Equatorial spread-F—Recent developments

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Recent developments in understanding the phenomenon of equatorial spread-F are reviewed. Emphasis is on the rocket-borne in situ studies of last decade, several of which were made from SHAR in India. Power spectral features of the electron density irregularities in different scale sizes and the mechanisms responsible for them are summarized. Recent developments in the ground-based optical techniques are described. The outstanding problems and the need for multi-technique campaigns are highlighted.

1 Introduction
The appearance of diffuse F-region trace on ionograms is termed as spread-F. It is over five decades since equatorial spread-F was first reported by Booker and Wells1 from ionosonde data at Huancayo. Equatorial spread-F is a nighttime phenomenon and restricted to latitudes up to about ±20° centred on dip equator2,3. A wide range of scale sizes in plasma density irregularities extending from few hundreds of kilometres down to a fraction of a metre are associated with equatorial spread-F and give rise to various phenomena like radar backscatter and radio wave scintillations. A great deal of work has been done on this subject, based on a variety of ground-based, rocket- and satellite-borne in situ experiments and numerical simulation studies. These results have been documented in reviews by many workers4-6.

The equatorial spread-F (ESF) studies were primarily based on ionospheric soundings during the first three decades following the first observations made by Booker and Wells1. The morphological features of the occurrence of spread-F like temporal and spatial variations, magnetic activity effects and the association with the post-sunset rise of F-layer preceding the onset of spread-F are well known7. Gradient drift instability (GDI) has emerged as one of the most promising mechanisms responsible for the generation of irregularities to explain bottomside equatorial spread-F (Ref. 8). However, inadequacies of the then existing theories were pointed out by Farley et al.9 based on the first comprehensive measurements from the VHF backscatter radar at Jicamarca. These observations showed that the ESF irregularities could be located in the bottomside or topside F-region and under conditions when F-layer is moving upwards, downwards or is stationary. Balsley et al.10 and Haerendal11 proposed the collisional Rayleigh-Taylor instability (RTI) to account for the irregularities seen both on bottomside and topside. Haerendal11 also suggested the concept of hierarchy (multi-step process) whereby the primary instability is gravity-driven on vertical density gradients and subsequently the instabilities grow on the gradients caused by primary instability. Each succeeding process is driven by smaller and smaller scale density gradients, thus giving rise to a spectrum of scale sizes. Further refinements in the Jicamarca radar resulted in the radar maps depicting the time evolution of the 3m irregularities. The plasma structures seen in such radar maps were suggested by Woodman and LaHoz12 as an evidence of the plasma depletions (arising due to RTI) moving upwards with large velocities.

First numerical simulation of the long wavelength RTI mechanism by Scannapieco and Ossakow13 could explain the observed features of the Jicamarca results. Such depletions were later observed by satellite-borne in situ instruments14. Further evidence of the bubble concept came from the near-simultaneous coherent and incoherent backscatter results from Altair which showed radar backscatter collocated with plasma depletions15.

2 Power spectral features of irregularities
The plasma density irregularities associated with ESF encompass a wide spectrum of scale sizes. Livingston et al.16 have classified them into the following categories: (i) planetary scale (>1000 km), (ii) medium scale (10-1000 km), (iii) intermediate scale (0.1-10 km), (iv) transitional scale (10-100 m) and (v) short wavelength scale (<10 m). Kelley17 has used essentially similar classification of the irregularities based on the rocket in situ spectra, the differences being intermediate scale from 0.1 to 20 km and long wavelengths above 20 km.
Power spectra of the type $k^{-2}$ were reported for satellite observations by Dyson et al.\textsuperscript{18} These observations were in the scale size range from a few km to 70 m. Rocket observations also showed similar spectral form\textsuperscript{19,20}. At first it was thought that spectral index of $-2$ is fundamental to ionospheric irregularities. However, Woodman and Basu\textsuperscript{21} showed that $k^{-2}$ dependence overestimates the power observed at 3 m. An extrapolation of $k^{-4}$ to $k^{-5}$ from 70 m to 3 m was found to be adequate to explain the observed power at 3 m. With the availability of radars at shorter wavelengths (at Altair at 96 cm and 36 cm and at Tradex at 11 cm), this extrapolation was, however, seen to underestimate power at 36 and 11 cm. Thus, it became obvious that the spectral forms are different in different scale size ranges. First, attempts were made to study the spectral form in different scale sizes, particularly, in the transitional and short wavelength scales during the PLUMEX campaign from Kwajalein\textsuperscript{22}. Two rockets were launched during July 1979 with plasma probes capable of a resolution up to about 1 m. The measurements covered the intermediate, transitional and short wavelength scales. In the transitional wavelength region, spectra of $k^{-5}$ type were observed in electron density irregularities above 280 km altitude\textsuperscript{23}.

Simultaneous electric field fluctuations showed spectra of $k^{-3}$ type at such altitudes. This was consistent with the explanation in terms of gradient-driven drift waves which act on the steep gradients caused by the primary larger wavelength instability. Below 280 km, shallower ($k^{-2}$ type) spectra were noted. Another finding which came from PLUMEX campaign was the observation of a break around 1 km wavelength in the spectral form in the intermediate scale range (shallower spectra with index less than 2).

Singh and Szuszczechwicz\textsuperscript{24} reported the first composite spectral picture in different scale sizes based on rocket and satellite in situ observations. Fig. 1 shows the vertical spectral picture based on PLUMEX rocket-borne data. The average spectral slope value found was $-1.5 \pm 0.4$ in the medium scale (1-40 km). In the intermediate wavelength scale the average index was found to be $-2.4 \pm 0.2$. This is in close agreement with the spectral indices obtained from simulation studies based on collisional RTI (Ref. 25). In the transitional scale, steep spectra with index value of $-4.8 \pm 2$ were found. Such spectra were found to be collocated with steep density gradients. In the short wavelength scale, often the power is less than the noise level. But spectra with significant signal show breaks around 3 m, suggesting the role of lower hybrid instability. In some of the spectra, there were multiple spectral peaks with equal power lying between 10 and 3.5 m. The horizontal wavenumber spectra shown in Fig. 2 are based on plasma probes flown on S3-4 satellite orbiting at low F-region altitude (270 km). The spectral index values found are $-1.4$ in the medium scale (1-60 km) and $-2.5$ in the intermediate scale (80 m-2 km). In the transitional scale, the index is $-1.3$ but with large standard deviation; the individual values varying between 0 and $-3$. Lower spectral index values in the satellite data (transitional
wavelengths) were suggested to be due to altitude threshold above which only steep spectra are noted.

3 Recent in situ observations

In the decade covering post-PLUMEX period, a number of rocket campaigns have been attempted, particularly, in India to study ESF. In the American zone, multi-technique campaign 'CONDOR' was attempted during March 1983 (Ref. 26). Table 1 lists all the rocket experiments conducted so far to study ESF. The rockets were launched from four locations under different ionospheric and geophysical conditions. Table 1 lists the location, time of launch, sunspot number, $k_p$ index, the instruments flown, apo-gee of the rocket, the base of the F-layer and the F-layer movement.

3.1 CONDOR campaign

Two rockets instrumented with probes to measure electron density, electric field and energetic particles were launched from Punta Lobos. One of the rockets was launched on 1 Mar. 1983 when F-layer base was high (above 400 km) and the other on 14 Mar. 1983 with F-layer base below 300 km. In addition, a number of ground-based experiments were conducted for complementary information. These included the VHF radar at Jicamarca, 14 MHz HF radar at Ancon, VHF, UHF and GHz

<table>
<thead>
<tr>
<th>Location</th>
<th>Date &amp; Local time (hrs)</th>
<th>Sunspot No., $R_p$</th>
<th>$k_p$ index</th>
<th>Payload</th>
<th>Apogee km</th>
<th>F-layer base km</th>
<th>Ionospheric condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>NATAL (6°S, 35°W, dip 6°N)</td>
<td>18 Nov. '73, 1902 LT</td>
<td>32</td>
<td>3-</td>
<td>LP Ba release</td>
<td>640</td>
<td>UP - DN 250</td>
<td>Layer ascending (radar/Ba release)</td>
</tr>
<tr>
<td>PUNTA LOBOS (13°S, 77°W, dip 1°N)</td>
<td>28 Mar. '74, 2100 LT</td>
<td>34</td>
<td>4+</td>
<td>IMS ESA SPS UVP/VP</td>
<td>742</td>
<td>UP 250 DN 265</td>
<td>Small upward motion</td>
</tr>
<tr>
<td>PUNTA LOBOS [CONDOR]</td>
<td>1 Mar. '83, 2150 LT</td>
<td>86</td>
<td>7</td>
<td>LP EF EPD</td>
<td>590</td>
<td>UP 440 DN 390</td>
<td>Layer descending (radar)</td>
</tr>
<tr>
<td>KWAJALEIN (9°N, 167°E, dip 9°N) [PLUMEX]</td>
<td>17 July '79, 0031 LT</td>
<td>153</td>
<td>1+</td>
<td>PP EFP MS</td>
<td>590</td>
<td>UP 240 DN -</td>
<td>Layer descending (ionosonde)</td>
</tr>
<tr>
<td>SHAR (14°N, 80°E, dip 11°N)</td>
<td>16 Feb. '82, 1843 LT</td>
<td>133</td>
<td>2+</td>
<td>Ba-Sr releases LP, MS</td>
<td>364</td>
<td>Not seen</td>
<td>Layer ascending (ionosonde)</td>
</tr>
<tr>
<td>SHAR</td>
<td>1 Mar. '82, 1842 LT, 1905 LT</td>
<td>129</td>
<td>6+</td>
<td>Na releases LP, MS</td>
<td>364</td>
<td>Not seen</td>
<td>Layer ascending (ionosonde)</td>
</tr>
<tr>
<td>SHAR</td>
<td>1 Oct. '80, 2103 LT</td>
<td>150</td>
<td>1+</td>
<td>LP</td>
<td>349</td>
<td>UP 250 DN 260</td>
<td>Layer descending (ionosonde)</td>
</tr>
<tr>
<td></td>
<td>23 Nov. '82, 2040 LT</td>
<td>91</td>
<td>6+</td>
<td>LP</td>
<td>335</td>
<td>UP - DN 320</td>
<td>Layer descending (ionosonde)</td>
</tr>
<tr>
<td></td>
<td>29 Nov. '82, 2220 LT</td>
<td>91</td>
<td>5+</td>
<td>LP</td>
<td>332</td>
<td>UP 235 DN -</td>
<td>Layer descending (ionosonde)</td>
</tr>
<tr>
<td>SHAR</td>
<td>4 Oct. '88, 2130 LT</td>
<td>125</td>
<td>1</td>
<td>LP EF</td>
<td>345</td>
<td>Layer descending (ionosonde)</td>
<td></td>
</tr>
</tbody>
</table>

Note: LP, Langmuir probe; PP, Plasma probe; IMS, Ion mass spectrometer; EFP, Electric field probes; SPS, Soft particle spectrometer; MS, Mass spectrometer; UVP, VP, Ultraviolet and visible photometers; RB, Radio beacons
scintillation recordings at Ancon which included VHF spaced receiver measurements to determine the horizontal drift velocity, digital ionosonde at Huancayo with echo location capability and Fabry-Perot interferometer at Arequipa to measure neutral winds. The results from this campaign have been reported in a series of papers with an overview by Kel-ley et al.26 The in situ observations verified the results of PLUMEX campaign with steep spectra of \( k^{-5} \) in transitional scale27. The \( k^{-3} \) type spectra for electric field was also verified. In the intermediate scale, shallower (index less than 2) spectra were also confirmed28. This shallowing of power above 1 km is significant, as none of the simulation studies have so far yielded an index less than 2. At the larger wavelengths the plume separation scales of about 150 km were noted from radar data and were suggested to be due to a generalized RTI which included velocity shears. Rocket-radar data also showed that during rapid decreases of the layer the ionosphere is tilted with westward gradients. With eastward winds this situation is suitable for the growth of irregularities. In addition to the in situ results, the CONDOR campaign has demonstrated the usefulness of the radio scintillation technique29. The radar backscatter with extended plumes were found to be associated with strong scintillations (1.7 GHz). The observed scintillation levels were also found to be compatible with the ambient density and irregularity parameters observed in situ. The spaced receiver drifts also were in agreement with those measured by radar interferometer.

3.2 Campaigns in India

There have been eight rockets launched from SHAR in India in two types of campaigns. First type of the campaign concerned with the study of the onset conditions of spread-F. Under this programme (attempted twice), RH-560 rocket was launched with a vapour release experiment during evening twilight followed by a launch of another rocket instrumented with Langmuir probe (LP) and mass spectrometer30,31. On both the occasions the F-layer base was above the apogee of the rocket at 364 km. One of the vapour release experiments had multiple blob releases to measure electric fields and neutral winds at four altitudes. Fig. 3 shows the zonal, meridional and vertical winds obtained from the rocket experiment on 16 Feb. 1982. The presence of vertical shears in both zonal and meridional winds and the presence of significant vertical winds (up to 40 m/s) were the major results from this flight30.

Fig. 4 shows the electron density plotted along the rocket trajectory for the flight on 29 Nov. 1982. Depending on the nature of the gradients, the trajectory has been marked as A through I. Strong irregularities have been found in the region of downward density gradients (B and H) and their absence in the region of upward gradients (C, G) supports the gradient drift instability mechanism. It must be pointed out here that the F-layer was descending with 35 m/s at the time of measurements. Near the apogee, there were strong irregularities, but in the absence of information on vertical gradients it is difficult to ascertain the likely mechanism. However, absence of appreciable horizontal gradients and the higher growth rate for RTI than for GDI at this altitude, lead to the conclusion that the irregularities are most likely due to RTI mechanism. Examples of the power spectra computed from the electron density fluctuations measured during this flight are shown in Fig. 5. Also shown in Fig. 5 are the raw data in log scale. Spectral slopes have been determined by straight line fit in the wavelength range 20-200 m. One distinct result from the spectral studies of electron density irregularities in the 20-200 m range
from SHAR was that no difference was noted in the spectral features with altitude. This is in contrast to the results in the PLUMEX and CONDOR campaigns. The spectral index \( n \), in fact, showed (Fig. 6) a linear relationship with the integrated power \( P_T \) by the relation

\[
n = -5.43 - 0.081 P_T \text{ (in dB)} \tag{1}
\]

This shows that maximum possible value of the spectral index would be \(-5.43\). This is in agreement with the laboratory experiments on drift waves. The normalized spectral index (at \(-10\) dB) as a function of altitude was shown to be independent of altitude (230-332 km).

### 3.3 Campaign of October 1988

The most recent rocket launch from SHAR on 4 Oct. 1988 carried a Langmuir probe and two pairs of electric field probes to measure fluctuations in electron density and electric field along and perpendicular to the rocket spin axis. Data from this flight are being analysed. This is the first time that simultaneous scintillation and good ionosonde data were also available from SHAR. Fig. 7 shows the height variation of the F-layer \( (h'F) \) and the vertical drift computed from the change in \( h'F \) values using rapid sequence of ionograms. The rocket launch at 2130 hrs IST is also marked in Fig. 7 with the altitude covered. The top boundary of the shaded region shows the maximum altitude at which range spread-F was seen in the ionograms. Large values of

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Fig. 4—Electron density measurements by Langmuir probe from SHAR on the night of 29 Nov. 1982, plotted along the trajectory [The trajectory is divided into nine regions (A through I) based on the characteristics of the irregularities and gradients (after Prakash et al.)]

Fig. 5—Examples of the power spectra of electron density irregularities on 29 Nov. 1982 with straight line fit in the wavelength region 20-200 m [Raw data in log scale are also shown at the top frame (after Prakash et al.)]
vertical drift velocity \( V_x \) (up to 80 m/s) are noted prior to the launch. It must be noted here that at a station away from the magnetic equator neutral winds also contribute to the vertical drift. However, the contribution of the neutral winds can be separated from simultaneous vertical drift obtained for a station near the magnetic equator. Periodic variations in \( h'F \) are the signature of gravity waves with horizontal wavelengths of a few hundreds of kilometres.

About 200 samples of scintillations, each of duration 100 s, were studied for power spectra. Fig. 8 shows an example of the spectrum. Since recording was at 10 Hz, this limits the spectra to 5 Hz or to about 20 m (assuming a drift of 100 m/s). On the longer wavelength side the Fresnel filtering puts a limit at about 800 m. The spectral slopes have been determined in the range 0.2-3 Hz. Most of the spectral index values range between \(-3\) and \(-5\) with a mean value of \(-4\). This would correspond to a one-dimensional index of \(-3\). Preliminary results of the scintillations recorded during this night have been reported by Chandra et al.\(^3\)\(^4\). Periodic fluctuations were seen both in \(S_q\) and \(n\) with a periodicity of about one hour. Spaced receiver scintillation measurements made earlier at Tiruchirapalli\(^3\)\(^5\) have shown eastward drift speed of the irregularities to be between 100 and 200 m/s. Periodicity of one hour would, therefore, correspond to a few hundreds of kilometres in the horizontal spatial scale. A plot of the mean values of \(S_q\) and \(n\) for different

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**Fig. 6**—Plot showing the variation of the spectral index with total spectral power \( P_T \) of irregularities (20-200 m) from data on 29 Nov. 1982 (after Prakash et al.\(^3\)\(^3\)).

**Fig. 7**—Curves showing the variations of F-region minimum height \( h'F \) and vertical drift as deduced from \( h'F \) changes on the night of 4-5 Oct. 1988 (The maximum altitude of the echoes in range-spread is also shown.)
ranges of $S_4$ values (Fig. 9) shows a linear relationship between the two parameters. Higher the scintillation index $S_4$, steeper is the spectral slope. Similar result has been obtained earlier by Basu et al.$^{36}$

4 Generation mechanisms

4.1 Large scales

Large scale waves are evident in the modulations of the bottomside structure deduced from radar data or $h F$ variations from ionosonde data$^{37,38}$. These structures have horizontal scales of about 200-1000 km. In recent scintillation measurements from SHAR, periodicity of about an hour to 75 min in the temporal variation of $S_4$ is seen which corresponds to a few hundreds of kilometres for an assumed drift velocity of 100 m/s. The plume separation scale of about 100-200 km is considered by Kelley$^{17}$ as due to the generalized Rayleigh-Taylor process which includes the effect of the vertical shears in eastward plasma drift that pushes the maximum growth rate towards larger wavelengths$^{39}$. However, the shears required are much higher than those observed at Jicamarca. Kelley et al.$^{26}$ argue that there could be localized regions of high shears. However, observations with good altitude resolution are required to test this, since there is not enough information about vertical shears.

4.2 Intermediate scales

The intermediate wavelengths have been studied most extensively. Generalized RTI is considered for the primary process. The generalized theory includes the effect of electric fields and neutral winds besides the gravity term. The growth rate factor is given by

$$\gamma_k = -\left(\frac{E \times B}{B^2} + \frac{g}{v_{in}} + W\right) \cdot \frac{L}{L^2} - \nu_R \quad \ldots (2)$$

Here, $-g/v_{in}$ is the gravitation term, $(E \times B)/B^2$ is the electric field term, $W$ the wind term, $L$ the gradient length for electron density and $\nu_R$ the effective recombination coefficient. The RTI acts on vertical gradients (upward) only, but the electric field term can operate both on vertical and horizontal gradients provided the drift is along the gradient. Likewise, the wind can be effective both on horizontal and vertical gradients depending on the direction of wind with respect to the gradients. The horizontal winds will be effective only when the ionosphere is tilted. Thus an eastward zonal wind ($u$) can be effective only when the gradients are partially westward. The growth rate for horizontal wind is given by

$$\gamma_u = \frac{1}{L} (u \sin \alpha) \quad \ldots (3)$$

where $\alpha$ is the tilt angle. Since the gravitation term is inversely related to the ion-neutral collision frequency, the growth rate for RTI term increases with altitude. At about 325 km the growth rate for RTI and GDI (for 25 m/s vertical drifts) are equal.

Sekar and Raghavarao$^{40}$ have considered the growth rate including the vertical wind term. They have shown that for an altitude of 300 km, downward wind of 16 m/s could be as effective as the gravitation term. It must be pointed out here that vertical winds of the order 20-40 m/s have, in fact, been observed from vapour release experiment conducted at SHAR. There has been good agreement of the
spectral index values (2-2.5) obtained from numerical simulations with those observed in situ. However, the recent result of shallow spectra (with spectral index less than 2) above 1 km is not understood, but efforts are on with simulation using vertical wind terms. Non-linear simulations have shown that vertical winds have significant growth rate even in the topside region where RTI was considered to be the main mechanism. Raghavarao et al. have computed growth rates for the gravity, electric field, eastward wind (for a tilted ionosphere of 10°) and vertical wind (20 m/s downward) for the observed gradients, winds and electric fields. These are shown in Fig. 10. At altitudes below 280 km, vertical winds of 20 m/s contribute maximum to the growth, whereas above it gravity has the main contribution. These calculations are based on linear theories only.

4.3 Transitional scale

Both PLUMEX and CONDOR data have shown steep \( k^{-5} \) type spectra. These results have confirmed the role of drift waves in producing irregularities in transitional scale range. However, the results from SHAR do not show such an altitude dependence of the spectra. Nevertheless, the results at SHAR show spectral index consistent with the drift wave theory. Low frequency drift waves are the likely candidates to account for the growth of irregularities in this range as proposed by Kelley et al.

4.4 Short wavelength

Shallowing of the spectra in short wavelength region has been observed in PLUMEX campaign. Apart from that, most of the information in the scale 1-10 m has come from coherent backscatter radars operating at 3 m, 1 m, 36 cm and 11 cm which show that \( k^{-5} \) extrapolation here underestimates the power. In situ electric field fluctuations in this wavelength range are difficult to measure because the boom separation length itself is of few metres. Lower hybrid drift mode which exists in the wavelength range between the electron and ion gyro-radius is the most likely mechanism. Clearly, there is a need for more in situ measurements in this wavelength region.

5 Recent developments in new techniques

The last decade has seen the development of new powerful techniques for measuring some key parameters very relevant for equatorial spread-F studies. Fabry-Perot interferometers have been used to measure temperature and winds in the thermosphere (250-300 km) using 6300 Å airglow emissions. This technique provides continuous measurement of neutral winds and neutral temperature through the Doppler shift and Doppler width from the emission line profile. In the Indian zone, temperature measurements have been made from Mt. Abu. Instrumentation has been upgraded for neutral wind measurements also. The advances in optical techniques have come to a stage where dayglow measurements are possible. A unique photometer capable of measuring line intensities of less than 0.1 per cent of the background continuum has been developed, and measurements made from SHAR. Another advancement has been the development of a low-light-level all-sky imaging system to map the dayglow emissions. This technique allows snap shots of the dayglow spatial intensity distribution which is related to the electron density. Thus large scale plasma depletions can be detected and followed. The technique thus permits study of the occurrence, spatial extent, degree of depletions and their movements. Such an instrument has been built recently in India and is being operated. In the ground-based radio techniques, new digital ionosondes capable of echo location have been used. Spaced receiver scintillation measurements have been used to determine horizontal plasma drift. The VHF backscatter radar, of course, gives drifts at different altitudes enabling one to know about the vertical shears.

6 Future scope

Even though considerable progress has been made in the understanding of the phenomenon of ESF, there are several unresolved problems to be answered. The role of various physical parameters in the triggering of ESF and the generation mecha-
nisms at different scale sizes are not fully understood. Particularly, there is a need for in situ measurements in the short wavelength and transitional scale wavelengths. Probes with capability to measure weak signals at 1 m scale are required for them. Day-to-day variability in the occurrence of spread-F is yet to be understood. Due to the complex nature of the phenomenon it is necessary to have spatial and temporal information of a number of key parameters. This requires a multi-technique approach. The key parameters which are essential to be measured are:

(i) Time evolution of the irregularities, (ii) DC electric fields (vertical and E-W), (iii) Neutral winds (meridional, zonal and vertical), (iv) Evolution of plasma depletions, and (v) In situ measurements of electron density, gradients in electron density, electron density and electric field fluctuations, ion and neutral composition, neutral winds and electric field both along vertical and horizontal directions.

The instruments required for measuring the above are ionosondes with HF Doppler, VHF backscatter radar (coherent and incoherent modes), 6300 Å photometer, imaging camera and spectrophotometers, spaced receiver scintillations, mass spectrometer with chemical release, along with in situ rocket-borne experiments with plasma probes and in situ satellite-borne experiments.

In the Indian context, an aeronomy satellite SROSS-3 is scheduled to be launched during 1991-92 time frame. This would carry (i) a Langmuir probe capable of measuring electron density with half a metre resolution and (ii) two pairs of double probes to measure electric field fluctuations along E-W and vertical directions. It would be ideal to have co-ordinated experiments in this time frame. Currently, a number of scintillation receivers are also operating. Fabry-Perot interferometer observations and imaging of 6300 Å emission are planned in near future. With the operating VHF backscatter radar at Thumba and the proposed MST radar at Tirupati (to be ready by 1991) it would be ideal to conduct major campaigns. These measurements should also be complemented by in situ rocket measurements. However, the presently available RH-560 rockets reach a maximum altitude of 325-350 km only. There is a need for rockets which can reach at least 500 km of altitude. This would enable us to have in situ measurements of irregularities just at the time of onset also.

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