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SOLAR ACTIVITY

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1 Introduction

Sun could have had a nice and perfect spherical symmetry in its atmosphere and probably no variation on timescales smaller than hundreds of thousand of years if (i) the energy produced in its core could be transported out and away by radiative processes alone, (ii) it was not rotating and (iii) it had no magnetic field But then perhaps it would not have been so interesting as it is for so many of us to have gathered here after travelling long distances inspite of the hazards offered by the 'Tamil Nadu Bundh"

However, it so happen that the energy produced in the sun is not adequate to keep it transparent upto the surface layers from where the radiation escapes In the outer 2/7th of sun s radius almost all the outflowing energy is transported by convection Besides, a minute fraction of energy has to be transported by non radiative non convective processes, mainly by waves and oscillations of various kinds The non radiative processes are inherently symmetry breaking and have variability on all possible scales down to seconds or even smaller

It is now well recognized that in the non radiative and non convective processes the breaking of symmetry and the short term variability involve effects of sun's complex magnetic field The whole class of the structures and phenomena related to asymmetries (inhomogeneties) and variabilities on various scales come under the present meaning of the term solar activity" Thus besides the conventionally listed structures and phenomena (like sunspots, plages prominences, flares, radio bursts and emission of relativistic particles) the presently generalized term also includes structures like spicules and thin kilogauss flux tubes as well as the recently discovered structures like coronal transients, ephemeral active regions and X ray bright points in the so called quiet sun

Because of the basic role of the magnetic field the term solar activity has become equivalent to the more apt term "solar magnetic activity" and because of its role in the energy transport in the outer atmosphere, 'solar activity" has also acquired the meaning of "stellar activity'

The study of solar activity also include that of its origin, viz the origin of the complex magnetic field, and its effects on the interplanetary space and on planets, especially the earth and its environment

I shall briefly describe these 'activity phenomena' and the physical problems offered by them

2 Sunspots

Sunspots are tiny temporary, darkenings of sun's surface usually of sizes between a few millionth to a few thousandth of the sun's surface area (Figure 1) Corresponding dimensions are ~ 2,000 to 70 000 km Dimensions of a medium sunspot are comparable to the diameter of the earth In a large sample the number of sunspots decreases rapidly with increasing size above the mean size and increases rapidly with decreasing size below

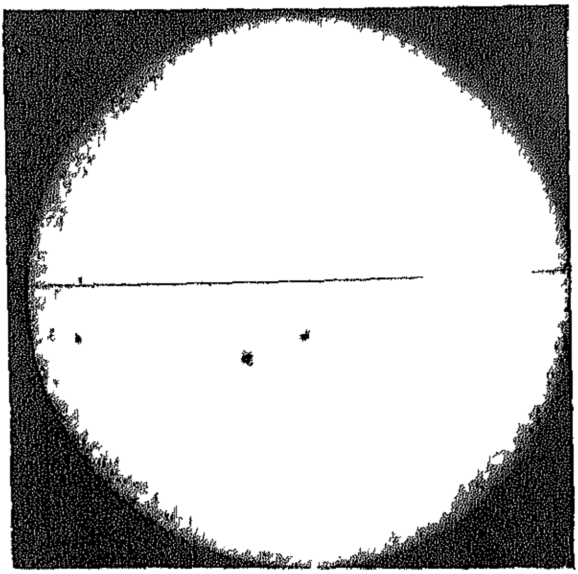

Fig. 1 Sunspots as seen in a white light photograph of the Sun The dark line is the image of the crosswire in the telescope

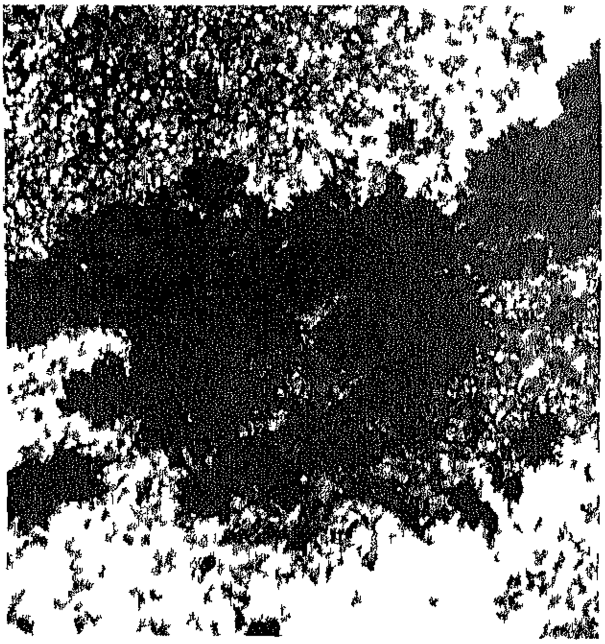

Fig. 2 A complex sunspot group showing dark central umbras surrounded by filamentary penumbras

the mean size (M H Cokhale and K R Sivaraman, J A A 2, 365) Their lifespans vary between a few hours to several weeks depending upon the maximum size attained

2.1 Structures and phenomena within a sunspot

All spots exceeding 50 millionth of solar hemi phere have a central dark area called umbra surrounded by annular ring of less dark area called penumbra Average temperatures in umbra and penumbra are 4000 K and 5200 K respectively In the umbra there are sometimes roundish inhomogeneities of slightly less darkness called umbral granules Penumbra is full of radially oriented dark and less dark structures of lengths of thousands of kilometers and thickne s a few hundred kilometers These are called penumbral filaments (Figure 2) The photosphere ('the apparent surface') in the umbra is a few hundred kilometers deeper than the normal photosphere and the photosphere of the penumbra joins the umbral and normal photospheres giving a saucer like shape to the sunspot photo phere In the penumbra there is a mas flow apparently starting from the inner boundary and reaching velocities 2 5 km/s at the outer edge Thi flow was discovered in 1909 at the Kodaikanal Observatory by John Ever hed and is named as Evershed flow Umbral photosphere i oscillating with periods 170 s whereas penumbral photospheric oscillations eem to be propagating outwards In the chromosphere the penumbral wave are seen as bright emission features propagating outward with speeds ~ 20 km s $^{-1}$

2.2 Magnetic Field

The magnetic field is about 3000 G in the umbra and gradually falls to photospheric value of across the penumbra The direction is more or less vertical in the umbra and fans out across the penumbra to almost horizontal at the outer edge The magnetic polarity in the western part of a spotgroup is same as that of the polar field in the same hemisphere All polarities including that of polar field reverse within an year or two after each sunspot maximum This defines a 22 y 'magnetic cycle' (Figure 3)

2.3 Statistical Properties

The occurrence of sunspots is irregular in time and in location over the surface Generally they occur in pairs or groups oriented with a small tilt with the local latitude such that westward end is towards the equator However there are some statistical regu larities Sunspots occur normally in a latitude zones of 5° 30° on either side of the sun's equator though on rare occasions spots have been seen in higher latitudes upto 60° The occurrence frequency varies, from a few per month to a few hundred per month, on timescales of 9 to 14 yrs with a mean period of 11 y (Figure 4) The amplitudes of this variation seem to be modulated over about eight cycles There is also an evidence that once in several centurie , the sun remains almost spotless for several decades There is also some indirect geological evidence that these various modulations existed even in precambrian era (~ 700 million years ago, see G W Williams and C P Sonnet 1985, Nature 318, 523)

The mean latitudes of sunspot activity gradually shift towards the sun's equator in both hemispheres from one sunspot minimum to the next An year or two before the 'end' of such a sunspot cycle, the 'beginning' of the next cycle is seen as small spots in high latitudes (Figure 5)

2.4 Formation and Decay of Sunspots

Beginning with darkening of intergranular lanes in the normal photosphere, and convergence of tiny clumps of strong magnetic field, sunspots grow rapidly reaching the maximum areas within an hour to a few days depending upon their size The decay is

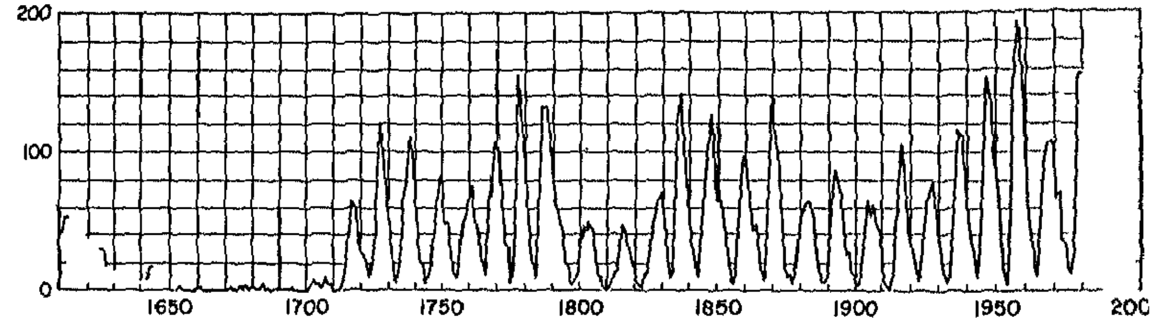

Fig 3 Annual mean sunspot numbers from 1610 to 1980 The sunspot cycle is irregular in period and amplitude Note the 'Maunder minimum' during 1645 1715

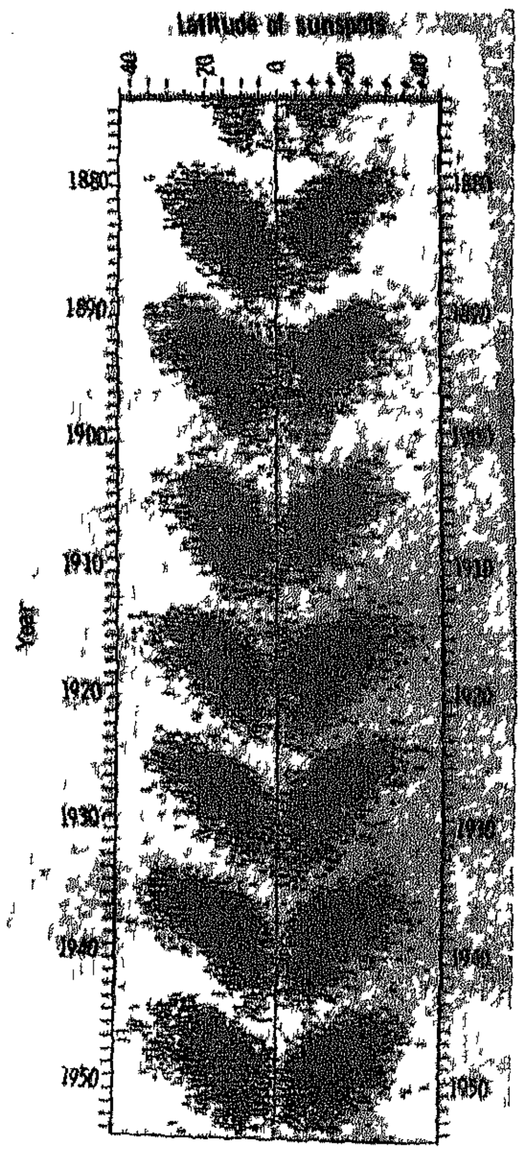

Fig 4. Butterly diagram showing the shift in the mean location of sunspot activity from 30° to low latitudes during each sunspot cycle Activity of previous cycle is present near equator when the activity of new cycle begins at 30°

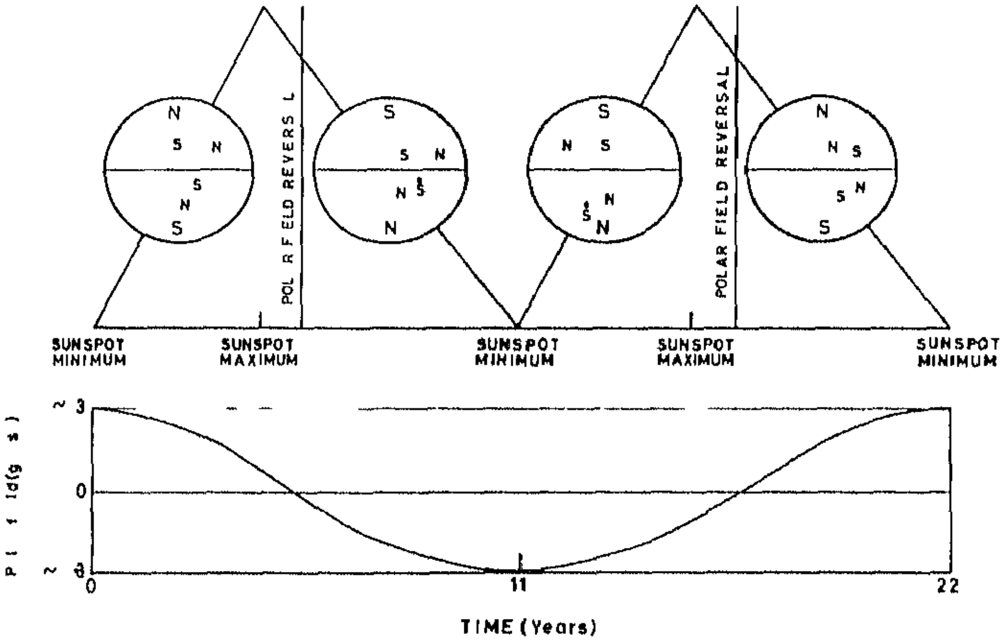

Fig.5 A schematic diagram showing polarities of bipolar sunspot groups and the polar fields defining a 22 year " olar magnetic cycle"

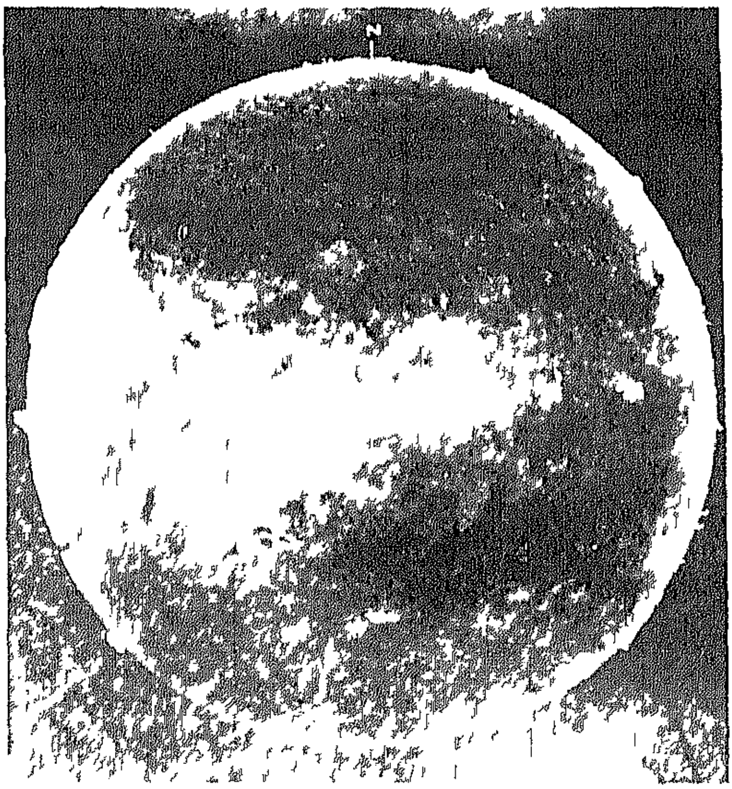

Fig.6. Balmer H alpha spectroheliogram showing prominences as bright arches on the limb and dark filaments on the disc

generally much slower and is sometimes associated with 'splitting During the decay of a spot, tiny elements of strong magnetic field are seem to move radially away from the outer edge of the penumbra

2.5 Theoretical Problems

Inspite of the long history of their observation and study, most of the theoretical questions about sunspots do not have definite answers as yet These problems pertain to the origin of sunspots, the formation of strong magnetic structure, its interference in the energy transport below the sunspot, dispersal and disappearance of the magnetic flux, formation and decay of the fine structures, the Evershed flow (its cause, beginning and end), the cause of the 11 y cycle of solar activity their role in the 22 y magnetic cycles and the long term modulation of the sunspot cycle

3 Prominences

These are magnetically supported cool dense structures in the corona which are seen as bright emission just outside the limb (during eclipses or using coronograph) and as dark features in photospheric absorption lines especially in the Balmer alpha line of neutral hydrogen (Figure 6)

Prominences occur in a very large variety of forms but are classified under two broad categories (i) 'Active more energetic and short lives (e g minutes hours) and (ii) Passive' less energetic but long lives (e g days several weeks)

3 1 General Properties (The values in the brackets are for the active prominences)

Length $\sim 10^{9}$ $10^{10.5}$ ($\sim 10^{8}$ $10^{9.5}$) cm, thickness $\sim 10^{8}$ ($\sim 10^{8}$) cm, heights: ~ 3 x 10^{9} (~ 1 3 x 10^{9}) cm, life days to several weeks (minutes to hours), temperature ~ 5000 7000 (~ 10 20 x 10^{3})°K, electron density 10^{10} (10^{11}) cm $^{-3}$, locations and position length running along photospheric magnetic neutral lines at the boundaries of the active regions or at boundaries of largescale field patterns anywhere on the sun (photospheric magnetic neutral lines within the active regions and at locations of the quiescent prominences during sudden erruptions of the latter), field ~ 10 (~ 20) G, field orientation arbitrary (small angle with the long axis)

3 2 Physical Problems

Formation (mass supply), equilibrium (MHD support), energy balance, stability of quiescent prominences and causes of their disruption, instabilities causing active prominences, disposal of mass and energy during disruption

3 3 Theorletical Models

Three varieties of models have been proposed in literature for MHD support The Kippenhahn Schluter model in which the mass is supported by the dips in the field lines, Kuperus Raddu model in which mass is supported by reconnection of active region field with quiet region field and the Mcville model in which the shear provides a magnetic spiral that supports the mass Latest models treat the system as a steady state re connection

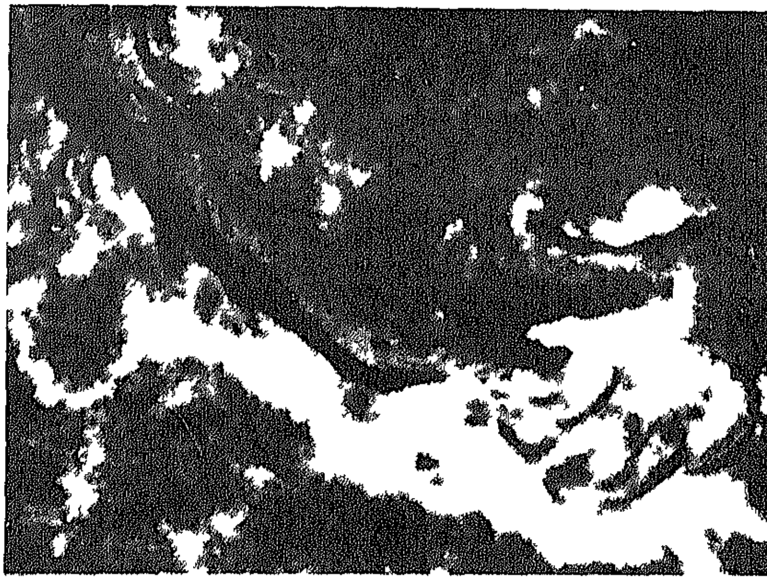

Fig.7(a) A Balmer H alpha filtergram showing a bright chromospheric flare

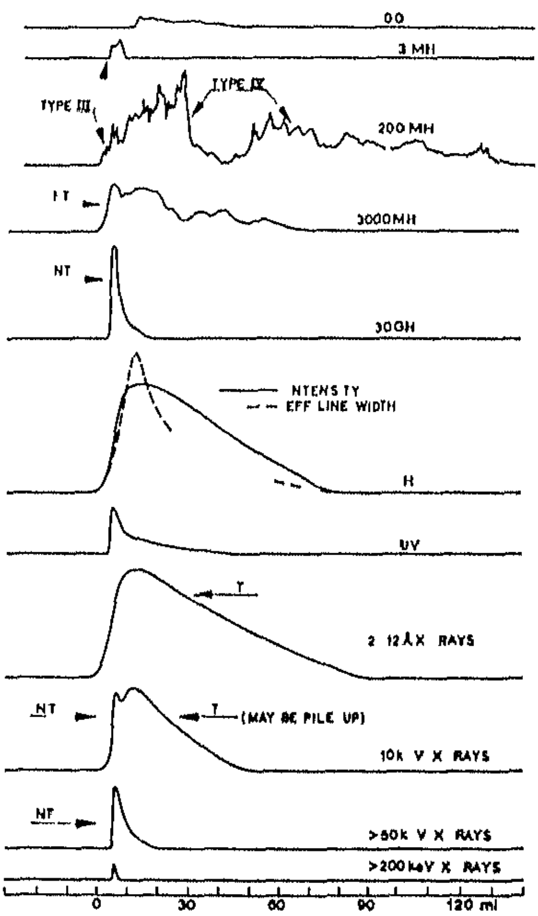

Fig.7(b) Curves showing typical time variation of radiations in different wavelengths during a flare

4. Flares

Flares are small scale sudden events on the sun in which large amounts of energy (~ 10^{29} – 10^{32} erg) are released from the sun from a small volume with dimensions of a few thousand kilometers on timescales of a few seconds to a few tens of minutes (Figures 7(a) and 7(b))

The released energy is detectable as excess emission over the whole electromagnetic spectrum, and often in the form of highly accelerated particle which lead to various radio bursts and to detectable effects in the atmosphere and environment of the earth

Most flares are associated with active prominences of many shapes sizes and dynamical properties, like loops, surges L sprays, disperation brusques L and so on

4.1 Theoretical Problems

Most studies of flares are addres ed to the following key questions (1) process of energy build up in small regions of the magnetic structure, (ii) process of instability that trigger the flare and (iii) mechanisms of conversion of magnetic energy into various form of radiation and particle accelerations in the proportions in which they are observed

4.2 Models

Two broad categories of models exist (i) Sudden rise and rearrangement of an existing magnetic loop and (ii) sudden reconnection of the magnetic structures (see "Solar Flares by E R Priest)

5 Activity Outside Active Regions

The following phenomena constitute 'small scale activity spread all over the sun

5 1 Ephemeral Active Regions

These are seen in whole disc magnetograms as tiny bipolar magnetic regions scattered all over the disc (Figre 8)

Sizes ~10^{8} – 10^{9} cm Magnetic fluxes ~ $10^{18.5}$ – $10^{19.5}$ Mx Life spans hours > 1 day Number ~100 per day, distribution All over the disc at all latitudes upto the poles Sunspot cycle variation Abundance in phase with sunspot abundance

5 2 X ray Bright Points

These are tiny emission regions seen on X ray images of the sun which have to be taken using rockets or space crafts (see Figures 9 11 in "Structure of the Solar Corona' this proceedings)

Sizes ~10^{8} – 10^{9} cm, Life spans ~ 8 hrs (≤ 1 day), Number 100 per day, Distribution All latitudes upto poles less in conventional active regions which themselves appear as bright X ray plages Sunspot cycle variation Abundance varie during sunspot cycle in antiphase with sunspot abundance

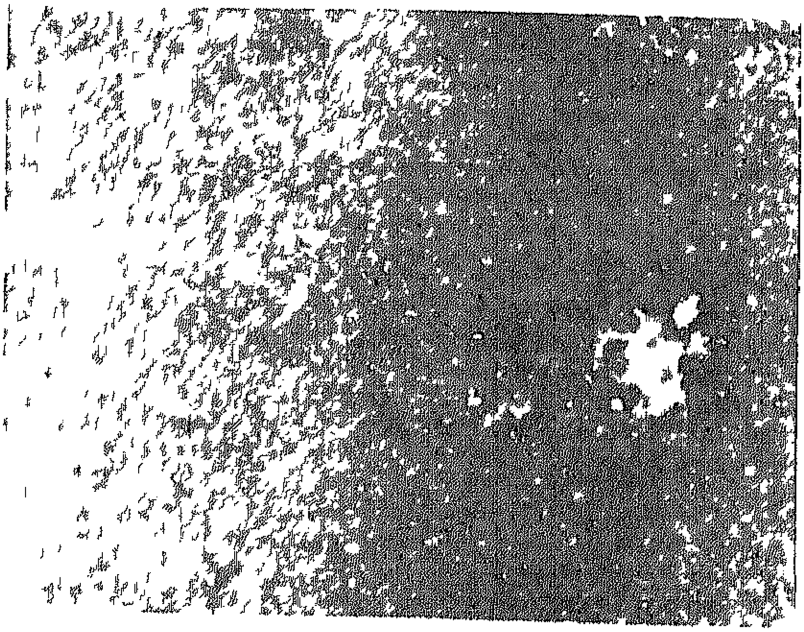

Fig 8 Magnetogram showing the longitudinal component of magnetic field on a 1000 x 12000" area on the Sun's surface in bright and dark depending on the field polarity at each point (phenomenal active regions are marked by circles)

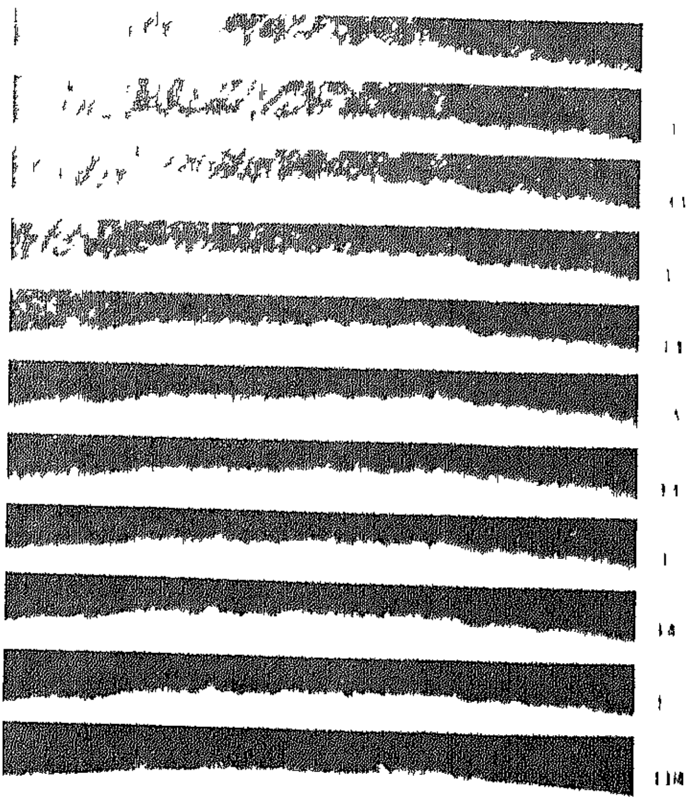

Fig.9 Spicules on the Sun's limb observed at various wavelengths in the red (positive) and blue (negative) wings of the H alpha line

5 3 Coronal Mass Ejections

These are seen as shortlived enhancements in the solar wind, and in coronograph pictures as sudden changes in the largescale structures of the solar corona (see Figure 15 in Structure of the Solar Corona", this proceedings)

Association with other events ~40% with flares, ~ 70% with errupting prominences ~ 48% with neither flares nor prominences, Speed 1200 kms $^{-1}$ in flare associated events ~ 600 kms $^{-1}$ in prominence associated and ~ 500 kms $^{-1}$ in "spontaneous' events Frequency Provides > 5% of the solar wind mass flux

5 4 Strong Thin Magnetic Flux Tubes

Most of the magnetic flux on the sun, in quiet as well as active regions excepting sunspot, is concentrated in "strong thin magnetic flux tubes of dimensions < 1 (≤ 700 km) and magnetic field intensity ~1000 2000 G They are responsible for most of the chromospheric emission concentrated along boundaries of supergranules

5 5 Spicules

These are hair like 'mini prominences' on the sun's limb seen in 1" resolution filtergrams in the H alpha emission Along these, matter is tossed up into the lower corona (see Figure 9) (Most of the matter however falls back undetected) Diameter ~ 500 1200 km, Heights ~ 6000 9000 km, Life spans ~ 3 5 min, Velocities ~ 20 40 km s^{-1} Temperature ≈ ~16000 K, Total number on the sun s surface ~ 10^5 10^6

6. Importance of Studying Solar Activity

Phenomena similar to solar activity have been detected on many other stars The study of solar and stellar activity phenomena are of vital importance in extending our knowledge of stellar structure and evolution beyond the conventional spherically symmetric non rotating, non magnetic stars with only radiation and convection as mode of energy transport They provide opportunities to study the intraction of ionized matter and electromagnetic fields on scales that can never be produ ed in any laboratory Solar activity has short term as well as long term ffects on the atmosphere and environment of the earth No wonder that most efforts in solar physics other than those in helio seismology are directed in the study of solar activity

7 Reference Material

Literature on solar activity is vast How ver condensed reviews on individual phenomenon can be found in various issues of Annual Reviews of Astronomy and Astrophysics reports of IAU Commissions 10 and 12, in "The Physics of the Sun' Volumes I III (ed Sturrock) in books 'Solar Magnetohydrodynamics and 'Solar Flares' by E R Priest Solar Flares by Z Svetska, Volume No 100 of the Journal Solar Physics General: 'Our Tubulent Sun' by K Frazier

Acknowledgement for Figures

1 Kodaikanal Observatory, 2,3,6 'Our Turbulent Sun , 4,7(a),9 Quiet Sun"; 7(b) 'Solar Flares", 8 Solar Physics'