Chapter 1

Introduction

The sun is the only star which provides data at high spatial and temporal resolution to study the underlying physical mechanism responsible for the activities happening in and on the sun. We now have data on the sun to understand the physics at the core of the sun through techniques like Helioseismology, direct observations in optical wavelengths for studying the photosphere which is the visible surface of the sun, observations in infrared to study the cooler layers in the solar atmosphere, radio observations and observations in X-ray to study the solar corona. In this thesis we will confine ourselves to observations in optical radiations.

Energy mechanisms responsible for the heating of the chromosphere are still not clearly known. Physical models of the solar atmosphere can be made only if we can first identify the major energy mechanisms and explain the process of energy transport from the lower to upper atmospheres. Features in the sun as small as a hundred kilometers in diameter are believed to act as conduits to transport energy from the lower to the upper atmosphere. Observational evidence has started to accumulate in support of this idea. The major limitation imposed on studying these very small features using ground based telescopes is the intervening earth's atmosphere.

Turbulence in the earth's atmosphere degrades the true object intensity distribution of astronomical sources. The thermal gradients in the air produce random phase delays in the wavefront that cause blurring of images. Limitations in image quality
is because of these inhomogeneities in refractive index caused by the random thermal
gradients present in the atmosphere. The effect of the atmosphere can be succinctly
described by its transfer function. This transfer function reduces the spatial fre-
quency content depending on the exposure time used for recording the images.

In the case of long exposure imaging, the atmospheric transfer function reduces the
spatial frequency response at high frequencies. This attenuation at high frequencies
is high and at times can reduce the effective resolution to very small values than what
one would have obtained if the same object had been imaged in the absence of the
atmosphere. Short exposure imaging is found to have more high spatial frequency
transfer function of the atmosphere at long exposure does not go to zero because
the functional form of the long exposure atmospheric psf has a finite value even at
higher spatial frequencies.

Usually all images which are exposed for several time scales of the atmospheric
turbulence are classified as long-exposure images. As a general rule of thumb, the
exposure times in excess of a few hundredth of a second are considered as long
exposure images. In long-exposure images the high spatial frequency information is
attenuated because the recorded image is the source convolved with the time average
of the point spread function (psf).

The long exposure atmospheric transfer function is real in the Fourier domain, i.e.,
its Fourier transform has no imaginary part. Hence the object’s Fourier phase is
preserved and we need to worry only about the true contrast of the feature during
reconstruction.

A straightforward method to measure the atmospheric psf is to measure the size of
the intensity profile of an unresolved source close to the object under study. Here
we assume that the medium through which the imaging is done behaves in the same
way for both the object under study and the point source. If one has to get the true
psf then the point source and the object under study should be within an isoplanatic
patch.
For the sun, we do not have access to a point source for comparison. Furthermore, for extended sources like the sun, the atmospheric psf will not be the same on all parts of the image. We have a problem in the case of images of extended sources in which each part of the object has been convolved with different psf's. Hence a single psf will not be a correct characterisation of the psf for an extended object.

Another technique (Collados 1987) for solar image reconstruction uses the limb of the moon in the photographs taken during partial solar eclipse. In the absence of earth's atmosphere the moon's limb would be seen as a sharp edge against the bright Sun's surface. When imaged using a ground based telescope, the moon's limb is blurred because of the atmospheric psf. The gradient of the blurred limb profile of the moon gives the psf of the telescope and atmosphere. The psf thus found is used for deconvolving the psf from the entire image. This psf can be used to remove blurring only near the limb of the moon and within the isoplanatic patch which encompasses the moon's limb. Use of this psf for deconvolution elsewhere in the image will not give true reconstruction.

Night time observers can have single stars for deconvolution. To get a reconstruction which is close to the true object intensity distribution, the star used for determining the psf of the atmosphere and the object under study have to be within the same isoplanatic patch. In the case of photometry of extended objects like clusters of stars, algorithms like Daophot are used (Stetson 1987) where nonisoplanaticity effects are not considered.

The conventional method is to make a gaussian fit to these observed profile and the full width at half maximum of the fitted gaussian is used to characterise the psf. This creates spurious features if the true psf is not a gaussian. In fact, there is theoretical and experimental evidence for the non gaussian nature of the atmospheric psf (Roddier 1980).

One of the main motivations of this thesis is to find the exact long exposure atmospheric psf and use this for reconstruction of images of extended objects. In case of stellar imaging we can hope to have a bright field star close to our object of obser-
viation and therefore correct for the object under study by observing the field star. In objects like the sun, one can never have a point source based on which one could correct for the other unknown features. Hence we need to have an independent way of evaluating the atmospheric psf when we image extended sources.

Once we get the Fried's parameter we need to remove the atmospheric transfer function from the degraded image. The biggest challenge in any restoration scheme is suppression of noise and removal of blurring functions, (in our case the atmospheric psf), without losing high spatial frequency information of the object.

Various novel techniques exist for image restoration. Most of these image restoration techniques target restoration of short exposure image.

The long exposure atmospheric transfer function is real in the Fourier domain and in the case of short exposure imaging the atmospheric transfer function is complex (Fried 1966). Hence the object's Fourier phase does not get contaminated by the long exposure atmospheric transfer function. The only source of contamination is the Fourier phase of the noise.

Chapter 2 discusses the technique of parametric search for determining the atmospheric point spread function.

In chapter 3, the parameter search method is used on real images and the Fried's parameter obtained. The Fried's parameter $r_0$ so obtained is compared to the Fried's parameter obtained using another independent method which requires point sources for $r_0$ determination.

In chapter 4, we discuss a filter for image restoration. Restoration is performed on simulated images and then on real images. The Wiener parameter in the Wiener filter is estimated assuming a simple model for the noise in the image. A comparison is made between the noise modeled Wiener filter and the standard Wiener filter. The comparison is made in terms of mean square error between the restored image and the filtered images. Some extended sources are restored using the above techniques and results presented.

In chapter 5 and 6 we present the results obtained using high resolution images of
magnetic bright points. To highlight the usefulness of high resolution images we present some results obtained using the data obtained at the Swedish Vacuum Solar Telescope. The data was obtained by a group elsewhere. A new technique called Phase diverse speckle restoration has been applied to the images to produce high resolution images. Small feature like the magnetic element bright point is thought to be one of the efficient ways in which energy is transported from the lower atmosphere to the upper atmosphere. They are difficult to observe because of their size scales. Typically a magnetic element bright point is about 300 km in diameter, which implies an angular size of approximately 0.4. For understanding the processes in the solar atmosphere such as field concentration, process of energy transfer from lower to upper atmosphere, mechanisms of energy storage and release, signature of pre flare processes and other such activities, we need to study the dynamics of small scale features.

In chapter 5 we look at the average properties of the magnetic elements and look for periodicities in their motion. The bright points are tracked using an object tracking technique and the velocities of the bright points determined. We then estimate the autocorrelation of the velocities. This gives an average behavior of the bright point irrespective of the location of the bright point. The bright points are found isolated as well as in clusters.

In chapter 6, to track the bright points without any ambiguity we selected bright points which are well isolated and estimated their velocities and relative intensities. We measure the velocities and lifetimes of these magnetic element bright points and try to look for a possible relationship between their dynamics and the chromospheric heating processes. Here, we attempt to highlight the usefulness of high resolution observations and the physics we can extract from these high resolution images.