

## Observations of Equatorial Spread F (ESF) using the Giant Meterwave Radio Telescope (GMRT), Global Positioning System (GPS) and geostationary satellites

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The present paper reports, for the first time, multi-frequency observations of amplitude and phase of the signal from a radio star, in conjunction with transmissions from Global Positioning System (GPS) and geostationary satellites, to study the development of equatorial spread F (ESF). A campaign mode observation of ESF was carried out at the Giant Meterwave Radio Telescope (GMRT), Pune (lat: 19.10<sup>0</sup>N, long: 74.05<sup>0</sup>E geographic; dip: 24<sup>0</sup>N) operated in the interferometry mode during March 25 through April 1, 2004. The amplitude and phase of signals at 235, 327, 610 and 1420MHz from a radio star 3C218 were recorded between 19 and 23LT. The 350km ionospheric pierce point of the source lies around 17<sup>0</sup>N and 75<sup>0</sup>E during the period of observation. A semi-codeless dual frequency GPS receiver was simultaneously operated from Pune to record plasma bubbles and associated structures, if any, on GPS links traversing the ionosphere in the region close to the magnetic equator. Routine monitoring of VHF and 1.5GHz transmissions from geostationary FLEETSATCOM (244MHz, 73<sup>0</sup>E, 350km subionospheric point: 21.10<sup>0</sup>N, 87.25<sup>0</sup>E geographic; dip: 28.65<sup>0</sup>N) and INMARSAT (1.5GHz, 65<sup>0</sup>E, 350km subionospheric point: 21.08<sup>0</sup>N, 86.59<sup>0</sup>E geographic; dip: 28.74<sup>0</sup>N) were done from Calcutta (lat: 22.58<sup>0</sup>N long: 88.38<sup>0</sup>E geographic; dip: 32<sup>0</sup>N). Simultaneously, under the GPS And Geo Augmented Navigation (GAGAN) operated by the Indian Space Research Organization (ISRO), the total electron content (TEC) as observed on several GPS links looking south from two stations, namely, Mumbai (lat: 19.09<sup>0</sup>N long: 72.85<sup>0</sup>E geographic; dip: 24.75<sup>0</sup>N) and Trivandrum (lat: 8.47<sup>0</sup>N long: 76.91<sup>0</sup>E geographic; dip: 0.6<sup>0</sup>S), were studied. The GMRT interferometry records show scintillations on 3 nights, namely, March 25, 26 and 29, 2004. Scintillations of both phase and amplitude were found to occur in distinct patches. On March 26, 2004, the occurrence of irregularities were found to be extensive causing amplitude and phase scintillations on 235, 327, 610 as well as 1420MHz starting around 20LT and extending up to 22LT. The most remarkable feature was the presence of smaller scale periodic structures in the phase records prior to the onset of scintillations. A spectral analysis of the periodic structure shows a preferred period of about 170s, which may be responsible for initiation of equatorial spread F. The GPS records from Pune showed a good correspondence with the GMRT interferometry data. Bite-outs in TEC were observed on March 25 and 26, 2004 on 8 to 10 GPS links starting around 19LT and sometimes extending to the post midnight hours. These periodic structures appeared on the leading (western) wall of the bubble. Scintillation observations from Calcutta utilizing satellite beacon transmissions from FLEETSATCOM and INMARSAT, and GPS match with the GMRT observations, of course with a systematic time delay. Observations under GAGAN, particularly from Mumbai and Trivandrum, corroborate the presence of bubbles and periodic structures recorded from Pune.