ Her 4575 region
w122_96_4807.fts ϕ Her 4465 region

Lecture 1 (Adelman/Bikmaev)

Photometry, spectrophotometry, and spectroscopy : resolution in terms of $\Delta\lambda/\lambda$ and some consequences in terms of S/N and the information content.

Modern detectors - how CCDs and other electron detectors have changed spectroscopy, why scattered light can no longer be ignored.

The need for biases and flats (lamp) exposures and how they affect the S/N level. How to optimize their use.

Arcs for spectroscopy

Line identification sources: atomic and stellar; sources of other atomic data

Selection of model atmospheres, the use of spectrophotometry and Balmer lines vs. photometry

convection theory - Mixing Length vs. Canuto-Mazzitelli (as it affects stellar parameters)

Lecture 2 (Bikmaev)

Modern spectrometers with modern detectors. The optical layouts of classical and echelle spectrographs with a careful discussion of the roles of the different parts (slit, grating, collimator, camera) in producing of spectra. Sources of scattering light. The advantages and disadvantages of each type.

The echelle instrument for the 1.5-m telescope.

Lecture 3 and 4a (Bikmaev) (one hour and 15 minutes)

Presentation and demonstration of the "2DI" portion of DECH-software for extraction of 1-d spectra from 2-d echelle-image.

Lecture 4b (Adelman) (15 minutes)

The extraction of classical coude spectra including optimal techniques as implemented in Program CCD by Gulliver and Hill. Comparison with 2DI.

Lecture 4c and 5a (Bikmaev) (30 minutes + 30-45 minutes)

Presentation and demonstration of "Dech20" portion of the DECH-sofware for continuum rectification over echelle-orders, sharp blaze-functions, preliminary line identification, etc.

Lecture 5b (Bikmaev and Adelman) (15-30 minutes)

Measurement of the instrumental profile. Problems in the standardization of equivalent width and line profile measurements from measurements taken with different instruments. How scattered light and noise affect the line profiles.

Lecture 6 (Adelman)

Presentation and demonstration of Graham Hill's software for measuring one-dimension spectra - REDUCE for normalization, VCROSS for relative radial velocities, TSTACK for coadding spectra, VLINE for line measurement

Lecture 7 (Adelman)

Computing synthetic spectra from Kurucz model atmospheres

Lecture 8 (Adelman/Bikmaev)

A discussion with the audience of high-resolution spectra studies of B, A, F, G -stars atmospheres with the goal of finding suitable studies for collaborative and individual efforts with the 1.5-m echelle

Lecture 1: Introduction to CCD Spectroscopy: with comments by Bikmaev to follow

This is an important period for Turkish Astronomy. Now there is a modern, but modest by present day standards, telescope in Turkey which has the potential to revolutionize the Turkish astronomical community and how it is seen by the international scientific community. Until now much of the high quality astronomical data used in Turkey was obtained using facilities outside of this country. This telescope changes the situation as it is capable of producing such data. The challenge is to make the best use of the 1.5-m telescope to investigate questions which its data can potentially answer as well as lay the foundation for investigations which are beyond its capabilities and will have to be conducted for some time elsewhere. I think that we all recognize and appreciate the labors of Dr. Zeki Aslan and his associates in creating the Turkish National Observatory. If the site proves to be as good as everyone here hopes, then by demonstrating that this community uses its equipment well will help to make the case for additional telescopes.

There are many observers who have a fondness to observe and to collect a lot of data. But unless that data ultimately is analyzed and published, I do not see the point in taking it. I remember going into the office of Dr. Armin Deutsch with whom I had worked for several months at Mt. Wilson Observatory a few days after his untimely death after being given permission to select those reprints which I could use. His office contained many large drawers of spectrograms that he had taken, which for the most part had not been analyzed. With the technology of 1970, it would have required four lifetimes to complete their analysis. Unfortunately since then these plates have been in the plate files and not studied. I resolved then not to let the same thing happen to me. I have completely published all of certain types of data that I took - my spectrophotometry and photographic DAO spectra. After the change from photographic to electronic detectors, I soon stopped analyzing my Kitt Peak and Mt. Wilson plates as my digital DAO spectral data was so much better.

This is not to say that one does not need a backlog of data. A few years worth should be sufficient for any of us. My collaborators, undergraduate students, and graduate students have helped insure that my backlog does not get too large. A problem with a coude spectrograph and a detector with a small wavelength range is that it can take a while to get sufficient spectra to study. To some extent the new longer CCD at the DAO is helping to solve that problem by requiring fewer spectral regions 8 instead of 17 for the coverage I desire.

I am very fortunate to have found in Austin Gulliver someone who is very interested in finding the optimal way to reduce our CCD exposures to one-dimensional spectra. Frankly I want a foolproof way which is relatively quick. I do not write great code. Once I have the data in a form which I can measure it, I want to do this efficiently and correctly. Graham Hill's programs have provided this ability. With the data measured, now I can analyze it and then contemplate what it means with due consideration for the errors. This later area for me is one of the pleasures of research.

In this workshop Ilfan Bikmaev and I will provide you with the tools to reduce and to measure spectroscopic data and then to analyze it to some extent.

The resolution one wants in the data to be obtained is an important figure of merit as with increasing resolution one increases the information content. Let us look at some types of observational techniques:

Consider a wavelength of 5000 A and 15 micron pixels for spectroscopy

Technique		$\Delta\lambda$ (Å) bandpass	resolution $\Delta\lambda/\lambda$(Å)	
Wide Band Photometry		1000	5	
Intermediate Band Photometry		300	17	
Spectrophotometry		20	250	
			1 pixel	2 pixels
Classification Spectroscopy	500 Å/mm	7.5	666	333
High Dispersion Spectroscopy	10 Å/mm	0.15	33333	16666
	2.4 Å/mm	0.036	138888	69444

For CCDs and spectroscopy we really should use 2 pixels as the resolution due to sampling theory. But often the 1 pixel values are quoted.

To obtain the same S/N ratio for each kind of data requires more photons for the higher resolution data which means greater exposure time or aperture or both. For most observations we want a final S/N to at least 100 after all systematic sources of error are removed.

With wide band photometry we can get estimates of temperatures and surface gravities as well as of some idea of the reddening. With intermediate band photometry we can do better and get improved information on reddening and metallicity. Spectrophotometry shows more details of the energy distribution as well as the strongest lines. By increasing its resolution slightly, it becomes calibrated classification spectroscopy.

For high dispersion spectroscopy the intrinsic size of the features in the spectrum determines the minimum resolution desired. One can compensate to some extent for lack of resolution by increasing the S/N. Some observers believe that it is the line width which is the key to setting the resolution. However, higher resolution permits one to better see the effects of line blending.

With IIaO Nitrogen baked photographic emulsions, I could obtain a S/N of order 25. By coadding many, I could reach S/N about 80. Using fine grain emulsions one could obtain S/N values of 50 to 100 or more at the cost of substantially increased exposure times. One also obtained a large spectral region. But photographic emulsions are non-linear detectors. Their quantum efficiencies were perhaps 1%.

With CCDs and coude type spectrographs, the wavelength ranges are limited. At the Dominion Astrophysical Observatory (DAO) 1.22-m telescope and long coude camera, in the blue to 63 Å (site 2) or 147 Å (site 4), but the S/N ratios are much higher. I typically aim for 200. Good CCDs have quantum efficiencies of 50% in the photographic and reach 95% in the red. Echelle spectrographs are a way to pack more spectral coverage on a detector. But one has to be very careful not to put the orders too close together.

Often the S/N ratios are quoted based on the pixel to pixel standard deviation. But one should correct such values for the effects of systematic errors - in particular for scattered light. Clean non-crossed dispersed spectrographs canonically are supposed to have scattered light amounting to 3 to 4 % of the signal. Measuring it is a tricky business. At the DAO 1.22-m coude spectrograph, we used to think it was 3.5 +/- 0.5%. So an apparent S/N = 200 spectra was equivalent to S/N = 140 after correction for such problems.

I have been taking spectra with apparent S/N = 200. This is to some extent a compromise value. The exposure time increases with the square of the S/N ratio. At this S/N, the uncertainties in the spectra do not substantially contribute to the errors in the abundance analysis if they are of order a factor of 2. But as these errors are reduced, the S/N for the spectra obtained probably should be increased. To be perfectly fair, for stars brighter than 3rd mag., I often go to S/N of 300 or more. The maximum number of photons which can be recorded on a CCD occurs when one does not superpixellate, i.e. read the signal from several pixels as if one. Of course one can coadd exposures to increase the S/N. The density of cosmic rays sets an upper limit on the desired exposure time. Usually one does not want to exposure for more than about an hour with two hours as the upper limit.

The bias level of a CCD is determined by the way the CCD is set-up. It is adjustable within limits. One wants it to be small so that one can accumulate lots of photons before the onset of saturation. For good CCDs, the standard deviation of the mean bias levels should be a few ADCU's. Ten exposures is adequate as at this level. Errors will have little effect on the final result. Obtaining a second set serves as a check which is important in case the first set is no good, due for example to being taken while the CCD is still cooling. The mean bias exposure is subtracted from the lamps, arcs, and stellar exposures.

One wants to make sure if at all possible that the flat or lamp exposure are at least as exposed as the stellar exposures. Often one makes then denser close to the point that the CCD no longer behaves linearly, say 75 to 90% of the saturation level. Any CCD exposure to be good should not be saturated at any point. As most lamp sources have finite lifetimes, constant time exposures slowly decrease in ADUC values. To correct for this effect, one often slightly increases the exposure times of the second set of flats. Further the CCD flat exposure times should be at least comparable with those of bright stars.

This slow drift of most lamps means that the standard deviations of the lamp exposures will be greater than those of the biases. The stellar exposures are divided by the mean lamp exposures to remove the sensitivity differences between pixels. Thus a high quality stable lamp is important for high S/N ratios.

For the DAO coude spectrograph, we use high temperature photoflood lamps with typically 3 hour lifetimes for the photographic and blue regions. Less luminous bulbs are used in the yellow and red. Proper lamp exposures are a more difficult problem for echelle spectrographs.

For many years the standard comparison spectrum for high dispersion spectroscopy was an iron arc. But now hollow cathode lamps of various types are employed as they are more consistent and reliable. Further as hollow cathodes are generally cooler sources the lines are narrower. But they age and one should compare its spectrum with some standard to make sure that it is satisfactory. The spectrum will change if there is an electronic failure.

The arc is often a ThAr lamp as Th has a high Z and numerous narrow lines.
The standard reference is D. Willmarth - KPNO/NOAO.
Go to http:://www.noao.edu/kpno/specatlas.
References: Palmer, B. A. & Engleman, R. J. 1983, Atlas of the Thorium Spectrum, Los Alamos National Laboratory, Los Alamos, NM
Norlen, G. 1973, Physica Scripta, 8, 249

But in the blue and optical ultraviolet shortward of 4400 A, a better arc is that of FeAr as this combination has many more lines which are stronger than those of ThAr. The above internet site also has a FeAr line list.
References: Crosswhite, H. M. 1975, Journal Research NBS, 79A, 17
Norlen, G. 1973, Physica Scripta, 8, 249

Line identification sources:
atomic - Moore, C. E., 1945, A Multiplet Table of Astrophysical Interest, Princeton University Observatory (also reprinted by NIST (NBS)) {This paper is also referred to as the RMT or revised multiplet table.}
Reader J., Corliss C. H., 1980, NSRDS-NBS 68, Part 1, US Government Printing Office, Washington, DC
Meggers, W. F., Corliss, C. J., & Scribner, B. F. 1975, Tables of Spectral-Line Intensity, NBS Monograph 145, US Government Printing Office, Washington, DC - good especially for singly-ionized rare earth elements

Supplementary sources - see Adelman, S. J. 2001, PASP, 113, 344 and earlier papers in this series. A pdf file is supplied on the CD. To see which ones are often used look at papers by Adelman and collaborators - in MNRAS and A&A. These are typically those for

(! = supplements Moore 1945)

P II (Svendenius N., Magnusson C. E., & Zetterberg P. O. 1983, Phys. Scripta, 27,339)
S II (Pettersson J. E., 1983, Phys. Scripta, 28, 421)
Ti II (! Huldt S., Johansson S., Litzen U., & Wyart J.-F., 1982, Phys. Scripta, 25, 401, expect a new revision in about a year in Phys. Scripta)
Mn I (! Catalan M. A, Meggers W. F., & Garcia-Riquelme O. 1964, J. Res. NBS, 68A, 9)
Mn II (Iglesias L. & Velasco R., 1964, Publ. Inst. Opt. Madrid, No. 23)
Fe I (! Nave G., Johansson S., & Learner R. C. M., Thorne A. P., Brault J. W., 1994, ApJS, 94, 221)
Fe II (Johansson S., 1978, Phys. Scripta, 18, 217 supplements RMT shortward of 4800 Å, longward replaces it)
(also Dworetsky M. M., 1971, Ph. D. thesis, University of California at Angeles; Guthrie B. N. G., 1985, MNRAS, 216, 1; and Adelman S. J., 1987, PASP, 99, 515)
Ga II (Isberg B. & Litzen U., 1985. Phys. Scripta, 31, 533)

If you have strong singly-ionized rare earth lines then you should look at the references for the doubly ionized rare earths.

There is a pdf file of finding list for Moore's newer multiplet table sections included on CD. (O II published after her death was not - see also Moore, C. E., edited by Gallagher, J. W. 1993, Tables of Hydrogen, Carbon, Nitrogen, and Oxygen Atoms and Ions, CRC Press, Boca Raton, FL {does not include Si revisions})

stellar - excellent but older source: Wright, K. O., Lee, E. K., Jacobson, T. V. & Greenstein, J. L. 1964, Pub. DAO, XII, 173

- Good examples are scarce in the literature, although they have to be done for complete elemental abundance studies. On the CCD, I have included line lists for several sharp-lined stars: HD 109995 and HD 161871, A type field Horizontal Branch stars, phi Her a HgMn star, o Peg a hot Am prototype, gamma Peg a B2 IV star, and sigma Boo a F2 V star. If you use them, please reference the published paper based on or containing them.

- Gulliver is currently putting Berahitdin Albayrak's line identification study of Deneb on an internet site at Brandon University. It will also include the spectrum. A preliminary line identification list is on the CD. The final version will cover additional spectral regions. A mirror site is planned at Ankara University. There will be other spectra and line identifications available for S/N = 80 studies based on photographic plates. Eventually higher S/N studies will be posted. This is a major project as the line identifications need to be checked against the original sources including ones published subsequently to when these studies were completed.

  I have made line lists and spectra of published studies available to various astronomers for specific purposes other than those I have had or planned. I will continue this practice in the future. When I have collaborators their approval is also needed.

Some Thoughts on How to Perform Line Identifications

1. Use REDUCE/VLINE to measure the spectra. Remove duplicate measures as well as those which are very weak or too narrow. (The line list can latter be pruned again. Problem regions can also be remeasured.) Use Program REF with concatenated REDUCE.OUT type files to produce a simpler output.

```
C PROGRAM REF TO REFORMAT REDUCE.OUT FILES
    3 READ(5,1,END=99)W,WL,DF,FW
    1 FORMAT(11X,F8.3,42X,F5.1,7X,F5.3,1X,F5.2)
```

```
      WRITE(6,2)W,WL,DF,FW
    2 FORMAT(2X,F8.3,2X,F5.1,2X,F5.3,1X,F5.2)
      GO TO 3
   99 CONTINUE
      END
```

2. For each spectrum identify some strong and symmetric medium strength lines to derive a provisional radial velocity. Use studies of stars of similar spectral type for guidance. I try to find Fe I and Fe II lines as well as those of species with no systematic shifts relative to them.

3. Transform the stellar wavelengths to the laboratory frame. (Program RVF can be used.)

```
C PROGRAM RVF TO ADD RADIAL VELOCITY TO REFORMATTED REDUCE.OUT FILES
      READ(5,1)RV
    1 FORMAT(1X,F9.3)
    3 READ(5,2,END=99)C,W,WL,DF,FW
    2 FORMAT(1X,A1,F8.3,2X,F5.1,2X,F5.3,1X,F5.2)
      RVN=1.0-(RV/3.0E+05)
      WLN=W*RVN
      WRITE(6,4)C,W,WL,DF,FW,WLN
    4 FORMAT(1X,A1,F8.3,2X,F5.1,2X,F5.3,1X,F5.2,2X,F8.3)
      GO TO 3
   99 CONTINUE
      END
```

4. One can perform a wavelength coincidence statistics study (see work by Charles R. Cowley) and/or look at line lists of similar type stars to get a list of candidate species.

5. Use the RMT (Revised Multiplet Table) to attempt individual identifications of other lines.
   a. Most identifications should be head on, that is the stellar and laboratory wavelengths should closely agree.
   b. Use the the widths of lines and stellar plots as guides for how far from the central wavelengths one should accept identifications.
   c. Identification lists of similar type stars are very useful.
   d. For a given species expect to see lines as weak as some lower intensity limit and the equivalent widths should roughly correlate with intensity for non-blended lines. Note that the intensity scales can be problematic over long wavelength intervals.
   e. In multiplets the relative line strengths are often correctly given in the RMT.

6. Use the supplemental sources to the RMT to extend the identifications especially Reader & Corliss, Meggers et al., and those more recent sources

used by Adelman and collaborators.

7. Also check for the strongest lines of other species with ionization potentials similar to those of species with known lines. You can crudely predict their equivalent widths by scaling using the solar abundances. If you find a few good identifications for a species, add it to the list of candidate species.

8. Make the identifications as consistent as possible.
   a. Determine approximate intensity ranges for each species for present lines, possibly present lines, and absent lines. These may be somewhat wavelength or excitation potential dependent. Examining multiplets may be useful.
   b. Characterize each candidate species as to whether it has many lines present, some lines, or only a few and note whether each has its strongest expected lines present. (Do this as you do 8a)
   c. Check and refine the line identification list source or spectra by spectra. Replace RMT wavelengths and intensities with those of newer supplemental sources. (This may be done in step 6). Keep notes describing what you have done. These should accompany the line list if and when it is published.

Sources of atomic data

gf values and damping constants:

NIST (NBS) - also bibliographies and publications
http://physics.nist.gov/PhysRefData/

VALD http://www.astro.univie.ac.at/~vald/ or
http://www.astro.uu.se/~vald/

Kurucz's website and CDs - http://cfaku5.harvard.edu

Model atmosphere codes:

LTE

ATLAS9 - early B to G - Kurucz - also ATLAS12 which permits non-solar scaled chemical compositions

Uppsala group - MARCS B. Gustaffson and colleagues - solar type stars

NLTE

TLUSTY - Hubeny and Lanz http://tlusty.gsfc.nasa.gov

PHOENIX - Hauschildt and associates
http://phoenix.physast.uga.edu/

The literature has references to other codes.

I prefer to derive effective temperature and surface gravity by comparison of optical region spectrophotometry and H-gamma profiles with theoretical model predictions. In the course of the analysis, I made adjustments for non-solar metallicities and for microturbulence. But for many stars, such data is not available, so I have to derive these values from photometry. For Strömgren and Hβ photometry see Napiwotzki R., Schönberner D., Wenske V., 1993, A&A 268, 653

Some comments about convection theories.

Mixing Length Theory is often used, but it has an adjustable parameter α which has to be specified. This is a heuristic theory, which is somewhat unsatisfactory. Fritz Kupka has advocated using Canuto-Mazzitelli theory which has no adjustable parameters. In the literature, there are suggestions that this is a better way to proceed, but it does not include overshooting. Fritz has made available a subroutine to use for ATLAS9. There are no observable differences between models with effective temperatures greater than about 8000 K. This boundary is surface gravity dependent and probably also depends on metallicity.

References:

Canuto V. M., Mazzitelli I., 1991, ApJ, 370, 295
Canuto V. M., Mazzitelli I., 1992, ApJ, 389, 724
Castelli F., Gratton R, G., Kurucz R. L., 1997, A&A, 318, 841
Smalley B., Kupka F., 1997, A&A 328, 349

Solar Abundances

Grevesse N., Noels A., Sauval A. J., 1996, in Cosmic Abundances, eds. S. Holt & G. Sonneborn (San Francisco, Astron. Soc. Pacific), ASP Conf. Series, 99, p. 117

Lecture 4b: The extraction of classical coude spectra including optimal techniques as implemented in Program CCD by Gulliver and Hill. Comparison with 2DI.

I use program CCD by Gulliver and Hill as implemented on OPENVMS Alpha systems. I contributed some of the ideas used to construct it based on my experience with the IUE Final Archives Committee. There I learned about optimal extraction techniques which were applied to 1-d and echelle spectra.

Program CCD is quite complex and the analysis of CCD images can be difficult. However most difficulties can be avoided by making sure the spectrograph is set up properly and that the observations are made in a consistent and adequate way; e.g. a minimum of 10 consecutive bias and lamp frames, regular arcs bounding the stellar observations and a properly cooled and aligned detector. X is the direction of the spectrum's wavelength. Y is perpendicular to it in what follows.

Program CCD reduces spectroscopic CCD observations to 1-D FITS files suitable for use with REDUCE or IRAF. The optimal extraction algorithm is based on Keith Horne's work at the Space Telescope Science Institute. For a successful reduction the observer needs to have made 2 groups of 10 consecutive biases (0 sec integrations) and lamp observations (start and end of night) so that the cosmic rays may be successfully removed from the adopted lamp and bias data. These results are stored as FITS files (Bias file prefixed with B; lamp with L). For coude work arc observations may be taken every few hours. Always care must be taken on the lamps and arcs to avoid saturation. One has to check the chip defects which are mainly in columns.

Given adequate observations, the reduction routine is simple and fast

1 Derive bias file
2 Derive mean lamp file
3 Determine the Y extent of the stellar image
4 Derive cross-section of stellar image (lamp with image-slicer) normal to the dispersion. Check to see that the derived Y extent of the spectrum is reliable.
5 Use cross-section (measure in Y) to see if spectrum is straight. Straighten if desired (now becoming possible)
6 Extract 1-D spectrum
7 Plot extracted 1-D spectrum

Cosmic rays are the bane of CCDs (and Reticons). The nice thing about CCDs is that the cosmic rays can be detected - at least the strong ones. Program CCD deals with them in differing ways:

1. For calibration data - mean biases and lamps - one performs an average where the extrema in each bin (X-Y position) are removed before the average is taken.
2. For arcs no cosmic ray extraction is performed.
3. For the darks the cosmic rays are removed by fitting a spline to the darks summed by DARK_LIMITS. Fifty of the largest extrema are removed and the fit repeated. The darks are then linearly interpolated under the extracted spectra. The spline fits may also be plotted.
4. In program stars the cosmic rays are detected by the data excursions above the surrounding points and then a 2-D Gaussian is fitted and data interpolated. Two passes are made because a cosmic ray may splash diagonally across the chip. We resorted to fitting the functions because Horne's algorithm which uses the known cross-section of a stellar image to detect deformations of the shape in presence of cosmic rays fails to

conserve the S/N in high S/N data. The removal of cosmic rays is a black art and hence some KEYWORDS which control the detecting and fitting are included . The cosmic ray results are presented in 2-D - by default the interpolated values are given but the cosmic ray may be examined by the looking at the raw values normalized to the background.

To reduce the read noise, one often superpixellates or reads several pixels, 2 to in the Y direction at once. This makes the removal of cosmic rays more difficult. Superpixellation also reduces the read time of the chip.

While a CCD may be able to be set up to avoid bad rows, if there are bad columns present these cannot be avoided; e.g. the SITE-2 chip has 3 bad columns in position 1087,1397 and 1398. The best one can do is to linearly interpolate across the bad columns. Similarly, if you cannot avoid the presence of bad rows then CCD allows you to linearly interpolate across them.

Occasionally you will see a data drop (one column) that appears on one frame and no other. The cosmic ray algorithm will not remove this effect, but you can use the BAD_COLUMNS command to correct the single image.

Observing with an image-slicer creates its own difficulties. Normalizing by the lamp for example. A simple division by the mean lamp will result in a divide by zero error for the unexposed part of the spectrum. For that reason sometimes the program will demand the Y limits of the spectrum before it will proceed. Once you have defined a digital profile the Y extremes will be determined though they still should be checked. Also at the edges of the image-slicer the intensity is quite low and so a division should be as accurate as possible. Hence the importance of getting many well-exposed lamps.

When you take a cross-section through a stellar image the effect of the image-slicer is readily seen at the peak of the image - a dip is there caused by the obscuration of the secondary.

By looking at the data in the Y direction one can remove the effects of the dark and scattering from the observations. In a properly cooled CCD the dark will be much less than that from scattered light which is ~3% of mean intensity. The dark is defined by the mean intensity at the edges of the CCD in the Y direction and then linearly interpolated through the image and subtracted The darks are removed from the data by fitting a spline (L2FRES) to the average of the two groups of rows used to define the darks.

Program CCD follows the conventions established in REDUCE and RET72 where by establishing a wavelength with a pixel number in the arc file, one can simplify later reductions. This information is transmitted to CCD through a KEYWORD LAMPIX or measured.

Program CCD operates with a combination of keywords and cursor commands. In general the cursor commands are used when you are checking a night's observing prior to reducing it. After each pass through the program all of the commands you have given to CCD are switched off - except for lamp normalizing, dark limits and spatial file information. Otherwise you would be left with a maze of repetitions. There is a KEYWORD trap that checks spelling but it only works if you have one keyword per line. KEYWORDS are bounded by blanks. There is also a keyword spelling checker resident in CCD. Keywords provide instructions to the program.

CCD is designed to run with the minimum of interaction (Automatic mode) or with varying amounts of interaction. There are always circumstances which hinder smooth operations:

1 Inadequate observations - too few biases or lamps
2 Saturated images - lamps or arcs in particular
3 Long exposures and weak images hence larger numbers of cosmic rays
4 Use of a detector which is warming up
5 Scrambled header information caused by -- whatever

A record of the operations and results are contained in the file CCD48.OUT or CCD72.OUT. The operations performed on a file are also noted in the FITS output headers. At its best CCD will run automatically using a minimum of keystrokes. At its worst the user will have moved down paths never used and Gulliver will be forced to modify the software or otherwise intervene to make Program CCD work. A night's observing on the 1.2-m might take 10-15 minutes to reduce using a DEC alpha; yielding 1-D FITS files and plots of the results.

For the optimal extraction algorithm to work: straightening, weighting, dark and cosmic ray removal, there must be about 15-20 pixels through the stellar image. Ideally a third of the Y extent should be star. If the Y data are compressed into super-pixels to reduce the effects of read-noise then you will have lost the other options noted above. The 1-D extraction can take place with the uncomplicated Reticon extraction. Make sure that the electronic gates are arranged to miss any chip defects along the rows. You will may not be able to avoid defects in the columns. These defects are handled by linear interpolation. The user will have to note the wavelength associated with the column defects when analyzing the data. CCD automatically corrects the bad columns in the SITE2 chip but you should still know where the data have been interpolated.

Lecture 5b: Instrumental Profiles and Scattered Light: with comments by Bikmaev

Instrumental Profile/ Scattered Light - based on Gulliver, Hill, and Adelman (1996, in Model Atmospheres, ASP Conference Series, Vol. 108, p.232)

Note to obtain instrumental profile want spectrograph well focused. Most spectrographs have focal planes which are slightly curved. But CCDs are often flat so the focus will be a compromise using lines midway between the center and edge. Alternatives for long CCDs are to use a field flattening lens or bend them.

Today the instrumental profile is often found with a laser whose width is much smaller than produced by the instrument.

The projected slit width is order independent, but the ghosts due to ruling errors go as the order squared. If the grating has 2 or more periodic errors then interference will occur with systems of ghosts far from their parent lines. The instrumental profile can also be slightly affected by the projection factor of the entrance slit and transmission optics. This is why it is a good idea to measure the instrumental profile at several wavelengths using a tunable laser.

Scattered light is due to some of the photons of each wavelength not going where the optical designer intended. There are two components one random and the other along the direction of dispersion. The random component is usually removed satisfactorily when one measures the background far from the spectrum. The other component is much more difficult. Scattered light is due to optical imperfections, dust in the air or optical surfaces, and/or diffraction due to instrumental aperture.

Ideally one wants to measure the instrumental profile in a wavelength interval comparable with the spectral bandpass of the system. This is usually not possible. The cumulative effect of the very weak instrumental profile wings and the spectrum of the star is significant. Murray Fletcher told me that a classical coude spectrograph with clean optical surfaces has scattered light whose intensity is about 4% of the continuum level. It is an integral involving the spectral responses of the instrument and detector, losses in the Earth's atmosphere, any filters, the stellar flux, and other factors. It is clearly wavelength dependent. Alexander Boyarchuk pointed out that it is modulated by strong Balmer lines in middle B to late A stars.

One tries to mean the instrumental profile with a source which has intrinsically narrow lines. One can use, for example, the arc lines to measure the center of the instrumental profile. But it is desirable to have values far from the profile center. To do this one can use a laser, but as lasers produce polarized light, one has to depolarize their radiation. As hallation occurs in CCDs, as in Reticons and photographic plates, the detector has to measure the central region. This limits the exposure times. But one can coadd to get the wings.

A classic study was done by Griffin in the Arcturus Atlas (Griffin, R. E. 1968, A Photometric Atlas of the Spectrum of Arcturus lambda lambda 3600-8825) with photographic plates.

A final point is the comparison of spectra of the same star and spectral region taken with different instruments. It is well known that in comparing equivalent widths derived from spectra using photographic emulsions that there can be large differences of 50% or more. But in the era of electronic detectors the discrepancies should be much smaller. If one is measuring equivalent widths, the discrepancies are likely due to differences in the removal of scattered light, in how the continuum level was set, and in the assumed form for the line profile. For blended lines how the blends were removed is also important.

An alternative is to overlay spectra so that one can compare the line profiles. If the spectra have different resolutions, one might have to account for the differences in the instrumental profiles. If the spectra have comparable resolutions, the agreement should be well within 5% in total equivalent width for unblended lines if the scattered light removal is the same and the continuum similarly placed.

Lecture 6: Presentation and Demonstration of Graham Hill's software for measuring one-dimension spectra

Please realize that I use Graham Hill's and Bob Kurucz's codes on a DEC STATION 3000 Model 330X running OPENVMS. This is the standard platform for both sets of programs. Graham's programs use Tektronix graphics in this form. I am not as proficient in using these programs on other platforms. I will discuss in particular Graham's programs which have been ported to WINDOWS by Austin Gulliver and his associates, especially David Holmgren. PGPLOT, which is freeware available from Caltech, has been used as the plotting program in part as it is available for many platforms. I will note a few related programs which can and probably should be ported to WINDOWS.

Of Graham Hill's programs - four: PLOTFITS, REDUCE, VLINE, and VCROSS

- now available using WINDOWS have been converted to run using Digital (Compaq) Visual FORTRAN (DVF) and PGPLOT. These all work with 1-dimensional spectra as they were intended for use with coude type spectra. They will work on individual orders of echelle spectra when one order is in a file. I think this is due to its fits reader. If and when CCD can reduce an echelle spectrum, these programs may be modified to work on multiple orders.

One needs to use DVF as these programs use many VAX Digital extensions. The WINDOWS versions are provided as executables so one does not need to purchase DVF. One needs DVF only to modify these codes. This is not a straight forward proposition. The only person other than Graham who understands all of them at present is Austin.

These programs all use fits files (.fts). I particularly like that fits headers retain a history of the file so that I can see what was done to them.

A fits file has one or more header blocks and the data follows in binary. There are now some alternative choices as to how the data is specified. This increase in choice including how many header blocks and data format can cause problems for reader programs of fits data. Another problem is that your reader has to understand the key words. There is a standards committee which tries to keep things in check. But when new standards are adopted, the readers and writers of fits need to be updated.

Graham has established some naming conventions. Those of relevance for 1-d spectra are:

F….fts files are exposures of arcs
S….fts files are exposures of spectra
W….fts files are wavelength calibrated spectra
R….fts files are normalized or rectified W files

At the Dominion Astrophysical Observatory the files produced by CCD detectors use the prefix C followed by the telescope diameter in cm, then an _, the last two digits of the year, then another _, and the sequence number for the year.

So C122_01_5934.fts is the 5934 th recorded exposure in 2001 at the 1.22-m (48") telescope and C182_99_13453 is the 13453 rd recorded exposure in 1999 at the 1.86-m (72") telescope

One of Graham's programs VSUN which determines the heliocentric corrections to the radial velocities has been combined with CCD which I discussed previously so that in the output file these values are available for the correction of the wavelength scale.

TSTACK is the next of these programs to be converted. It permits one to add or coadd spectra together to increase the resultant S/N (signal-to-noise) ratio. One needs the common wavelength interval, the radial velocities relative to one of the spectra taken as the order, the weights, and the output wavelength interval. There is no set convention to naming the output files. I have tended to use an A as the prefix. One can use either rectified or unrectified spectra. The weights are usually taken to be proportional to the square of the S/N of the individual spectra.

Here is a file known as ADENEB4630.STK

The STK suffix is needed for TSTACK to recognize the master file.

```
'R122_98_8741.fts'  0.06 'P' 0.7 4597.56 4659.40 0.02 ' ' 999 0 0 1
'R122_98_8743.fts' -0.12 'G' 0.5 4597.56 4659.40 0.02 ' ' 999 0 0 1
'R122_98_8747.fts' -0.32 'G' 1.2 4597.56 4659.40 0.02 ' ' 999 0 0 1
'R48901735.FTS'    -6.48 'G' 0.7 4597.56 4659.40 0.02 ' ' 999 0 0 1
'R122_98_8745.FTS'  0.0  'G' 2. 4597.56 4659.40 0.02 'Adeneb4630.FTS' 0 600 0 1
'END'/

 name            rv    weight  wavelength  Delta
                                range     wavelength
```

The first file has a 'P' as it is the one used as a template. The last full line contains the name of the output file. There are many switches set which were relevant when it output spectra on a Calcomp plotter.

When this program becomes available using WINDOWS instruction will be made available as part of its distribution.

PLOTFITS is a program to plot FITS files. It can plot all or part of a 1-d spectrum. The normal Y range is from 0 to the maximum intensity or from minimum to maximum intensity. There are a variety of options that can be used. It was original written for Tektronix graphics.

Austin Gulliver has written a program to overplot two spectra which is based on plotfits known as OVERPLOT

```
c                Program to plot up to 3 spectra (or ratios or sums
c                thereof) on the same graph with different symbols
c                and variable offsets.
c                Each spectrum is scaled between 0 and 1 for plotting
c
c       Parameters:
c         Observed spectra P(m,n_pixels) where n_pixels is the number of
```

```
c                               spectral elements and m is the number of
c                               observations shifted to correspond to zero
c                               primary RV
c          Measured velocities RV(m)
c          Min and max wavelengths are: W_low and W_hi
c          Wavelength increment is W_del
c          n_pixels is (W_hi - W_lo)/W_del + 1
c          Number of data points n is (W_hi - W_lo)/W_del + 1
```

VCROSS is a program which uses wavelength-linearized and rectified data over a restricted wavelength range or a ln lambda linearized scale or measure radial velocity differences between stars by cross-correlated one stellar spectrum with another. The choice of reference standard is arbitrary.

Rectification is very important as the sharpness of the resultant cross-correlation function is vitally dependent on the presence of trends in the continuum. Each end of the spectrum is tapered by a cosine bell function and affects one-twelfth of end end of the Fourier transform and results in a sharper cross correlation function peak and a reduction of the background.

Once the cross correlation function is displayed the velocity measurement can be made by

1) fitting a parabola to the peak
2) fit a Gaussian or Lorentzian to the profile
3) fit a number of Gaussian or Lorentzian profiles to the data

REDUCE is a spectrophotometric reduction and analysis program intended to generate intensity-rectified spectra, leading to the measurement of radial velocities, equivalent widths, and the apparent rotational velocity. It is written in FORTRAN 77 in modular form so that a series of logically chosen operations may be performed on spectral data.

REDUCE allowed the measurement of arcs, intensity calibrations, clear plate, the definition of filters as the processing of the resulting filtered intensity data to rectified intensity. Rather than passing through all of the steps while the data are in core memory, the various functions or operational options are linked by a disk read/write program in fits format which enables the user to store intermediate results in a condensed, quickly readable form. Those functions which were applicable to obsolete equipment or to photographic plates but not digitized electronic images have been disabled. Each function is linked to an index. The user enters these indices in order, to create a sequence of operations that can be repeated indefinitely on different data. This sequence can be altered by using the command system. There are a few constraints, the most notable is that the data has to be read first before it can be processed. Measuring equivalent widths is not recommended until a spectrum has been rectified.,

* = obsolescent, probably not working
\+ = I do not use

```
Index   Function

 3       Read data from FITS disk files
 4       Measure arc
 5       Read known arc coefficients
 6   *   Measure clear -  plates
 7   *   Read known clear - plates
 8   *   Measure calibration - plates DAO system
 9   *   Read known calibration file
10   +   Create filter
11   +   Filter given file
12       Linearize stellar wavelength file
13       Read processed data on disk
14   *   Perform density to intensity conversion - plates
15       Measure continuum and then rectify spectrum
16       Measure stellar spectrum - VLINE  (use as stand alone program)
17   +   Measure stellar spectrum - VELMEAS (rv only)
18   +   Measure stellar spectrum - VLINESUM (rv only)
19       Convert linearized file to ln lambda file
```

My uses are: 3 & 4 to measure the arc file produces and *.arc file
3,5 & 12 to create wavelength calibrated stellar spectrum
13 & 15 to create a rectified spectrum

Instead of 13 & 16, I use VLINE as a stand alone program

I will demonstrate rectifying the stellar spectrum as well as VLINE in detail as these are most useful to this audience.

VLINE is an interactive program which enables the users to measure for each lines wavelength, equivalent width, full width half maximum, and v sin i in wavelength-calibrated rectified or unrectified intensity spectra by simultaneously fitting mixtures of up to 12 Gaussian, Lorentzian, rotation, or standard (digital) profiles and a linear continuum to selected lengths of spectra. One can study double-lined spectroscopic binaries or deconvolve moderately blended features. One can fix the separation between a pair of unresolved profiles to deconvolve more severely blended features or fix the FWHM or depth. Alternatively one may bypass the profile fitting measuring only the continuum and then measure equivalent widths by integrating areas between the adopted continuum and the spectrum.

VLINE line uses CURFIT (Bevington, P. R. 1969, Data Reduction and Error Analysis for the Physical Sciences (McGraw-Hill: New York)){there is a second edition by Bevington and D. K. Robinson 1992} to derive a composite function with a maximum of 38 unknown. CURFIT needs starting estimates which the user provides by using the cursor option on the graphics terminal. This kind of program can have problems due to the user's input as it can fail in the matrix inversion if poor starting values are given.

VLINE can be used in Mode 1: A list of lines can be used to direct VLINE which is somewhat dangerous or Mode 2: Here one steps through the spectrum record by record generally beginning at the lowest wavelength. By default the initial length of the data stream is 901 points, but it can be changed.

The measuring process is straightforward, but time-consuming as CURFIT requires staring values of the function parameters: mean position of the central wavelengths, FWHMs, and line depths and of the linear continuum-level. These values are directed to VLINE by cursor placements. A continuum level is set on the first (CL) and last (CR) placements and each line profile is defined by 3 settings: left half-width LH, center and depth CD, and right half-width RH). For one line the order of cursor placements is CL, LH, CD, RH, and CR. For more than one line the sequence of measures is CL, (LH, CD, RH), (LH, CD, RH), ..., CR. The central wavelength and FWHM values come directly from the encoded X positions, The continuum height and slope are derived from the encoded X positions and the intensity value of the data nearest the cursor (but these can also be defined with the cursor). The line depth is measured with reference to this continuum level and the intensity value of the data point nearest the central cursor measure. The line depth can also be defined by the cursor. So the starting values come from mixtures of encoded positions and the intensity of the data points nearest the cursor.

CURFIT can tolerate poor starting values, but care is required to deal with weak lines in strong line wings. Here the continuum of the weak line is basically that of the profile of the strong line. The initial value of the depth must be encoded from a Y placement of the cursor. Fairly good starting values result in a speedier and more reliable convergence in CURFIT.

Once CURFIT has converged the resultant function is graphed through the data so one can gauge the adequacy of the fit. For each line this process results in a central wavelength, depth, FWHM (or v sin i), and a theoretical equivalent width based on the function parameters and the continuum height. One can choose to integrate both the data and the fitted curve between cursor-defined bounds and the continuum. So three equivalent widths can be generated for each line.

For some stars, the weakest lines will have rotational profiles, stronger lines Gaussian profiles, and the strongest (and He I) lines Lorentzian profiles. This is due to the convolution of the stellar and instrumental profiles. If finds a star with weak lines having rotational profiles and stronger lines Gaussian profiles, provided one is working on a limited wavelength range, there should be a well defined cross-over region.

VLINE Step Summary
1. Select and read the appropriate wavelength file
2. Assign a line list file if one wants to directly derive radial velocity (I do not do this.)
3. Assign an output file to store the results (can use default name)
4. Here the data are displayed, edited, and fitted with a composite function to yield the central wavelength, full width at half maximum, and equivalent width for each line.

Lecture 7: Kurucz's LTE Model Atmosphere Codes

At the present time Kurucz's suite of programs has been optimized to run on OPENVMS Alpha computers. These codes are available for use on many other platforms. They work well for many types of stars as long as plane parallel model atmospheres with LTE physics is appropriate This is from middle B through the G stars and maybe a little hotter or cooler depending with whom one speaks and is somewhat dependent on how one is analyzing the star. So for example, one can use these atmospheres to study photospheric lines in A supergiants provided one carefully selects the stellar parameters. There are also certain lines in B through G stars, which although LTE atmospheres are reasonable approximations, require Non-LTE physics.

The major programs of interest are: ATLAS9 the model atmospheres code, WIDTH9 the code to convert equivalent widths to abundances, and SYNTHE (written with Avrett) which is the spectrum synthesis code. There is also BALMER9 (written originally by D. Peterson) which calculates the profiles of the four strongest Balmer lines: Hα, Hβ, Hγ, and Hδ. For many years when I worked with photographic plates, I used this code extensively. But now I use SYNTHE to calculate a synthetic spectra of the H-gamma region for comparison with observations.

There is also ATLAS12 which permits one to have an atmosphere with a composition other a scaled solar composition.

The He I lines are not properly calculated by SYNTHE. Fiorella Castelli has an Atlas compatible program which will do this. I use program in the TLUSTY suite of codes by Hubeny, called SYNSPEC, for this purpose. TLUSTY is a complete NLTE physics code. Another alternative is PHOENIX.

Kurucz's internet site: http://cfaku5.harvard.edu contains lots of data and programs

ATLAS9

Kurucz R. L. 1970, SAO Special Report No. 309 - basic program

Kurucz R. L. 1979, ApJS 40, 1

Kurucz R. L., 1993a, ATLAS9 Stellar Atmosphere Programs and 2 km/s grid, Kurucz CD-Rom No. 13, Smithsonian Astrophysical Observatory, Cambridge

Kurucz R. L., 1993b, in Peculiar Versus Normal Phenomena in A-Type and Related stars, Astron. Soc. Pacific Conference Series 44, p. 87

ATLAS calculates model stellar atmospheres in radiative and convective equilibrium for the complete range of stellar temperatures. The approximations used limit the program to plane-parallel, horizontally-homogeneous, steady-state, non-moving atmospheres with energy and abundances constant with depth. The programs allow detailed statistical equilibrium calculations, but only hydrogen continuum and H- are coded at present. Current versions use statistical opacity distribution functions to represent the opacities of atomic lines.

Models are calculated with coarse and fine odfs (A and F models). Models are named a or f, then p or m (plus and minus, respectively) and a number corresponding to 10 times log Z relative to the sun, the temperature in K, g, 10 times log g, k, and the microturbulence in km/s. p00 corresponds to a solar composition model while m10 to one with 0.10 solar metals.

calculating a coarse grid model

apnew2a.com

```
$set def dka100:[adelmans.atlas9]
$ASSIGN dka100:[adelmans.atlas9]KAPP00.ROSS FOR001
$ASSIGN P00BIG2.bdf FOR009
$ASSIGN SYS$INPUT FOR005
$ASSIGN fp00t9000g400K2.DAT FOR003
$ASSIGN ap00T9288g410K2.NEW FOR007
$RUN DKA100:[ADELMANS.ATLAS9.P10]ATLAS9MEM
READ PUNCH
VTURB 2.E5
ITERATIONS 15
```

```
PRINT 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
PUNCH 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
FREQUENCIES 337 81 337 BIG
SCALE 64 -5.875 .125 9288 4.10
BEGIN
ITERATIONS 15
PRINT 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
PUNCH 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
SCALE 64 -5.875 .125 9288 4.10
BEGIN
END
```

Now to calculate a fine grid model

fpnew2a.com

```
$set def dka100:[adelmans.atlas9]
$ASSIGN P00LIT2.bdf FOR009
$ASSIGN SYS$INPUT FOR005
$ASSIGN fp00t9288g410k2.DAT FOR003
$ASSIGN Fp00T9288g410k2.new FOR007
$assign temps.out for006
$ASSIGN FLUXES.OUT FOR016
$RUN ATLAS9vF
FREQUENCIES 1221 81 1221 LITTLE
ITERATIONS 15
PRINT 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
PUNCH 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
READ PUNCH
BEGIN
ITERATIONS 15
PRINT 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
PUNCH 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
BEGIN
ITERATIONS 15
PRINT 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
PUNCH 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
BEGIN
ITERATIONS 15
PRINT 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
PUNCH 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
BEGIN
END
```

The trick is to get the models to converge to 1% in flux and in flux derivative with the first task being much easier than the second. For many possible models ATLAS converges on its own. But for others it needs some help which means one needs to do some adjustment of the temperature scale and see what happens.

Kurucz provides extensive grids of models. Many other astronomers have their own grids including Gulliver and myself. Often one can get a model from one of these individuals. If you do ask about its convergence properties.

WIDTH9
Kurucz R. L., 1993, ATLAS9 Stellar Atmosphere Programs and 2 km/s grid, Kurucz CD-Rom No. 13, Smithsonian Astrophysical Observatory, Cambridge

WIDTH9 is Kurucz's code to derive abundances from equilvalent widths. One needs a model atmosphere as well as atomic data for each line.

nfe1gs.com

```
$SET VERIFY
$SET DEF dka600:[ADELMANS.width9]
$ASSIGN NFE1gs.DAT FOR005
$ASSIGN NFE1gs.OUT FOR006
$RUN WIDTH9
```

nfe1gs.dat

One can do the calculations for 1 to 3 microturbulences. Lines contained between pairs of AVER lines result in useful plots, averages, standard deviations of mean abundances, and calculations of trends.

For each line one includes on line 1 the equivalent width in pm, the wavelength in nm, and a stellar label with an optional label, on line 2 the wavelength in nm, the log gf value, lower J, lower energy level in inverse cm, upper J, upper energy level in inverse cm, and a species identification in the form Z.x where Z is the atomic number and X the state of ionization with 00 meaning neutral and 01 singly ionized, etc.; on line 3 the wavelength in nm, the species number (z-1) times 6 + 1 + X, the logs of the radiative, Stark, and van der Waals damping constants (if not specified classical damping is used).

```
VTUR
    3  0.0  1.0  2.0
AVER
LINE      6.48  391.448  gamser     Mult    3
  391.450  -4.05   2.5   13474.411  1.5   39013.206    26.01
  391.450  152  8.46 -6.73 -8.01  MF
LINE      2.01  398.161  gamser     Mult    3
  398.161  -5.05   0.5   13904.824  1.5   39013.206    26.01
  398.161  152  8.46 -6.69 -7.92  KX
LINE      6.93  411.953  gamser     Mult   21
  411.953  -4.92   2.5   20516.960  2.5   44784.761    26.01
  411.953  152  8.61 -6.67 -7.88  KX
LINE      0.86  471.318  gamser     Mult   26
  471.318  -4.93   0.5   22409.852  1.5   43620.957    26.01
  471.318  152  8.49 -6.54 -7.91  KX
LINE      5.87  412.874  gamser     Mult   27
  412.874  -3.77   2.5   20830.582  1.5   45044.168    26.01
```

```
  412.874  152  8.61 -6.67 -7.95  MF
LINE      8.12  427.332  gamser     Mult   27
  427.332  -3.34   1.5   21812.055  0.5   45206.450    26.01
  427.332  152  8.62 -6.54 -7.88  MF
...
LINE     2.19   448.069  gamser     Mult    -
  448.069  -2.389  2.5   50212.826  1.5   72524.566    26.01
  448.069  152  8.65 -6.54 -7.90  KX
AVER
END
TEFF   6300.  GRAVITY 5.00000 LTE
TITLE ATLAS9 MODEL WITH SDSC solar OPACITY  VTURB 2 KM/S CM convection
  OPACITY IFOP 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 0 0 0 0 0
 CONVECTION ON   1.25 TURBULENCE OFF  0.00  0.00  0.00  0.00
ABUNDANCE SCALE   1.00000 ABUNDANCE CHANGE 1 0.91100 2 0.08900
 ABUNDANCE CHANGE  3 -10.88  4 -10.89  5  -9.44  6  -3.48  7  -3.99  8  -3.11
 ABUNDANCE CHANGE  9  -7.48 10  -3.95 11  -5.71 12  -4.46 13  -5.57 14  -4.49
 ABUNDANCE CHANGE 15  -6.59 16  -4.83 17  -6.54 18  -5.48 19  -6.82 20  -5.68
 ABUNDANCE CHANGE 21  -8.94 22  -7.05 23  -8.04 24  -6.37 25  -6.65 26  -4.52
 ABUNDANCE CHANGE 27  -7.12 28  -5.79 29  -7.83 30  -7.44 31  -9.16 32  -8.63
 ABUNDANCE CHANGE 33  -9.67 34  -8.69 35  -9.41 36  -8.81 37  -9.44 38  -9.14
 ABUNDANCE CHANGE 39  -9.80 40  -9.54 41 -10.62 42 -10.12 43 -20.00 44 -10.20
 ABUNDANCE CHANGE 45 -10.92 46 -10.35 47 -11.10 48 -10.18 49 -10.58 50 -10.04
 ABUNDANCE CHANGE 51 -11.04 52  -9.80 53 -10.53 54  -9.81 55 -10.92 56  -9.91
 ABUNDANCE CHANGE 57 -10.82 58 -10.49 59 -11.33 60 -10.54 61 -20.00 62 -11.04
 ABUNDANCE CHANGE 63 -11.53 64 -10.92 65 -11.94 66 -10.94 67 -11.78 68 -11.11
 ABUNDANCE CHANGE 69 -12.04 70 -10.96 71 -11.28 72 -11.16 73 -11.91 74 -10.93
 ABUNDANCE CHANGE 75 -11.77 76 -10.59 77 -10.69 78 -10.24 79 -11.03 80 -10.95
 ABUNDANCE CHANGE 81 -11.14 82 -10.19 83 -11.33 84 -20.00 85 -20.00 86 -20.00
 ABUNDANCE CHANGE 87 -20.00 88 -20.00 89 -20.00 90 -11.92 91 -20.00 92 -12.51
 ABUNDANCE CHANGE 93 -20.00 94 -20.00 95 -20.00 96 -20.00 97 -20.00 98 -20.00
 ABUNDANCE CHANGE 99 -20.00
READ DECK6 64 RHOX,T,P,XNE,ABROSS,ACCRAD,VTURB
 1.27820031E-03   4257.7 1.278E+02 2.230E+10 1.043E-03 1.513E-01 2.000E+05
 1.66050823E-03   4283.8 1.661E+02 2.864E+10 1.283E-03 1.616E-01 2.000E+05
 2.08074957E-03   4308.3 2.081E+02 3.555E+10 1.539E-03 1.670E-01 2.000E+05
 2.55189803E-03   4333.2 2.552E+02 4.324E+10 1.818E-03 1.698E-01 2.000E+05
 3.08647060E-03   4358.4 3.086E+02 5.191E+10 2.126E-03 1.708E-01 2.000E+05
 3.69846016E-03   4383.4 3.698E+02 6.177E+10 2.468E-03 1.728E-01 2.000E+05
 4.40317178E-03   4408.5 4.403E+02 7.305E+10 2.853E-03 1.746E-01 2.000E+05
 5.21761006E-03   4433.6 5.218E+02 8.602E+10 3.287E-03 1.762E-01 2.000E+05
 6.16121627E-03   4458.6 6.161E+02 1.009E+11 3.780E-03 1.776E-01 2.000E+05
 7.25643857E-03   4483.6 7.256E+02 1.182E+11 4.340E-03 1.792E-01 2.000E+05
 8.52928957E-03   4508.6 8.529E+02 1.381E+11 4.977E-03 1.810E-01 2.000E+05
 1.00099766E-02   4533.6 1.001E+03 1.611E+11 5.703E-03 1.832E-01 2.000E+05
 1.17339169E-02   4559.1 1.173E+03 1.877E+11 6.530E-03 1.864E-01 2.000E+05
 1.37419139E-02   4585.0 1.374E+03 2.186E+11 7.476E-03 1.907E-01 2.000E+05
 1.60811836E-02   4611.4 1.608E+03 2.544E+11 8.556E-03 1.957E-01 2.000E+05
 1.88073182E-02   4638.6 1.881E+03 2.960E+11 9.789E-03 2.008E-01 2.000E+05
 2.19851711E-02   4666.6 2.199E+03 3.444E+11 1.120E-02 2.059E-01 2.000E+05
 2.56903903E-02   4695.4 2.569E+03 4.006E+11 1.281E-02 2.109E-01 2.000E+05
 3.00106780E-02   4724.8 3.001E+03 4.661E+11 1.465E-02 2.160E-01 2.000E+05
 3.50484484E-02   4755.1 3.505E+03 5.423E+11 1.675E-02 2.218E-01 2.000E+05
 4.09222172E-02   4785.9 4.092E+03 6.309E+11 1.916E-02 2.284E-01 2.000E+05
 4.77674781E-02   4816.9 4.777E+03 7.339E+11 2.193E-02 2.368E-01 2.000E+05
 5.57436214E-02   4848.4 5.574E+03 8.537E+11 2.509E-02 2.459E-01 2.000E+05
 6.50393070E-02   4880.2 6.504E+03 9.932E+11 2.871E-02 2.557E-01 2.000E+05
 7.58744226E-02   4912.3 7.587E+03 1.155E+12 3.284E-02 2.665E-01 2.000E+05
 8.85058456E-02   4944.4 8.851E+03 1.344E+12 3.756E-02 2.786E-01 2.000E+05
 1.03232615E-01   4976.6 1.032E+04 1.564E+12 4.297E-02 2.926E-01 2.000E+05
 1.20396001E-01   5009.2 1.204E+04 1.819E+12 4.918E-02 3.098E-01 2.000E+05
 1.40380505E-01   5041.8 1.404E+04 2.116E+12 5.635E-02 3.318E-01 2.000E+05
```

```
 1.63637565E-01   5075.3 1.636E+04 2.463E+12 6.457E-02 3.563E-01 2.000E+05
 1.90710648E-01   5109.7 1.907E+04 2.866E+12 7.396E-02 3.834E-01 2.000E+05
 2.22231610E-01   5145.0 2.222E+04 3.339E+12 8.470E-02 4.138E-01 2.000E+05
 2.58938706E-01   5181.7 2.589E+04 3.891E+12 9.698E-02 4.478E-01 2.000E+05
 3.01688985E-01   5220.1 3.017E+04 4.540E+12 1.111E-01 4.865E-01 2.000E+05
 3.51418750E-01   5260.9 3.514E+04 5.310E+12 1.274E-01 5.328E-01 2.000E+05
 4.09166839E-01   5305.3 4.092E+04 6.228E+12 1.465E-01 5.871E-01 2.000E+05
 4.76115699E-01   5353.9 4.761E+04 7.329E+12 1.686E-01 6.500E-01 2.000E+05
 5.53482034E-01   5408.6 5.535E+04 8.675E+12 1.951E-01 7.281E-01 2.000E+05
 6.42426055E-01   5471.0 6.424E+04 1.035E+13 2.269E-01 8.211E-01 2.000E+05
 7.44174925E-01   5542.7 7.442E+04 1.247E+13 2.652E-01 9.312E-01 2.000E+05
 8.59805784E-01   5625.2 8.598E+04 1.524E+13 3.125E-01 1.065E+00 2.000E+05
 9.90033893E-01   5720.0 9.900E+04 1.897E+13 3.721E-01 1.231E+00 2.000E+05
 1.13407537E+00   5832.8 1.134E+05 2.427E+13 4.548E-01 1.475E+00 2.000E+05
 1.28914524E+00   5966.5 1.289E+05 3.214E+13 5.707E-01 1.816E+00 2.000E+05
 1.45188502E+00   6122.5 1.452E+05 4.424E+13 7.350E-01 2.294E+00 2.000E+05
 1.61693862E+00   6307.6 1.617E+05 6.387E+13 9.876E-01 3.042E+00 2.000E+05
 1.77759946E+00   6525.5 1.778E+05 9.680E+13 1.379E+00 4.200E+00 2.000E+05
 1.92769468E+00   6780.7 1.928E+05 1.537E+14 2.012E+00 6.081E+00 2.000E+05
 2.06206530E+00   7079.6 2.062E+05 2.548E+14 3.059E+00 9.186E+00 2.000E+05
 2.17746054E+00   7423.7 2.177E+05 4.353E+14 4.850E+00 1.452E+01 2.000E+05
 2.27242426E+00   7822.1 2.272E+05 7.639E+14 8.022E+00 2.398E+01 2.000E+05
 2.34765540E+00   8271.9 2.348E+05 1.350E+15 1.375E+01 4.131E+01 2.000E+05
 2.40435716E+00   8800.2 2.404E+05 2.437E+15 2.501E+01 7.541E+01 2.000E+05
 2.44495604E+00   9377.7 2.445E+05 4.284E+15 4.624E+01 1.209E+02 2.000E+05
 2.47667095E+00   9831.9 2.477E+05 6.351E+15 7.195E+01 1.238E+02 2.000E+05
 2.50647748E+00  10147.6 2.506E+05 8.166E+15 9.587E+01 1.069E+02 2.000E+05
 2.53706779E+00  10428.6 2.537E+05 1.007E+16 1.222E+02 9.121E+01 2.000E+05
 2.57018400E+00  10648.1 2.570E+05 1.176E+16 1.464E+02 7.701E+01 2.000E+05
 2.60720226E+00  10868.2 2.607E+05 1.365E+16 1.740E+02 6.673E+01 2.000E+05
 2.64954283E+00  11050.6 2.649E+05 1.538E+16 1.996E+02 5.651E+01 2.000E+05
 2.69868562E+00  11246.5 2.698E+05 1.740E+16 2.296E+02 4.933E+01 2.000E+05
 2.75652212E+00  11411.1 2.756E+05 1.927E+16 2.567E+02 4.164E+01 2.000E+05
 2.82516228E+00  11597.8 2.825E+05 2.154E+16 2.898E+02 3.625E+01 2.000E+05
 2.90730099E+00  11751.3 2.907E+05 2.364E+16 3.193E+02 3.159E+01 2.000E+05
PRADK 2.1061E+00
BEGIN                    ITERATION   3 COMPLETED
END
STOP
```

SYNTHE

Kurucz R. L., Avrett E. H., 1981, Smithsonian Astrophysical Observatory Report 391 (see also Kurucz, R. L., Furenlid, I. 1980, Smithsonian Astophysical Observatory Report, 387)

The spectrum calculations require a pre-existing model atmosphere. Quantities that need be computed only once for the model atmosphere are pretabulated. The model is read in. The continuum opacity is tabulated at wavelength points on both sides of every photoionization edge and throughout the Balmer and Paschen continua for later use in estimating the strengths of line wings relative to the continuum. The atomic and molecular number densities divided by partition functions are pretabulated for later use in Boltzmann equiations. Doppler velocities are also pretabulated for each atom and molecule with allowance for depth-dependent microturbulence.

xnpfsb.com

```
$set def dka100:[adelmans.synthe.xnfp]
$assign dka100:[gulliver.synthe] synthe:
$assign sys$output for006
$!  MODxxx IS INPUT ATMOSPHERE, XNFPxxx.DAT IS OUTPUT TABLE
$ASSIGN MODsb.DAT FOR005
$ASSIGN XNFPsb.DAT FOR010
$ASSIGN CONTINUA.DAT FOR017
$RUN synthe:XNFPELSYN
$exit
```

modsb.dat

```
SURFACE FLUX
SURFACE INTENSITY 1 1.
SURFACE INTENSI 17 1.,.9,.8,.7,.6,.5,.4,.3,.25,.2,.15,.125,.1,.075,.05,.025,.01
ITERATIONS 1 PRINT 2 PUNCH 2
CORRECTION OFF
TEFF   6800.  GRAVITY 4.00000 LTE
TITLE ATLAS9 MODEL WITH SDSC solar OPACITY  VTURB 2 KM/S L/H 1.25
 OPACITY IFOP 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 0 0 0 0 0
 CONVECTION ON   1.25 TURBULENCE OFF  0.00  0.00  0.00  0.00
ABUNDANCE SCALE   1.00000 ABUNDANCE CHANGE 1 0.91100 2 0.08900
 ABUNDANCE CHANGE  3 -10.88  4 -10.89  5  -9.44  6  -3.48  7  -3.99  8  -3.11
 ABUNDANCE CHANGE  9  -7.48 10  -3.95 11  -5.71 12  -4.46 13  -5.57 14  -4.49
 ABUNDANCE CHANGE 15  -6.59 16  -4.83 17  -6.54 18  -5.48 19  -6.82 20  -5.68
 ABUNDANCE CHANGE 21  -8.94 22  -7.05 23  -8.04 24  -6.37 25  -6.65 26  -4.52
 ABUNDANCE CHANGE 27  -7.12 28  -5.79 29  -7.83 30  -7.44 31  -9.16 32  -8.63
 ABUNDANCE CHANGE 33  -9.67 34  -8.69 35  -9.41 36  -8.81 37  -9.44 38  -9.14
 ABUNDANCE CHANGE 39  -9.80 40  -9.54 41 -10.62 42 -10.12 43 -20.00 44 -10.20
 ABUNDANCE CHANGE 45 -10.92 46 -10.35 47 -11.10 48 -10.18 49 -10.58 50 -10.04
 ABUNDANCE CHANGE 51 -11.04 52  -9.80 53 -10.53 54  -9.81 55 -10.92 56  -9.91
 ABUNDANCE CHANGE 57 -10.82 58 -10.49 59 -11.33 60 -10.54 61 -20.00 62 -11.04
 ABUNDANCE CHANGE 63 -11.53 64 -10.92 65 -11.94 66 -10.94 67 -11.78 68 -11.11
 ABUNDANCE CHANGE 69 -12.04 70 -10.96 71 -11.28 72 -11.16 73 -11.91 74 -10.93
 ABUNDANCE CHANGE 75 -11.77 76 -10.59 77 -10.69 78 -10.24 79 -11.03 80 -10.95
 ABUNDANCE CHANGE 81 -11.14 82 -10.19 83 -11.33 84 -20.00 85 -20.00 86 -20.00
 ABUNDANCE CHANGE 87 -20.00 88 -20.00 89 -20.00 90 -11.92 91 -20.00 92 -12.51
 ABUNDANCE CHANGE 93 -20.00 94 -20.00 95 -20.00 96 -20.00 97 -20.00 98 -20.00
 ABUNDANCE CHANGE 99 -20.00
READ DECK6 64 RHOX,T,P,XNE,ABROSS,ACCRAD,VTURB
 2.59250874E-03   4598.4 2.592E+01 8.866E+09 5.144E-04 1.226E-01 2.000E+05
 3.39248787E-03   4624.7 3.392E+01 1.129E+10 5.975E-04 1.274E-01 2.000E+05
 4.31334112E-03   4649.2 4.313E+01 1.403E+10 6.906E-04 1.310E-01 2.000E+05
 5.37524367E-03   4675.6 5.375E+01 1.727E+10 7.990E-04 1.336E-01 2.000E+05
 6.59950459E-03   4703.0 6.599E+01 2.110E+10 9.240E-04 1.349E-01 2.000E+05
 8.01192079E-03   4731.0 8.012E+01 2.558E+10 1.067E-03 1.352E-01 2.000E+05
 9.64342989E-03   4759.4 9.643E+01 3.085E+10 1.232E-03 1.347E-01 2.000E+05
 1.15286715E-02   4788.0 1.153E+02 3.704E+10 1.422E-03 1.350E-01 2.000E+05
 1.37053899E-02   4816.9 1.371E+02 4.430E+10 1.643E-03 1.365E-01 2.000E+05
 1.62180838E-02   4846.1 1.622E+02 5.283E+10 1.897E-03 1.375E-01 2.000E+05
 1.91210003E-02   4875.5 1.912E+02 6.283E+10 2.189E-03 1.382E-01 2.000E+05
 2.24779418E-02   4904.8 2.248E+02 7.454E+10 2.523E-03 1.386E-01 2.000E+05
 2.63638135E-02   4934.2 2.636E+02 8.824E+10 2.905E-03 1.390E-01 2.000E+05
 3.08663757E-02   4963.5 3.087E+02 1.043E+11 3.342E-03 1.394E-01 2.000E+05
 3.60845473E-02   4992.9 3.608E+02 1.230E+11 3.846E-03 1.412E-01 2.000E+05
 4.21296956E-02   5022.6 4.213E+02 1.450E+11 4.428E-03 1.438E-01 2.000E+05
```

```
 4.91263574E-02   5052.7 4.913E+02 1.709E+11 5.105E-03 1.478E-01 2.000E+05
 5.72175158E-02   5083.5 5.722E+02 2.014E+11 5.888E-03 1.519E-01 2.000E+05
 6.65705361E-02   5115.1 6.657E+02 2.375E+11 6.794E-03 1.562E-01 2.000E+05
 7.73787171E-02   5147.4 7.738E+02 2.800E+11 7.841E-03 1.606E-01 2.000E+05
 8.98648532E-02   5180.4 8.986E+02 3.304E+11 9.053E-03 1.652E-01 2.000E+05
 1.04284779E-01   5214.0 1.043E+03 3.898E+11 1.046E-02 1.705E-01 2.000E+05
 1.20923813E-01   5248.4 1.209E+03 4.602E+11 1.209E-02 1.772E-01 2.000E+05
 1.40117623E-01   5283.3 1.401E+03 5.432E+11 1.397E-02 1.841E-01 2.000E+05
 1.62264431E-01   5318.8 1.623E+03 6.413E+11 1.615E-02 1.913E-01 2.000E+05
 1.87832441E-01   5354.4 1.878E+03 7.567E+11 1.864E-02 1.989E-01 2.000E+05
 2.17357194E-01   5390.1 2.174E+03 8.918E+11 2.153E-02 2.086E-01 2.000E+05
 2.51442663E-01   5425.7 2.514E+03 1.050E+12 2.487E-02 2.206E-01 2.000E+05
 2.90797159E-01   5461.8 2.908E+03 1.237E+12 2.873E-02 2.343E-01 2.000E+05
 3.36241726E-01   5498.1 3.362E+03 1.455E+12 3.317E-02 2.506E-01 2.000E+05
 3.88695053E-01   5535.1 3.887E+03 1.714E+12 3.834E-02 2.703E-01 2.000E+05
 4.49201037E-01   5573.0 4.492E+03 2.019E+12 4.433E-02 2.929E-01 2.000E+05
 5.18964386E-01   5612.1 5.190E+03 2.383E+12 5.130E-02 3.191E-01 2.000E+05
 5.99309052E-01   5652.9 5.993E+03 2.819E+12 5.944E-02 3.497E-01 2.000E+05
 6.91673191E-01   5696.0 6.917E+03 3.347E+12 6.903E-02 3.859E-01 2.000E+05
 7.97552089E-01   5742.4 7.975E+03 3.993E+12 8.046E-02 4.292E-01 2.000E+05
 9.18271522E-01   5793.4 9.182E+03 4.798E+12 9.448E-02 4.850E-01 2.000E+05
 1.05469038E+00   5851.2 1.055E+04 5.831E+12 1.121E-01 5.570E-01 2.000E+05
 1.20715090E+00   5918.0 1.207E+04 7.189E+12 1.345E-01 6.503E-01 2.000E+05
 1.37532841E+00   5996.0 1.375E+04 9.022E+12 1.638E-01 7.716E-01 2.000E+05
 1.55827149E+00   6086.7 1.558E+04 1.154E+13 2.024E-01 9.333E-01 2.000E+05
 1.75282271E+00   6198.6 1.753E+04 1.527E+13 2.572E-01 1.162E+00 2.000E+05
 1.95657611E+00   6318.3 1.956E+04 2.031E+13 3.294E-01 1.511E+00 2.000E+05
 2.15099448E+00   6567.1 2.151E+04 3.366E+13 5.109E-01 2.350E+00 2.000E+05
 2.30441797E+00   6887.1 2.304E+04 6.037E+13 8.644E-01 3.573E+00 2.000E+05
 2.44928560E+00   7015.7 2.449E+04 7.676E+13 1.077E+00 3.959E+00 2.000E+05
 2.60379687E+00   7159.4 2.603E+04 9.921E+13 1.367E+00 4.632E+00 2.000E+05
 2.76088168E+00   7350.2 2.760E+04 1.361E+14 1.851E+00 5.801E+00 2.000E+05
 2.91416820E+00   7559.1 2.914E+04 1.885E+14 2.549E+00 7.312E+00 2.000E+05
 3.06070913E+00   7794.9 3.060E+04 2.655E+14 3.619E+00 9.718E+00 2.000E+05
 3.19228819E+00   8100.8 3.192E+04 3.983E+14 5.591E+00 1.402E+01 2.000E+05
 3.30692612E+00   8407.1 3.306E+04 5.787E+14 8.519E+00 2.058E+01 2.000E+05
 3.40005535E+00   8837.4 3.399E+04 9.237E+14 1.492E+01 3.480E+01 2.000E+05
 3.47148330E+00   9241.7 3.470E+04 1.367E+15 2.446E+01 4.055E+01 2.000E+05
 3.53666562E+00   9505.8 3.535E+04 1.732E+15 3.309E+01 3.490E+01 2.000E+05
 3.60257334E+00   9744.7 3.601E+04 2.117E+15 4.280E+01 3.071E+01 2.000E+05
 3.67275354E+00   9939.9 3.671E+04 2.476E+15 5.225E+01 2.715E+01 2.000E+05
 3.74964913E+00  10142.2 3.747E+04 2.886E+15 6.343E+01 2.504E+01 2.000E+05
 3.83556233E+00  10321.8 3.833E+04 3.290E+15 7.465E+01 2.277E+01 2.000E+05
 3.93268745E+00  10517.3 3.930E+04 3.766E+15 8.821E+01 2.163E+01 2.000E+05
 4.04344382E+00  10700.6 4.040E+04 4.253E+15 1.022E+02 1.996E+01 2.000E+05
 4.17065761E+00  10901.2 4.167E+04 4.823E+15 1.189E+02 1.926E+01 2.000E+05
 4.31731440E+00  11101.1 4.314E+04 5.436E+15 1.367E+02 1.777E+01 2.000E+05
 4.48843919E+00  11307.2 4.485E+04 6.114E+15 1.556E+02 1.831E+01 2.000E+05
PRADK 2.8357E+00
BEGIN                    ITERATION   5 COMPLETED
```

xnfpsb.dat is a binary file

Lines are divided into two groups for treatment. In the first group the source function for the lines if the Planck function or some other specified function that accounts of non-LTE effects in the surface region. Program SYNTHE processes this first group of line sto produce a summed line absorption coefficient for the wavelength interval of interest, which can be specified for either air or vacuum wavelenghts.

In the second group of lines, the program calculates a source function for eachlines, which reduces to the Planck function in LTE. The source functions are computed from the departure coefficients. Program SPECTR processes this group of lines directly by summing the line opacity and source function contributions at every wavelength and combining these results with the line opacity and source function obtained from SYNTHE.

The line list contains Kurucz's calculated values with corrections and deletions together with many additional lines from the literature. Only lines with real wavelengths are used in this calculation. For cooler stars one can include some molecules.

Program SYNTHE extracts a smaller list of lines that fall in or overlap the desired wavelength interval. For each, the air or vacuum wavelength, the exact upper and lower energy levels, and the gf values must be given. Other data may be specified, such as the upper and lower J, labels for the upper and lower levels, radiative, Stark, and van der Waals constant, fractional isotopic abundances for treated isotopic lines, comments, and references. Departure coefficient indices for the upper and lower levels, line strength, partial redistribution, and autoionization parameters may also be specified for later use in the individual line calculations.

synsb.com

```
$set def dka100:[adelmans.synthe.spectra]
$assign dka100:[gulliver.synthe] synthe:
$assign dka100:[gulliver.synthe.lines] lines:
$assign sys$output for006
$ASSIGN TAPE08.DAT FOR008
$ASSIGN TAPE09.DAT FOR009
$ASSIGN TAPE12.DAT FOR012
$ASSIGN TAPE13.DAT FOR013
$ASSIGN TAPE14.DAT FOR014
$ASSIGN TAPE15.DAT FOR015
$ASSIGN TAPE17.DAT FOR017
$ASSIGN TAPE19.DAT FOR019
$ASSIGN TAPE93.DAT FOR093
$RUN SYNTHE:SYNBEG
AIR       424.0     444.0     500000.   0.0         0  10000 .001         0   00
AIRorVAC  WLBEG     WLEND     RESOLU    TURBV  IFNLTE LINOUT CUTOFF  IFPREDNREAD
$!
$! LIGHT ELEMENTS THAT CAN BE TREATED IN NON-LTE BY AVRETT
$!ASSIGN nsynlines:NLTEvega4530new9.DAT FOR011
$!RUN synthe:RNLTE
$!
$!  LAB MEASUREMENTS FOR IRON GROUP ELEMENTS THAT REPLACE LINES ON GFIRON
$!ASSIGN nsynlines:linvega4530new9.DAT FOR011
$!RUN synthe:RLINE
$!
$!
$ASSIGN LINES:NLTELINES.DAT FOR011
$RUN SYNTHE:RNLTE
```

```
$!
$!ASSIGN LINES:GFIRONLAB.DAT FOR011
$!RUN SYNTHE:RLINE
$!
$ASSIGN LINES:GULLIVER.DAT FOR011
$RUN SYNTHE:RLINE
$!
$ASSIGN LINES:BELLLIGHT.DAT FOR011
$RUN SYNTHE:RBELL
$!
$ASSIGN LINES:BELLHEAVY.DAT FOR011
$RUN SYNTHE:RBELL
$!
$ASSIGN dka100:[adelmans.synthe]GFIRON.DAT FOR011
$ASSIGN SYNTHE:DELETEGFIRON.DAT FOR026
$RUN SYNTHE:RGFIRON
$!
$!      -----------------------------------------------------
$!  READ IN IONIZATION FRACTION/PARTITION FUNCTION DATA
$!
$ASSIGN dka100:[adelmans.synthe.xnfp]xnfpsb.DAT for010
$RUN synthe:SYNTHE
$!  READ IN MODEL ATMOSPHERE
$ASSIGN dka100:[adelmans.synthe.xnfp]modsb.dat for005
$ASSIGN SYNsb.DAT FOR007
$ASSIGN SYS$INPUT FOR025
$RUN synthe:SPECTRV
0.        0.        1.        0.        0.        0.        0.        0.
0.
RHOXJ     R1        R101      PH1       PC1       PSI1      PRDDOP    PRDPOW
$!      ------------------------------------------------------
$!  ADD ROTATIONAL BROADENING
$!
$ASSIGN SYNsb.DAT FOR001
$ASSIGN SYS$INPUT FOR005
$ASSIGN R3sb.DAT ROT1
$!ASSIGN R02ARC.DAT ROT2   !R02 MOVE TO ROT1, R00 DELETED FROM ROT1
$RUN synthe:ROTATE
    1
   3.
$!2
$!0.        2.0
$!       ---------------------------------------------------
$!   ADD MACROTURBULENCE here
!MACRO     1.0       KM
$!       ---------------------------------------------------
$!   ADD INSTRUMENTAL BROADENING
$!
$ASSIGN R3sb.DAT FOR021
$ASSIGN B3sb.DAT FOR022
$RUN synthe:BROADEN
PROFILE        32.00
RED         0.101518  0.096484  0.084203  0.069204  0.055881  0.043371  0.030640
RED         0.019478  0.011624  0.007428  0.005594  0.004696  0.003504  0.002669
RED         0.002294  0.002069  0.001746  0.001472  0.001267  0.001090  0.000911
RED         0.000756  0.000624  0.000507  0.000398  0.000298  0.000212  0.000141
RED         0.000082  0.000034  0.000004  0.000000
BLUE        0.101518  0.096484  0.084203  0.069204  0.055881  0.043371  0.030640
BLUE        0.019478  0.011624  0.007428  0.005594  0.004696  0.003504  0.002669
BLUE        0.002294  0.002069  0.001746  0.001472  0.001267  0.001090  0.000911
BLUE        0.000756  0.000624  0.000507  0.000398  0.000298  0.000212  0.000141
BLUE        0.000082  0.000034  0.000004  0.000000
$!        --------------------------------------------------
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Lecture 8: Discussion lead with Bikmaev

A discussion with the audience of high-resolution spectra studies of B, A, F, G, K -stars atmospheres with the goal of finding suitable studies for collaborative and individual efforts with the 1.5-m echelle.

Hot Stars (radiative envelopes)

O and early B stars (NLTE physics and winds)
Wolff-Rayet stars

Supergiants (NLTE physics, winds, spherical atmospheres) - variability mechanisms

pulsating B stars : β Cep = β CMa, 53 Persei type, non-radial pulsators

Magnetic Chemically Peculiar stars (magnetic physics)

Non-magnetic CP stars (very stable atmospheres)
Mercury-Manganese Stars
Metallic Lined Stars

Lambda Boo stars

Middle-B to middle-F superficially normal main sequence band stars

Be stars

δ Scuti/δ Del Stars

Population II stars
RR Lyrae Stars
Field Horizontal Branch Stars
subdwarfs

Do normal cluster/association stars have the same abundances?, consistency of abundance questions

Binary stars

Solar Type Stars (convective envelopes)

Normal F5 and cooler stars

What distinguishes stars with planets from those without planets?

Evolutionary effects up the giant branch
- CH stars
- AGB stars

Cepheids and related supergiants

Population II
- subdwarfs

Binary stars - barium stars, S type binaries

Carbon Stars