Chapter 2

Observations and analysis

The main results of this work are based on ground based low and high resolution optical spectra.

2.1 Observations

The low resolution optical spectra were obtained from 2.3m and 1.2m telescopes at Vainu Bappu Observatory, Kavalur. The 2.3m telescope is equipped with a medium resolution Boller and Chivens (B&C) spectrograph \(^1\) and a medium resolution Optometrics Research Spectrograph (OMRS), at the Cassegrain focus (f/13 with a scale of 6.8"/mm). These spectrographs use 150l/mm, 300l/mm, 600l/mm, 650l/mm and 1200l/mm gratings. For an optimum slit width, the spectrographs gives a maximum resolution of 2.5Å at 5000Å. The 1.2m telescope is equipped with a Universal Astronomical Grating Spectrograph (UAGS) at the Cassegrain focus. This gives a maximum resolution of 0.8Å with 1800l/mm grating. At the Coude focus there is Echelle spectrograph which gives a resolution of 0.4Å at 5000Å. For some of the bright

\(^1\)Recently modified into a medium resolution spectropolarimeter
sources we have used this spectrograph. A 1024x1024 pixel TEK CCD, with a pixel size of 24μ is used in all these instruments.

The high resolution spectroscopic data for the detailed chemical composition analysis were obtained with the European Southern Observatory (ESO) Coude Auxiliary Telescope (CAT) equipped with a Coude Echelle Spectrograph (CES). The Coude Auxiliary Telescope (CAT) was designed to feed the Coude Echelle Spectrometer (CES). The telescope has a clear aperture of 1.4m. We have also obtained data from the 2.5m Isaac Newton Telescope (INT) located at La Palma, which is equipped with a Intermediate Dispersion Spectrograph (IDS), mounted in cassegrain.

All our program stars are IRAS sources with circumstellar dust shells. For some of our program stars we have analysed the IUE low resolution spectra, which are available in the IUE archive.

2.2 Data reduction

The data is reduced using Image Reduction and Analysis Facility (IRAF) software developed by National Optical Astronomy Observatories (NOAO). Combining the frames, bias subtraction, flatfielding is done by the CCDRED package in IRAF (Philip Massey). The spectroscopic reduction, that is converting into a one dimension image, wavelength calibration, flux calibration and normalization are done using the SPECRED and ECHELLE packages in IRAF. Measuring the equivalent widths and deblending the lines were done by the SPLOT package in IRAF. This uses a Guassian, Lorenzian or a Voigt profile to get the equivalent widths. Multiple gaussians are fit for blended lines. The SPECRED and ECHELLE packages have routines for air mass corrections and removal of telluric lines.

The IUE data were reduced using the IUERDAF software which uses the (Interactive Data Language) IDL routines.
For the emission line analysis, especially for the nebular lines we have used the NEBULAR package of STSDAS in IRAF environment. They use the statistical equilibrium of five levels. The electron density, electron temperature and ionic abundances are derived using various line ratios. A three zone model is used which separates out the low, medium and high ionization zones from different lines and derives the $N_e$, $T_e$ and other parameters separately for each region.

2.3 Analysis

The analysis involves following steps.

1. Preliminary estimates of the stellar parameters.
2. Choosing a realistic stellar atmospheric model.
3. Calculation of the theoretical spectrum, using the spectrum synthesis techniques and model atmospheres.
4. Comparing the theoretical spectra with the observed spectrum and deriving the atmospheric parameter and chemical composition of the program stars.

2.3.1 Initial estimates of stellar parameters

The most commonly used methods for determining the stellar parameters are the photometry, spectrophotometry and hydrogen line profiles.

2.3.1.1 Photometry

The intensity of stellar flux varies as a function of wavelength and these variations are linked to temperature, surface gravity and chemical composition. A measurement of stellar flux at several wavelengths can be used to determine such parameters.

Wide and intermediate band photometric systems have been developed to describe the shape of stellar flux distributions via magnitude (colour) differences. Since they
use wide bandpasses, the observations can be obtained in a fraction of the time required by spectrophotometry and can be extended to much fainter magnitudes. The use of standardized filter sets allows for the quantitative analysis of stars over a wide magnitude range.

By carefully designing the filter bandpasses that define a photometric system, colour indices can be obtained that are particularly sensitive to one or more of the stellar parameters. Indeed, photometric surveys of faint stars are used to identify anomalous stars which warrant much closer spectroscopic investigation. Photometric colour indices, once calibrated with model atmospheres, can be used to determine atmospheric parameters. Three photometric systems are in general use:

The most widely used photometric system is the UBV system, developed by Johnson & Morgan (1953). The calibrations by Buser & Kurucz (1978, 1992) are worth noting. However, while UBV colours do agree well with spectral type for stars of similar composition, they do not provided for the separation of luminosity classes and are strongly affected by reddening (Johnson, 1958). The uvbyβ system, developed by Strömgren (1963, 1966) and Crawford & Mander (1966), overcomes some of the limitations of the UBV system. Several model calibrations have been produced, including Relyea & Kurucz (1978), Moon & Dworetsky (1985), Lester, Gray & Kurucz (1986), Kurucz (1991), Castelli (1991) and Smalley & Dworetsky (1994). Moon (1985) produced two very useful programs for dereddening observed uvbyβ colours (UVBYBETA) and obtaining T\text{eff} and log g (TEFFLOGG). Geneva seven-colour system has been used since around 1960 at the Geneva Observatory. Calibrations include North & Hauck (1979), Kobi & North (1990) and North & Nicolet (1990).

2.3.1.2 Spectrophotometry

In contrast to the wide bandpasses used by photometric systems, spectrophotometry is the measurement of stellar flux through (generally) narrow bandpasses, usually over
wider wavelength ranges. Only a restricted wavelength range can be observed from
the ground; optical spectrophotometry generally covers 3300-10000Å. However, a lot
can be determined from such spectrophotometry, since it contains the Balmer Jump
and the Paschen continuum, as well as representing a large fraction of the total energy
output of A and F stars (Malagnini et al., 1986). Since the emergent flux distribution
of a star is shaped by the atmospheric parameters, we can use spectrophotometry
to determine values for these parameters, by fitting model atmosphere fluxes to the
observations.

2.3.1.3 Hydrogen line profiles

The Balmer lines provide an excellent Teff diagnostic for stars cooler than about 8000
K due to their virtually nil gravity dependence (Gray, 1992). For stars hotter than
8000 K, however, the profiles are sensitive to both temperature and gravity. For these
stars, the Balmer lines can be used to obtain values of log g, provided that the Teff
can be determined from a different method. While the hydrogen lines are relatively
free from other absorption lines in most B-type stars, the same cannot be said of
stars later than mid A-type. Fitting is hampered by the numerous metal lines in
the spectra of these stars, ironically just as the hydrogen lines become insensitive
to log g! Nevertheless, by careful reductions and analysis, observations of Balmer
lines can still be used to determine Teff. Normalization of the observations is critical.
Naturally, the shape of the Balmer line must be preserved (Smith & van't Veer, 1988).
A useful check is to observe Vega or Sirius and compare the reduced spectrum with
those given by Peterson (1969). While it is very difficult – if not impossible – to use
Echelle spectra, medium-resolution spectra can be used. We have to allow for the
effects of blending of metal lines and the effects of rotation. Rotation is potentially
a more difficult problem, since by increasing resolution we can reduce the effects of
blending, but not that caused by rotational smearing. The continuum changes due
to metallicity also. Overall, hydrogen lines give very good values of Teff for A and
F stars, with internal errors of the order of 100 K or less. But, naturally, the actual value of Teff is model dependant.

All the stars in our selected sample have IR excess, which indicates the presence of dust. So getting the extinctions due circumstellar dust and correcting the fluxes obtained from the photometry is difficult. And hence deriving the stellar parameters from photometry is not very accurate. The Balmer line profiles in the spectral region A-F depends both on the $T_{eff}$ and log g values. So one has to have a estimate of one of the parameter to obtain the other. The balmer lines Hα and Hβ, in some of the objects are affected by the emission due to wind and circumstellar gas. However the higher members of the Balmer series the effect due to circumstellar may not be significant. So we have used Hγ and Hδ lines. Objects for which we had obtained high resolution spectra, we had derived more accurate values of the stellar parameters from the line analysis and spectrum synthesis.

2.3.2 Choice of the stellar atmospheric model

The stellar atmospheric models are generally defined by the effective temperature $T_{eff}$, surface gravity log g, the metallicity [M/H] and the microturbulaence velocity $\xi$. To decide upon the correct models generally one uses, the excitation equibrium for the correct temperature of the model, and ionization equilibrium is used to decide the correct surface gravity of the model. Microturbulence velocity is a parameter that is generally not considered physically except in the sun. Usually it is treated as the parameter that minimizes scatter among the lines of same ion in the abundance analysis. Microturbulence varies with temperature, gravity and chemical composition.

The trigonometric parallaxes measured by the Hipparcos mission provide accurate appraisals of the stellar surface gravity for nearby stars, which are used (C.A. Prieto et al. 1999) to check the gravities found from the photospheric iron ionization balance. They find an approximate agreement for stars in the metallicity range -1.0
but the comparison shows that the differences between the spectroscopic and trigonometric gravities decrease towards lower metallicities. This casts a shadow upon the abundance analysis for extreme metal-poor stars that make use of the ionization equilibrium to constrain the gravity. The strong-line gravities (by matching the profile) derived by Edvardsson (1988) and Fuhrmann (1998) confirms that this method provides systematically larger gravities than the ionization balance. Even there are inconsistency in the obtained temperature of the models using the excitation equilibrium.

2.3.3 Stellar atmospheric models

After obtaining equivalent widths and line profile from a high resolution and high signal to noise ratio data, it is analysed using a classical model atmosphere, which has following assumptions:

- local thermodynamical equilibrium (LTE), hydrostatic equilibrium, conservation of flux, and plane-parallel stratification. Also, the mixing-length theory is used to take convection into account.

Plane parallel models are usually hotter the than corresponding spherical models in the region of line formation. So calculated neutral lines will often be weaker and ionized lines stronger for plane parallel models than for spherical ones.

In low metallicity stars there is much weaker metal-absorption in the ultraviolet, so more amount of non-local UV flux is able to penetrate from the deeper layers. This flux is vital in determining the ionization equilibrium of the atoms. As a consequence the role of radiation on the thermodynamical state of matter becomes more important, resulting in stronger deviations from LTE. These are even more critical in the low gravity stars due to low densities.

We have used the Kurucz (1993) stellar atmospheric models, which are LTE line blanketed models, which assumes plane parallel geometry. The Kurucz model grids
are separated by 250K in $T_{\text{eff}}$ and 0.25 in log g values around temperatures, 10000K. For lesser temperature the separations are more closer. The models are available for four different values of microturbulence velocities (2, 4, 6, 8 kms$^{-1}$).

### 2.3.4 Atomic data for spectroscopy

In many cases lack of accurate atomic data is still the major obstacle for extracting the finer details embedded in the observations. The primary parameters for making the line identifications in stellar spectra are wavelengths, energy levels and oscillator strengths. Most serious problems appear in the short wavelength end of the satellite region. The accuracy of 5 to 10 percent obtained from OP and OPAL databases, is at present sufficient for the "visible" opacities. I.e. the structure of interiors and atmospheres of stars, accretion disks etc. can be calculated reliably. However, when visible layers are modelled, e.g. by spectrum synthesis techniques, certainly better line opacity data than presently available are required. These needs include accurate line positions and oscillator strengths, in particular for the ions of iron group. Seaton (1995) lists the basic atomic data required for astronomers. For light elements having few valence electrons the theoretical $gf$ values are better. In the case of iron group elements the experimental data is more accurate.

The atomic data which we have used for the theoretical spectrum synthesis is taken from the Vienna atomic line database (VALD) where all the new atomic lines data is been compiled. The major source of the archive is by Piskunov et al. (1995) and reference therein. We have also used the linelist complied by Kurucz (1994). It is a huge linelist, but in cases where there are no reliable atomic data available in the literature, semi-empirical values are used in the Kurucz linelist.
2.3.5 Line analysis and Spectrum synthesis

We have used the MOOG (Sneden 1973, 1998) LTE stellar line analysis program for radiative transfer calculations through cooler stars and for calculations of theoretical spectrum synthesis. The code was originally written for cool stars and later modified to include other stars also. The molecular dissociation equilibrium is included in deriving the abundances. The program has many driver routines:

- **synth** - spectrum synthesis, varying abundances
- **isotop** - spectrum synthesis, varying isotopic abundances
- **abfind** - force-fitting abundances to match single-line equivalent widths
- **cog** - curve of growth creation for individual lines
- **cogsyn** - curve of growth creation for blended lines
- **ewfind** - calculation of equivalent widths of individual lines

MOOG uses super-MONGO plotting package. It uses KURUCZ (1993) models and also MARCS models. The various smoothing mechanisms are included, rotation, instrumental broadening, and macroturbulence.

The SYNSPEC (Hubeny 1985) spectrum synthesis code is used for slightly hotter stars. It does not use molecular dissociation equilibrium in the abundance determinations. SYNSPEC reads the input model atmospheres from Kurucz (1979, 1993) and TLUSTY (Hubeny 1988) and solves the radiative transfer equation, wavelength by wavelength, in a specified wavelength range and in a specified resolution.

In principle, the line and continuum opacity sources used in calculating a model stellar atmosphere and in calculating the detailed spectrum should be identical. However, it is a common practice that model atmospheres, particularly those allowing for some departures from LTE, are calculated with fewer opacity sources than a subsequent calculation of a synthetic spectrum. The rationale for this approach is that the atmospheric structure is predominantly influenced by the strongest opacity sources,
while the emergent spectrum has to be computed in detail.

SYNSPEC also offers broadening by rotation and instrumental resolution. It uses the IDL plotting routines for graphics.

Our program stars belong to A-F spectral type which do not have too many crowded lines compared to the cooler spectral types. So the line analysis is easy. And also compared to the hotter spectral types A-F stars are less affected by NLTE effects. So the above model atmospheres and the spectrum synthesis, line analysis gives a reliable results. The error in our estimations are $T_{\text{eff}} = 500K$, $\log g=0.5$ and 0.2 dex in the chemical composition.