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First Indian Solar Astronomical Program at Antarctica: Study of Large Convective Cells

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Abstract

Continuous monitoring of the sun has great advantage in finding answer to many problems such as helioseismology, evolution of activity and supergranulation which has a lifetime of about 20 hours. To study the evolution and decay of these large convective cells known as supergranules, a solar telescope was set up at the Maitri station in Antarctica region during the local summer months (December 1989 through March 1990). The need for astronomical observations from Antarctica, the experimental set up to obtain the filtergrams of the sun through K-line(l .2 A pass band) filter and the observing conditions at Maitri have been described.

Calcium K-line filtergrams at an interval of about 10 minutes were obtained whenever clear weather permitted. The analysis of a continuous sequence of filtergrams obtained for 106 hours indicates that the most probable lifetime of the calcium K network is about 22 hours. The lifetime depends upon the size of the cell and is larger for bigger cells. The data also show that ceils (of a given size) associated with remanent magnetic field regions live longer than those in the field free region. It may mean that magnetic field is playing an important role in the confinement of these structures.

Introduction

The small scale structures over the image of sun can be seen at the time of good seeing. These structures known as granules are of the size of 700-1400 km and have lifetime of about 10-20 minutes. Leighton, Noyes and Simon (1962) discovered the presence of large cells from the velocitygrams obtained during the summer of 1960 and 1961. They found that these cells have horizontal outward flow and material moves with an average velocity of ~0.5 km/sec. These large cells or 'supergranules' have a typical size of 30,000 km and average life of 20-24 hours. They concluded that supergranulation pattern is surface manifestation of convective currents which come from relatively great depths inside the sun. Subsequently Simon and Leighton (1964) showed that there is similarity in the appearance of calcium K network and supergranular cells. Worden and Simon (1976) have investigated the velocity and magnetic field associated with supergranulation using Sacramento Peak Observatory Diode Array Magnetograph, Their observations indicate that the supergranular velocity cells may have lifetimes in excess of the accepted value of 24 hours.

The calcium K network seen in K-line spectroheliograms or filtergrams has a wide range of shapes that are frequently irregular and in many cases even incomplete. The autp-correlation technique used to determine the size of supergranule would give a value which is likely to be effected by the presence of incomplete cells. Therefore, Singh and Bappu (1981) used a technique to measure the individual cells to study the dependence of cell size on solar cycle. Their measurements indicated that the most probable size of this cell is smaller than estimated earlier by Leighton, Noyes and Simon (1962). The significant result of this analysis is the variation of cell size with the phase of solar cycle, the cell size being smaller by 5% at solar maximum than at minimum.

The study of evolution of these large cells will reveal the physical characteristics of the deeper convective layers and manifestation of the magnetic fields on the sun. To achieve this goal one needs data at least for 2-3 days without the interruption of day-night cycle. To obtain continuous data first attempt was made, during the international Geophysical year (July 1957-December 1958) by setting up worldwide network of small telescopes equipped with hydrogen H-alpha filters to record solar activity (Harvey, Pomerantz and Duvall, 1982). The collective contribution from different observatories, although substantial, lacked uniformity and there were frequent gaps in the data. Despite these problems, a network station is still the accepted method for carrying out solar research requiring continuity over long periods of time. A network of 6 stations known as Global Oscillation Network Group (GONG) is being planned to study oscillations on the solar surface and thereby probe the interior of sun.

Another way to avoid the sunset without leaving the surface of earth is to travel poleward of the Arctic or Antarctic circles during local summer. We then experience the midnight sun and weather permitting can observe without interruption. The first observations of this kind were made in 1966 from Thule, Greenland 10° above the Arctic circle. Rogers (1970) has estimated the lifetime of 25 ± 1.6 hours for H- alpha chromospheric network using a nearly continuous sequence of H-alpha pictures of sun over a 62-hour interval obtained from Greenland. Later Kusoffsky and Pomerantz (1980) conducted the solar patrol using H-alpha filter for 120 hours continuously from the south pole in the summer of 1979. The unique feature of the site at south pole is that it offers the opportunity for obtaining continuous homogeneous observations with a single instrumental system over extended period of time.

To understand the evolution of the supergranules it was thought to make continuous observations from Maitri (latitude 70° 45' 39" S, longitude 11° 44' 49" E), Indian permanent station in Antarctic region. At the photospheric levels, these cells are seen only in Dopplergrams obtained in Fraunhofer lines. An easier way is to observe their counterparts at the chromospheric level where they can be seen conspicuously in the monochromatic images of the sun, for example, in the K-line of ionized calcium at 3933.684 A. The correspondence between super-granules and calcium K network makes the experimental set up easier than viewing them through Dopplergrams. Our plan was to design and fabricate a telescope suitable for Antarctic region, install it at Maitri and obtain calcium K filtergrams continuously at least for 2-3 days, to study temporal features of these convective cells. Of course, one may note that final aim is to do the helioseismology from Antarctic region after developing reliable, accurate and sophisticated equipment capable of measuring velocity of the order of 5-10 m/sec.

Experimental Arrangement

The solar telescope meant for operation at Antarctica was designed and built in the laboratories of Indian Institute of Astrophysics, Bangalore. The set up consists of a heliostat

Fig. 1. The photograph of the heliostat installed at Maitri and the tube structure to house the objective and narrow band K-line filter. The Maitri station, permanent Indian station in Antarctica region, and the polar ice seen in the background are in south direction.

with a 15 cm aperture mirror mounted on a pillar 2 m high (Fig. 1). The flat mirror, driven by a synchronous motor through a worm wheel assembly, collected the light from the sun and directed it in the direction parallel to the rotation axis of the earth. A second flat mirror kept at the bottom of the heliostat tube collected the sunlight beam reflected from the first mirror and folded it horizontal to feed an objective of 10 cm aperture and 300 cm focal length. The second mirror has a push-pull arrangement to position and centre the solar image onto the filter. The converging beam from the objective entered a narrow band (1.2 A pass band) K-line filter made by 'Day Star' of U.S. The pass band of this filter was calibrated for various temperature settings using very high resolution spectrograph of Solar Tower Telescope at Kodaikanal. Minolta X-700 camera mounted on K-line filter had the facility to record automatically the epoch of every exposure on the corner of each frame of the filtergram. This set up enabled us to obtain the calcium K-line filtergrams with an image scale of 66 arcsec per mm and a spatial resolution, of about 2 arcsec.

Observing Conditions and Observations

The Department of Ocean Development has set up a permanent station at a logistically good location in the Schirmacher hill range in Antarctic region. This station known as Maitri, is situated at latitude 70° 45' 39" south and longitude 11° 44' 49" east. After reaching Maitri on December 27, 1989, the expedition team surveyed the area around the station and nearby hills with the help of IAF helicopter to select a site for the telescope from where the sun could be observed for maximum number of hours on a given day. It was found that the sun could be observed 24 hours a day in the month of December and early January from a few sites in the northern side of the lake and only for 22 hours from the southern side of the lake. Keeping in view the logistics and time available for observations it was decided to put up the telescope on the southern side of the lake and close to Maitri station. The team consisting myself and Dr. G.S.D. Babu, both of Indian Institute of Astrophysics and Mr. Wahab Uddin of U.P. State Observatory, was able to complete the installation of the telescope by Jan. 6, 1990. The alignment and testing at the telescope was done during the few hours of sunshine available for next three days. During our stay of 50 days, in total, there were 10 full clear days out of which there were 5 days with negligible wind. It was possible to obtain the filtergrams in calcium K-line on 7 days. On each day, sunshine at the telescope was available for 21.5 hours during the second week of January and for about 18 hours towards the end of January. The polar ice in the southern direction obstructed the view of the sun for about 2 hours each day. These filtergrams recorded on 35 mm Kodak 2415 film were developed in D-19 developer in a make-shift arrangement at the expedition ship, *Thuleland.*

The data on four days are of good quality representing quiet and steady atmospheric conditions while on the remaining 3 days they are just good indicative of moderate seeing. These filtergrams show very well the sunspots, plages and network pattern (Fig. 2) and

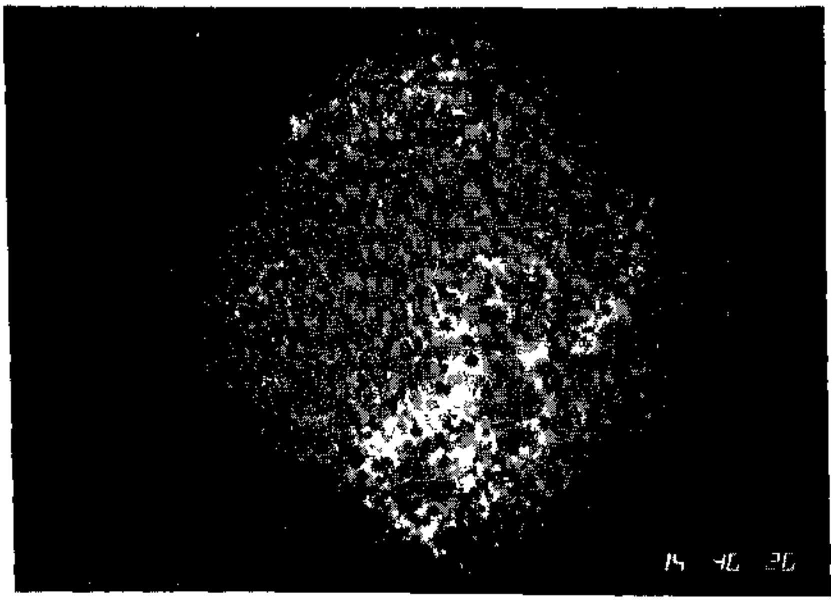

Fig. 2. An example of the Calcium K-line filtergram of the sun taken on Jan 10, 1990 through the narrow band (1.2 A pass band) 'Day Star' filter. The network pattern which is the subject of study of this observational programme can be seen well in the filtergram. Also are seen other features associated with solar activity like the sunspots (dark spots) and bright emission area surrounding sunspots, called the plages. The epoch of this filtergram in h, m, sec. (U.T.) is printed on the right hand corner of the photograph.

provide a good collection for the study of evolution and decay of supergranular cells. In all, we have been able to obtain about 2000 filtergrams of the sun in calcium K-line at the rate of one photograph every 10 minutes. The longest sequence spans a period four and a half days from Jan. 9-13, 1990. We have also obtained filtergrams at a rapid rate, once every 40 seconds on two days to study the evolution and decay of magnetic fields connected with the flare activity. A look at the data has shown that a flare occurred on February 12, 1990. NPL scientists have measured the UV radiations from the sun from the Maitri station. This data will be useful for detecting a possible correlation between flare intensity and measured UV radiations.

Data Analysis and Results

Each filtergram belonging to the time sequence of 106 hours was enlarged to a size of 283 ± 1 mm. The peak emission on the boundary of the cells was marked to delineate the nearly complete calcium K network cells. The selected network cells were recognised on frames 10 minutes apart. To determine the lifetime of a supergranule, we have adopted the following procedure. Suppose a cell with complete boundaries is just seen at an epoch t_2. Then we looked at the same region in the prints of filtergrams obtained earlier than this epoch. The careful examination of the filtergrams showed that a configuration of bright points similar to the boundary of the network cell appeared at time t_1. The same configuration later formed the complete boundary of the cell at time t_2. The difference between these two epochs t_1 and t_2 is about 1-2 hours. The epoch $(t_1 + t_2)/2$ has been taken as the time of formation of the cell. Similarly epoch of decay has been found for the cell by observing the epoch of beginning of disintegration and complete decay. Difference between two epochs has been taken as the lifetime of the cell.

The measurement of areas on the enlarged prints was done by use of 1 mm grid. The values of the areas have less than 3% variation caused by the measuring technique. To measure the perimeter of the cell, ,the boundary was divided into 5 to 10 segments each one nearly a straight line. Each segment was measured by using an eye piece fitted with a scale to an accuracy of 100 microns corresponding to a value of 0.7 arcsec on the sun. The uncertainty in the determination of the perimeter is less than 4%. The areas and perimeters of the cells were corrected for foreshortening.

We could select only 64 calcium K network cells for the present study due to limited available data. We have divided all these calcium network cells in two groups depending upon its distance from the calcium plage region (see Singh *et al.,* 1993). A cell seen close to the periphery of a plage with boundary emission larger than the average has been labelled as an active region cell. The cells away from the plage region and showing normal boundary emission have been labelled as quiescent region supergranules. Using this method of classification we got 35 cells belonging to active region and 29 to the quiescent region. In this paper we shall refer to them as 'active cells' and 'quiescent cells'.

We have tried to estimate the lifetimes of the calcium K network cell by two methods: (i) by finding the mean lifetime and (ii) by most probable lifetime from the frequency distribution curve. Due to less number of data points available, we have considered both types of convective cells together to determine the average lifetime to calcium K network cells. The histogram in Fig. 3 indicates that the most probable lifetime of a cell is about 22

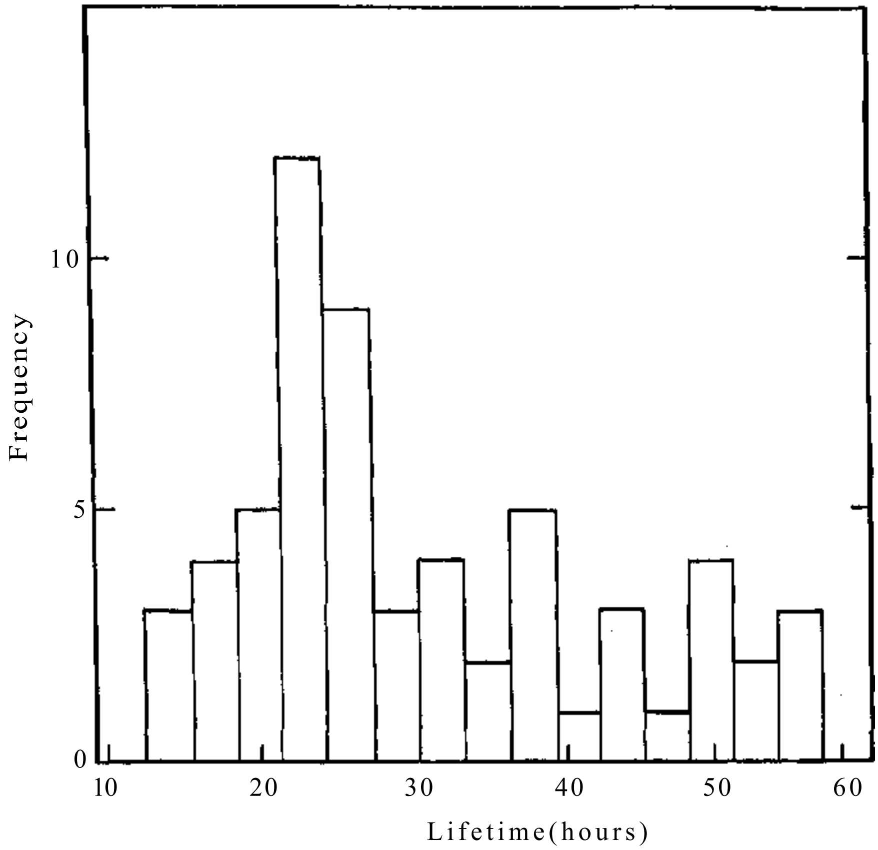

Fig. 3. Frequency distribution of the lifetime of calcium K network cells. The histogram has be made by making bins of 3 hours interval.

hours. The mean lifetime of cell is ~ 31 hours when all the 64 cells are taken together. The large difference between the mean lifetime and the most probable lifetime of a cell is because the frequency distribution of lifetime is not gaussian. The extended tail due to large values of lifetime of a few cells contributes to the large value of the mean lifetime of a cell. The average lifetime of calcium K network agrees well with the lifetime of a supergranular cell estimated by Leighton, Noyes and Simon (1962).

To find the relationship between the size and lifetime of a cell, we have measured the area of the cell at an interval of one hour, The area of most of the cells remained same within a variation not larger than 10%. A few cells showed a gradual decrease in the area and final area at the time of decay remaining 70 - 80% of the original area. Area of some of the cells increased gradually and became about 120-130% of the original area at the time of decay. The average area of each cell was computed and plotted against lifetime as shown in Fig. 4 for active and quiescent cells. From this figure a correlation between the lifetime and the cell size is apparent; the value of correlation coefficient is 0.58 for the active and 0.79 for the

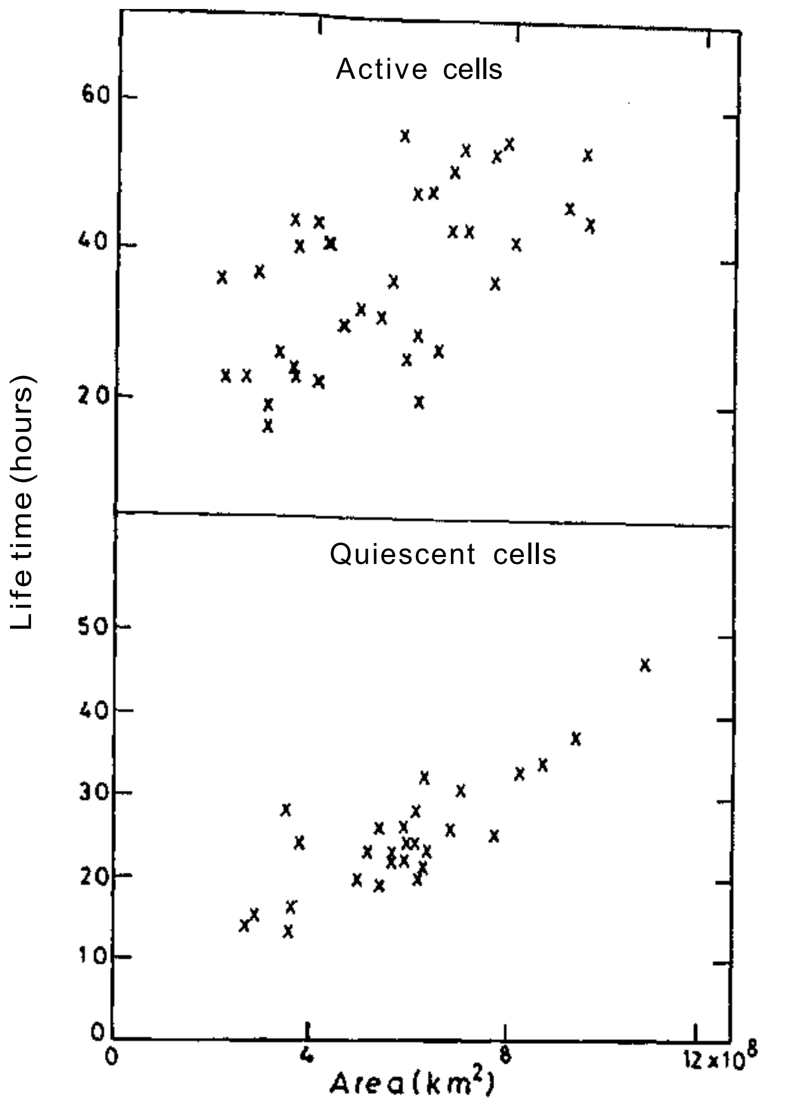

Fig. 4. Observed correlation between area and the lifetime of calcium K network cells. Top panel is for 'active cells' and bottom for 'quiescent cells'.

quiescent cells. These values of correlation coefficients indicate the confidence level about 99 per cent (Snedecor and Cochran, 1967). This means that the lifetime of a cell depends on its size and is larger for the bigger cells. This figure also shows that active cells live longer than the quiescent cells of comparable size.

Howard (1959) showed that a close correlation exists between the general pattern of emission in the calcium K-line and the magnetic fields in the underlying regions. This relation holds for the chromospheric network as well as for the active regions near the sunspots. It is, therefore, expected that the active cells, close to the peripheries of plages having larger emission at the cell boundary are associated with stronger magnetic field. Hence, the confining properties of the magnetic field may be responsible for the longer life of active cells. This possibility can be explored by studying the dynamics of velocity and magnetic field in the cells. One more point to be noted is that the scatter in the lifetime versus cell size plot for the quiescent cells is much less than that for active cells. This is a pointer to the role of the varying activity in the evolution of the cells.

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