CHAPTER - 4

GROUND BASED INSTRUMENTATION TO PROBE THE UPPER ATMOSPHERE

4.1 Introduction

The investigation of airglow / aurora by the optical instruments are considered to be somewhat analogous to passive remote sensing of the upper atmosphere. These instruments have a tremendous potential in inferring the behavior of the upper atmosphere. After the advent of satellites, there has been a remarkable growth in the general understanding of the emission mechanisms.

The ground-based investigation by the photometry and spectrometry gives us a wealth of information on the behaviour of the upper atmosphere, at different heights.

(A) By using a calibrated photometer, one can infer the columnar density of the emitting species, as the airglow emission intensity has a direct relationship with the reacting species.

(B) If an emitting species is in thermal equilibrium with the ambient medium, its emission line profile can be used to estimate Doppler temperature, and the wavelength shifts in the peak give the line-of-sight winds.

(C) One can determine the rotational temperature, by knowing the rotational structures of molecules. When the rotational levels are such that they are sensitive to the ambient gas temperature, as in the case of N_2^+, the emission from the rotational levels give a direct indication of the ambient gas temperature at the altitude of their origin. Several naturally occurring band emissions such as O_2, N_2^+, OH bands etc., have been effectively used to determine the rotational temperature of the respective altitude regions.

(D) The optical airglow emissions are global in nature and by selecting different regions of the sky using a narrow field--of–view instrument, could effectively lead to information from different neighbouring latitudes with fine spacial resolution. Also, the gravity wave activity influence the photochemistry and composition of the thermosphere **[1].** As the airglow emission intensity gets modulated by the atmosphere dynamics, propagation characteristics of wave phenomena like the atmospheric gravity waves could be inferred from the spacial variability of the airglow emissions **[2]**.

(E) The airglow emissions originate at different heights. By measuring the intensities of different wavelengths nearly simultaneously one can infer the vertical propagation of waves from one region to another thereby giving important clues on the modes of coupling of these different regions.

The nightglow measurements have been used to investigate all the above mentioned aspects.

During twilight time, the ground is in the shadow of the earth and the upper atmosphere which is still illuminated by sunlight, hence one can measure the intensity of twilightglow with ease. With the rotation of earth, the height to which solar radiation reaches moves up at a given location. *Rusch* **[3]** showed that, the observations under such conditions can be used to infer the emission intensity profile of that particular emission. From 630.0 nm twilightglow, *Noxon and Johanson* **[4]** showed that the changes in the thermospheric O_2 are abundance.

The instrumentation involved in the nightglow observation is fairly simple and straightforward. The airglow emissions do occur during daytime as well. During daytime, the contribution due to solar continuum is orders of magnitude higher than the nightglow emission intensities and hence, one has to involve innovative methods for detecting the same. Such attempts have been made mainly for detecting the OI 630.0 nm dayglow of the thermospheric origin. Notable among them, which have met with success, are a photometric technique by *Noxon and Goody* **[5]**, a high-resolution spectrometer by *Cocks and Jacka* **[6]** and the dayglow photometer by *Narayanan et al.* **[7]**.

4.2 Fabry Perot Interferometer (FPI)

The airglow emission regions also move with neutral air. By observing the apparent wavelength of a prominent airglow line it is possible from the Doppler shift, to determine the component of velocity in the line of sight. This has become a well established technique for the winds in the thermosphere, using a Fabry-Perot interferometer to find the

Doppler shift of the 630.0 nm oxygen line. In the typical instrument the separation of the Fabry-Perot plates is varied cyclically with a period of a few seconds by means of a pressure cell or a magnetostrictive device, so as to scan the interferometer through the airglow line. For a neutral air wind of 50 m/sec the Doppler shift of the 630.0 nm line is only 10^{-4} nm, the velocity can be measured to 1 m/sec with a modern instrument. The horizontal wind vector is determined by observing in two directions more or less at right angles. The width of the line gives the air temperature.

Construction

The high resolution Fabry-Perot interferometer is relatively simple inexpensive and highly cost effective with a high light gathering power. The FPI consists of two parallel flat transparent plates, coated with reflective films and separated by fixed distance. This arrangement is known as "*etalon*". When a light wave incident on the etalon at an angle normal to the mirror, it will undergo multiple reflections within the space between the mirrors. The intensity pattern of the reflected and transmitted beams is a set of bright concentric rings or fringes on a light background for the reflection case. The angular diameter (O), the spacing between the etalon mirrors (t) and wavelength (λ) of incident light are related by

$$n\lambda = 2\mu\, t \cos\theta$$

Where, 'n' is order of interference and μ is refractive index of medium.

The FPI can be used as high resolution scanning spectrometer by changing the refractive index of the spacer “r” medium. So the change in pressure (dp), change in refractive index ($d\mu$) and change in wavelength ($d\lambda$) of light are related by

$$\frac{dp}{p} = \frac{d\mu}{\mu - 1} = \frac{d\lambda}{\lambda}$$

Here, we assume that temperature inside the etalon is constant. The fringe system obtained from the sky is imaged at the focal plane of the objective lens and then through circular scanning aperture, falls on a collimating lens and then falls on the condensing lens through required interference filter. Finally emission light in the form of spot falls on a photomultiplier tube (PMT).

The output profile from PMT is a convolution of instrumental profile and the true line profile. So, the recovery of the true line profile can be obtained using the standard source (He-Ne Laser) for observation. Hence, the bulk of kinetic temperature (T) of emission region of thermosphere can be obtained by using following formula.

$$\delta\lambda = 7.16 \times 10^{-7}(T / M)^{1/2}$$

Where $\delta\lambda$ is line width of half intensity, T is center wavelength of observed line and M is atomic mass of the emitting species.

The line of sight component of wind velocity ‘V’ is given by ,

$$V = c\,\frac{(\lambda' - \lambda)}{\lambda}$$

Where 'λ' is observed Doppler shifted wavelength, 'c' is the velocity of light. So this instrument measures simultaneously both the temperature and horizontal motions (meridional and zonal).

A pressure scanning high resolution Fabry-Perot spectrometer has been developed by I.I.G, **[8]** funded by DST under AICPITS project. The interferometer is shown in Fig- 4.1 and the schematic diagram in Fig.4.2.

4.3 – Ground-based Detection of Nighttime Airglow OI 630.0 nm.

On a moonless night, sky is illuminated with light, about 40-50 % of lights are due to nightglow, originating from the region of upper atmosphere (90-400 km). Though the 630.0 nm emission is situated in the visible portion of electromagnetic spectrum (red line) its intensity is too faint to be detected without the aid of sophisticated instrumentation.

Airglow observation in the visible portion of electromagnetic spectrum have been extensively studied on the basis of ground based and spacecraft measurement **[9, 10]** . It is also well established that airglow observations provides a convenient tool for remotely sensing the dynamical properties of upper atmosphere. Of the various lines studied so far, oxygen 'redline' emission of 630.0 nm continues to be of unique interest as a tracer of dynamical processes such as F-region peak height variations, thermospheric neutral wind modulations and F-region plasma irregularities occurring in the lower portion of the ionospheric F-layer **[11-14]**. The important experimental work of 630.0 nm nightglow started after 1930. *Bates* gave a proposal regarding ionospheric reactions responsible

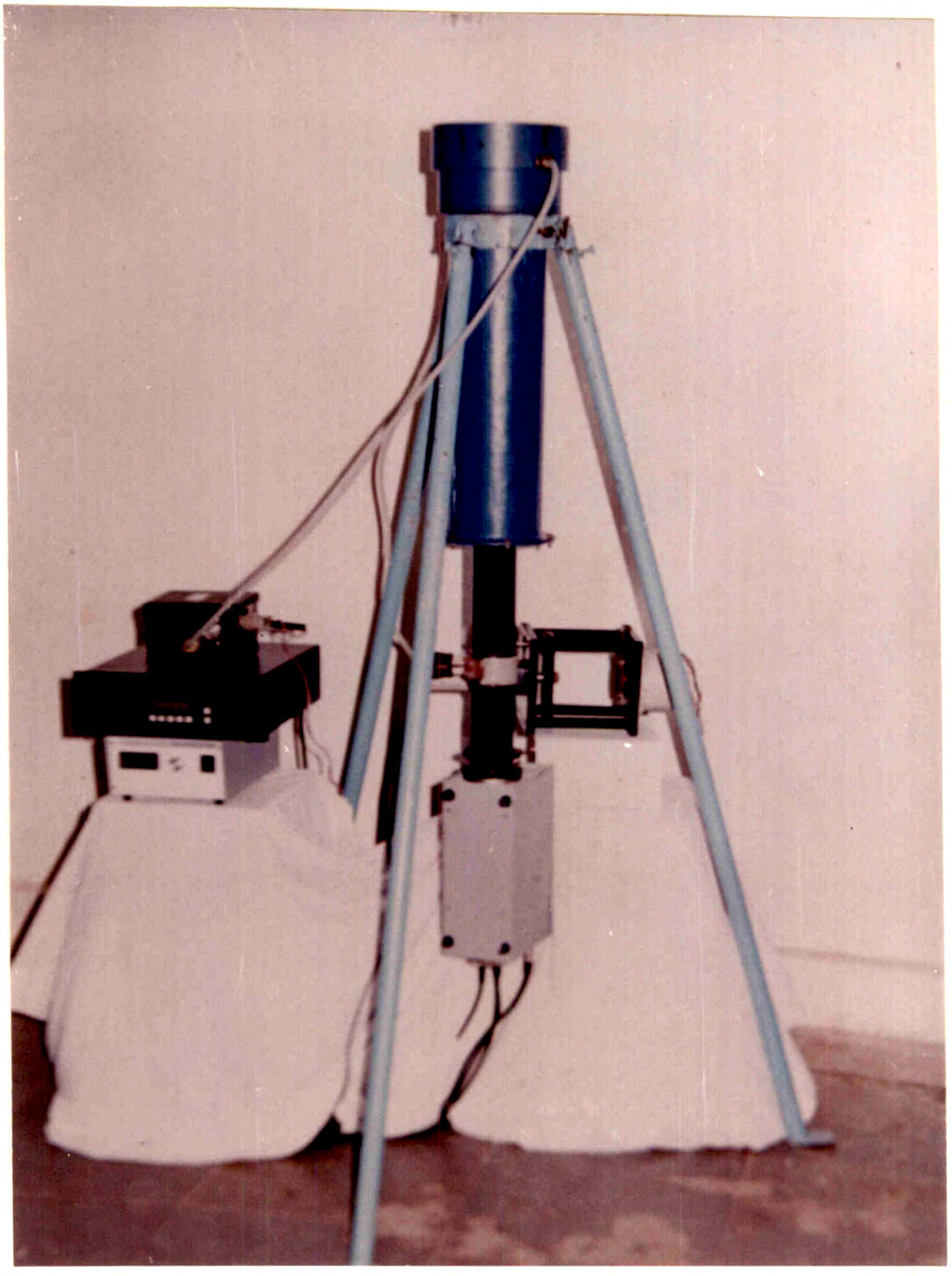

Fig. 4.1. Fabry-Perot interferometer (FPI)

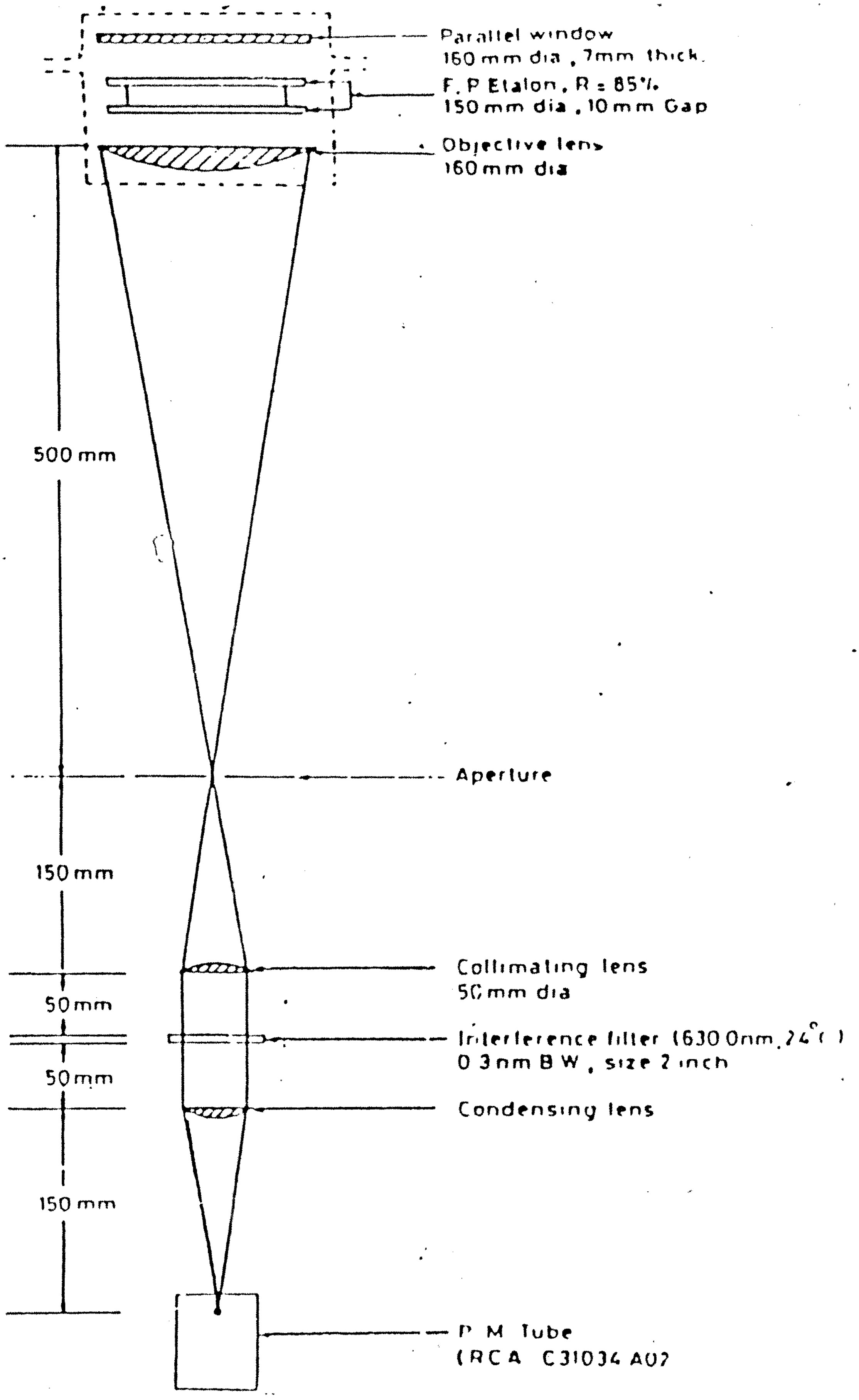

Fig. 4.2. Schematic diagram of Febry-Perot interferometer (FPI)

for the airglow, which together with the numerous observations of the nighttime OI 630.0 nm airglow established and confirmed that OI 630.0 nm ionospheric emission **[15]**.Which originates wholly in the F-region at around 250 km height by a layer of about 50 km thickness and is caused by dissociative recombination **[16]** of the molecular ions that produces 'redline' airglow.

Some of the instruments to observe the nightglow emission from ground are discussed below.

4.3.1 High Resolution Filter Tilting Nightglow Photometer (NGP)

The nightglow high resolution filter tilting photometer**[17, 18]** used for the present work was developed by P. L. Dyson, Department of Physics, La Trobe University, Bundoora, Victoria, Australia. Three such photometers are installed at a low latitude station, Kolhapur. This photometer is capable of retrieving faint light emissions (OI 630.0 nm) intensities from the background of the nighttime sky.

The photometers were originally fabricated to study the velocity of airglow structures, gradients (zonal meridional) in 'redline' intensity and F-region plasma irregularities.

The first objective of the design was to retrieve the oxygen 'redline' emission from the background emission. This is achieved by the filter tilting mechanism. In this mechanism, both 'redline' emission and 'background' lights were allowed to pass through the normal and tilted modes. In tilted mode the pass-band of filter is shifted to the lower wavelength side so that only the background light is transmitted. The difference between two consecutive records taken at the two positions gives the actual intensities of 'redline' emission.

The second design objective was to make the recorded noise as small as possible relative to the corresponding red oxygen-light. This is achieved by making photometers light collecting surfaces of 'sizeable' areas. The ultimate form of the overall photometer was such that it could be used to monitor the ionosphere of about 5 km in diameter at 250 km height.

The advantages of using the tilting photometer are that, the same filter is used to observe the background as well as the line emission. Details of the individual parts of the overall instrument are given below.

Technical Details of the Photometer (NGP)

Any photometer, to be capable of measuring intensities of faint light emissions in the presence of background, should be able to isolate and provide the intensity of the line emission alone.

The nightglow photometer makes use of objective lens, collimator, narrow bandwidth interference filter to isolate the wavelength of interest, rotating cam for tilting the interference filter, condenser lens followed by photomultiplier tube. The photons let through the condenser lens are counted by a photomultiplier tube and output of photomultiplier tube fed to a suitable strip chart recorder. Also, the analog signal is retrieved in digital form. The photograph of such photometer is shown in Fig.4.3 and

Fig.4.3. High resolution filter tilting Photometer(NGP).

schematic diagram as shown in Fig.4.4.

The photometer is having a field of view (overall) of about 1° in diameter (at F-region height). The interference filter used in Nightglow Photometer (NGP) is of a narrow band-width of 1 nm (FWHM), centered at the wavelength where it is 'tuned', which in our case is OI 630.0 nm emission line originating from the thermosphere (~250 km). As these are interference filters, one can 'tune' them in such a way that the peak of the transmission is at the emission line being investigated. The behaviour of filter with tuning can be understood by the interference formula,

$$2\mu t \cos\theta = n\lambda$$

Where, μ is the refractive index, t is the path length, θ is the angle of incidence, and λ is the wavelength.

These interference filters are coated with dielectric materials alternatively having high-and-low refractive indices with an absentee coating in between. Details on the behaviour of filters with different reflection coatings, information of the transmittance, reflectance and absorption characteristics with respect to various layers of coating materials, etc are dealt with in detail by *Hernandez* **[19]**. As the refractive index 'μ' of the dielectric material changes with temperature, by altering the filter temperature one can change the central wavelength of transmission (for rest of the parameters, t, θ and n being the same). The interference filter has a pass-band centered at about 630.0 nm for normally incident-

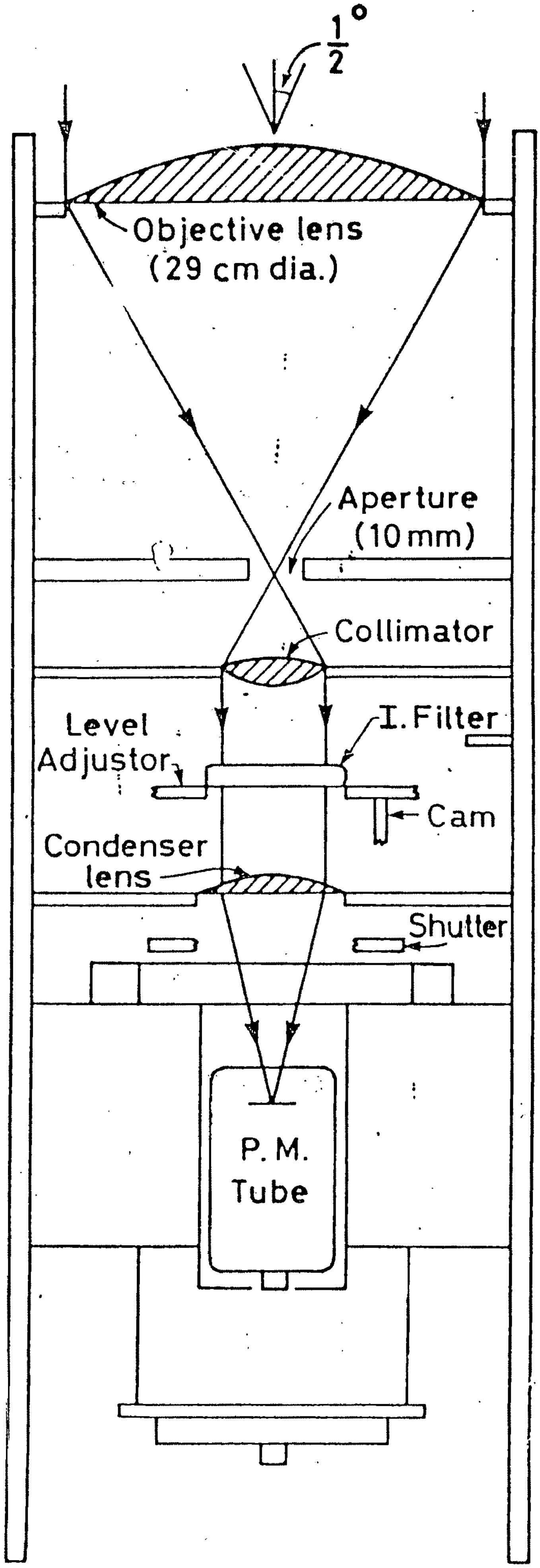

Fig. 4.4 Schematic diagram showing the major parts of tilting photometer.

light and kept at a temperature of 23° C by electronic circuitry.

The interference filter is housed in a filter tilting cam assembly and rotation of tilting cam is controlled by motor, the fastest data point can be obtained at 12 sec interval. The light emerges from the photomultiplier tube by means of condenser lens.

The photomultiplier tube has quantum efficiency of ~ 6% at 630.0 nm. This PMT is cooled to a temperature of atleast -10° for minimizing the thermal noise. In the present setup the photomultiplier tube (PMT) is operated at –1650 V at which the signal-to-noise ratio is minimum. The output from the PMT consist of negative V shaped pulses typically of about 5-10 mV. These pulses were amplified through a rate meter to a few volts d.c. output and fed to a Kipp and Zonen strip chart recorder.

Functioning of NGP

The photometer is having a field of view of about one degree in diameter. The light coming from the objective lens falls on collimating lens through an aperture (10 mm). Then it falls on a interference filter. The filter has two modes,

(1) Normal mode – In normal mode both 'redline' emission and the 'background' lights are allowed to pass trough the filter. Here the pass-band of the filter is centered at 630.0 nm for normally incident light. Then it falls on the condensing lens and finally the light is collected by PMT. The output of PMT is given to chart recorder and data is recorded.

(2) Tilting mode – In the tilting mode the interference filter is tilted by filter

tilting cam and the rotation of the cam is controlled by a motor. In this case the pass-band of the filter is shifted to lower wavelength side so that only the background light is transmitted. The light emerging from the interference filter is guided on to the PMT by means of condenser lens. Thus the image of the objective lens is formed on the photocathode. The output of PMT is given to chart recorder and the data is recorded.

Thus, a measurement of the 'redline' emission is given by the difference between the two consecutive records taken at the two position (normal mode and tilting mode).

Calibration of the Photometer

A diffuse light source of known brightness can be used for reducing airglow intensities to absolute intensities. Such light sources which are frequently used are: (1) radio active phosphor source (2) the blackbody radiation source, and (3) diffuse light from a standard filament bulb.

In practice, a small diffuse white light source which filled the field of view of the photometer was compared in brightness to the much larger calibrated light source. Since the calibrated light source also filled the field of view, for comparison of intensities, the respective sources were placed over the photometer. With the knowledge of source brightness, absolute airglow intensities could be deduced. The absolute airglow intensities is measured in Raleigh [1Rayleigh = 10^6 photons cm^{-2} S^{-1} Sr]. Typical airglow intensities are 100 R at night and 2.5 kR at daytime.

4.3.2 Multi-Wavelength Scanning Photometer

The temperature of mesosphere is very important parameter in the remote sensing investigations. The Hydroxyl molecule (OH) produced in the mesosphere emits wide-range of molecular bands in the visible and near infrared regions of the electromagnetic spectrum. By observing the nightglow OH emissions we can estimate the mesospheric kinematic temperature and other parameters such as 'O' density, morphology and kinematics. For studying the dynamics of the mesosphere and thermosphere a scanning photometer is used.

Such scanning photometer unit has been designed and fabricated in I.I.G, Mumbai, for studying the dynamics of the mesosphere and thermosphere. A precession position controller (PPC) is used for controlling the movement of the photometer in the meridional and azimuthal planes for five filter positions. This movement is controlled through two stepper motors. The 'PPC' also controls one more stepper motor one more stepper motor to change the position of the five filters (692.5 nm, 683.0 nm, 665 nm, 557.7 nm, 630nm). By giving the step size of rotation in both azimuthal and meridional directions of time to remain filter in its position, it takes a few minutes to complete one sequence of observations with five filters including background and dark counts in a given meridional plane. It starts scanning in the reverse direction after completion of forward scan, with same filter position time used in forward motion.

The signal from photomultiplier tube (PMT) in the form of pulses is amplified by a pulse amplifier and discriminator and fed to the Kipp and Zonen strip chart recorder, and processed further for future analysis.

For finding kinetic temperature of mesopause, molecular bands {7,2} of 'OH' emissions, are chosen. The individual intensity within the bands are isolated by interference filters and the corresponding ratio of intensities is used to calculate kinetic temperature. The three filters used are 692.5 nm for line emission, 683.0 nm for total R-branch and 665.0 nm for background. The thermospheric study is based on the measurement of the neutral oxygen (OI) emission at 630.0 nm selected by an interference filter.

4.3.3 All –sky Camera

A photomultiplier tube (PMT) is used as a detecting unit in a simple photometer (NGP). The PMT converts the incident light radiation's (photon) into a large number of secondary electrons which gives rise to currents proportional to the intensity of input light. The all-sky camera (fig.4.5) consists of semiconducting silicon chip called as Charge Coupled Device (CCD) as the detecting device. The CCD was invented by *S. Boyle and George E. Smith in late 1960's* in the Bell laboratory, U.S.A. The superiority of the CCD over all other image forming devices is its high resolution, high spectral response, low noise and large dynamic range **[20,21]**.

A CCD based all-sky (180° field of view) airglow imaging system was operated from a low latitude station, Kolhapur (16.8°N; 74.2°E; 10.6°N

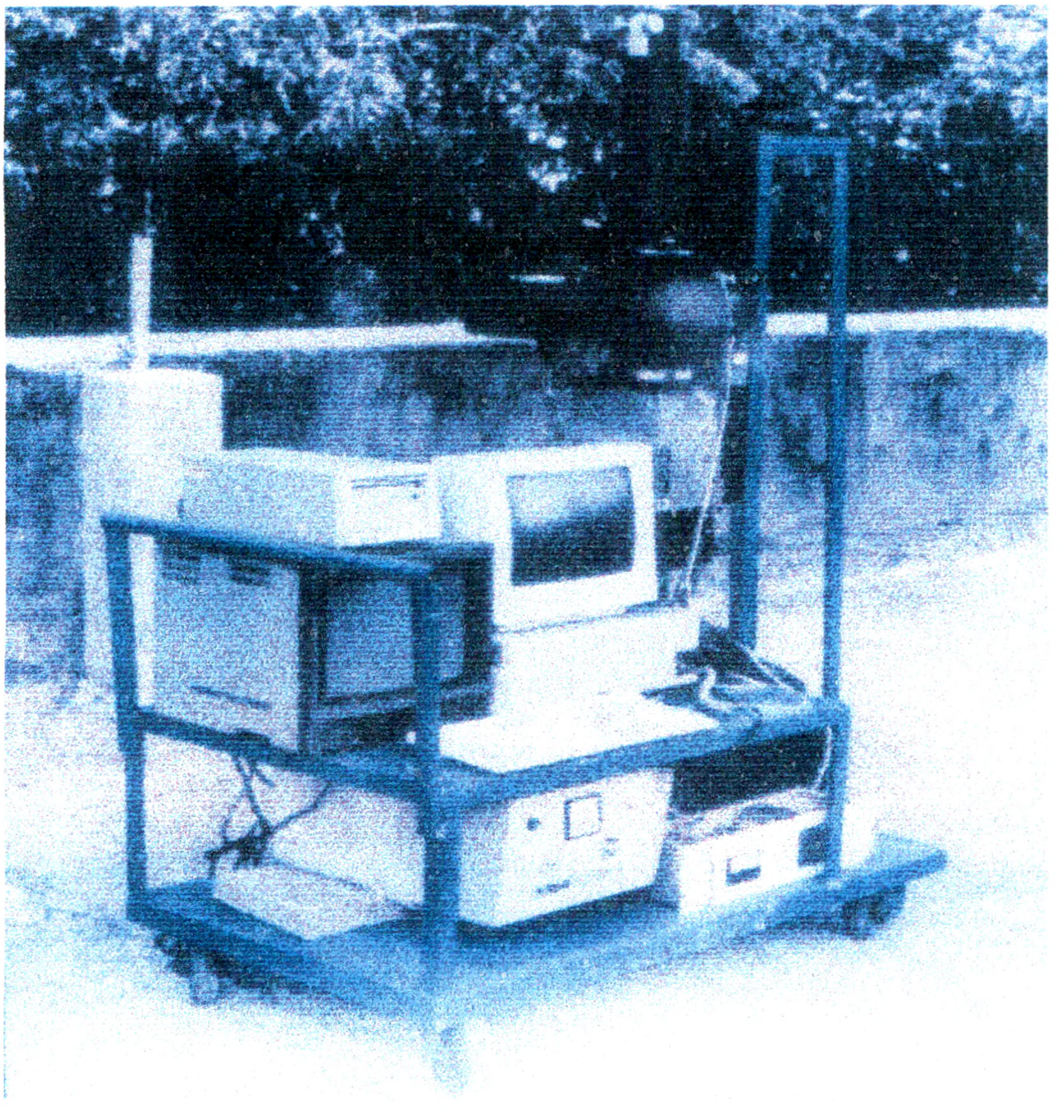

Fig. 4.5 All-Sky imaging system.

dip lat) to map the thermospheric motion and to study the low latitude ionospheric irregularities by measuring the nightglow signatures at 630.0 nm. In general, all-sky imaging techniques offer broad, instantaneous coverage (2.5 million Sq km area at 150° field of view at 300 km height) of the spatial and temporal characteristics of the airglow features from the selected layers of the thermosphere and ionosphere system.

The salient features of the design of the CCD based imaging system have been explained by *Baumgardner and Karandanis* **[22]**and *Mendillo et al,* **[23]**. The fish-eye lens at the top of camera takes in light in 2Π-steradians from the sky. The fish-eye lens produces circular image of sky and is directed into collimator. Finally the light after passing through filter is re-imaged onto the photocathode of the intensified CCD of Fairchild-3000 model and intensifier of type 4727 of ITT. It uses a very narrow bandwidth (1.2 nm) interference filter. There are six filter positions and are computer controlled and can be used to study various emission lines. The camera stores image frames each occupying *98620 bytes (384 x256 pixels)* memory space in computer hard disk (20 GB). The spectral line at 630.0 nm is indicative of dissociative recombination involving O_2 molecules and electron near 300 km altitude **[24]**.

The all-sky images of nightglow emissions (630.0 and 557.7 nm) are used to provide unique two-dimensional data on the data on the spatial and temporal characteristics of short period gravity waves (1-3 hrs periods) over a large geographic area and with high temporal resolutions.

Also field aligned large depletions (bubbles) can very well map their movement in imaging photograph. The all-sky imaging has revealed the movement of north-south (magnetic) aligned structures of airglow depletions. East-west extension of these depletions vary from 50 to 250 km with smaller structures (irregularities) as small as few km in size within them give rise to radio beacon scintillation. The north-south extent of these depleted plasma regions are more than 1000 km in length [25]. One image obtained from all-sky imaging system is shown in Fig.4.6.

As the all-sky camera is not yet calibrated with a standard source, it cannot give absolute values of airglow intensity. However, the intensities are classified from lowest value 0 (zero) (blue) to highest value 255 (magenta) called the data number. The product of the data number and the constant of the calibration source would give the absolute intensity in Rayleigh.

The all-sky camera has been developed with collaboration of Prof. Mendillo and his group at Boston University, Boston, U.S.A.

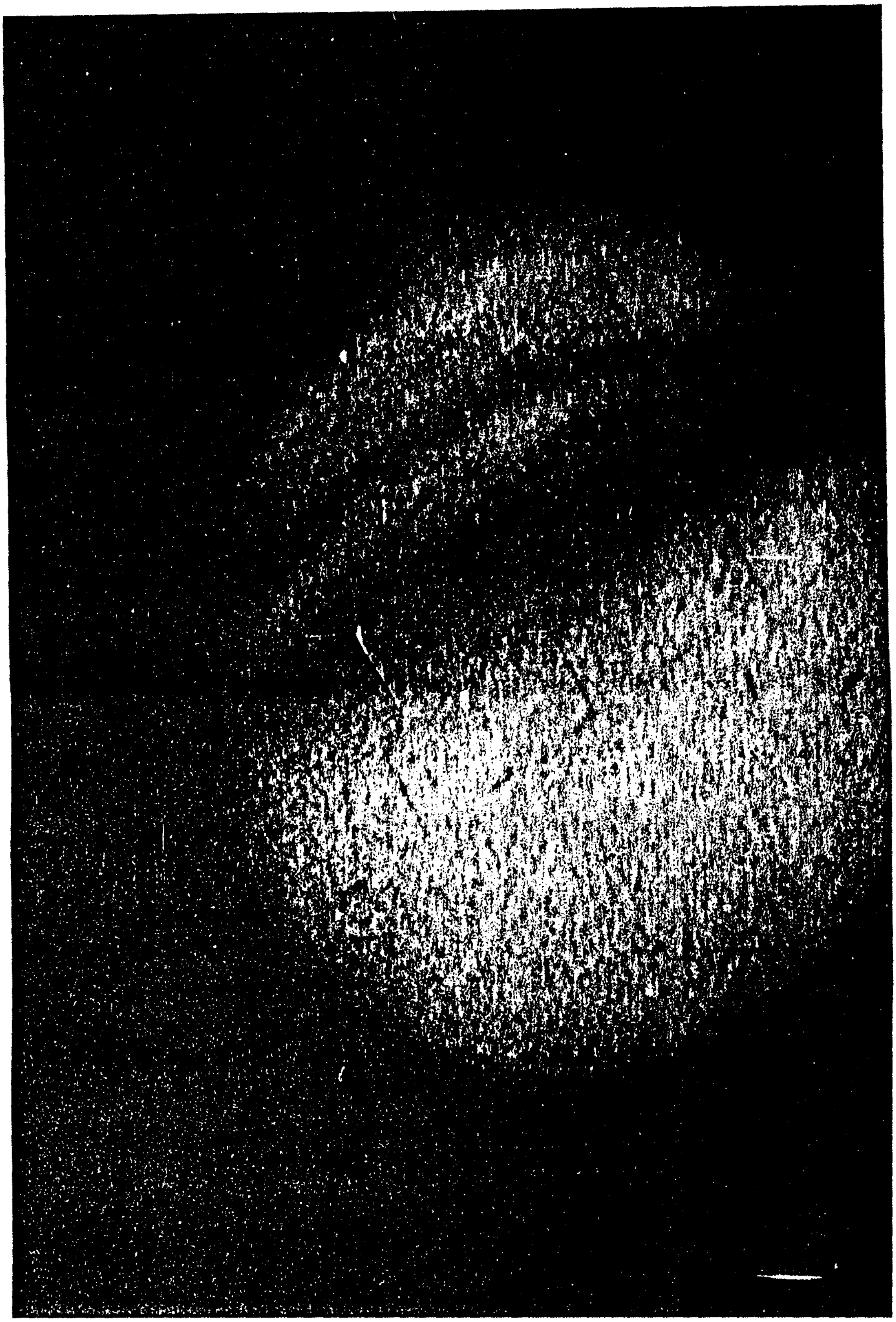

Fig. 4.6. All Sky image taken with filter 630 nm on March 3, 2000, at 23:57 hrs .

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