# New ionograms observed by satellite radio sounding from below of the F-layer maximum

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**Abstract.**

Ionograms that have never been observed before in topside ionosonde soundings are presented. They were recorded on the onboard ionospheric sounder operated on the MIR manned space station. A new type of ionogram, where the specific form of a reflection from the Earth is visible, is described. Some details of these ionograms from different parts of the Earth are shown and an explanation of their origin is given.

## 1 Introduction

During the Intercosmos-19 flight, it was shown that the investigation of the ionosphere is possible using transionospheric radiosounding (Danilkin, 1994), making sounding not from a height of 1000 km but from much lower ones (~ 350-400 km) where manned space stations fly. For such low orbits, the ionospheric sounder in some regions of the planet can be higher, lower or in the maximum of electron concentration of the F2 layer. In the middle latitudes region generally MIR was above the ionosphere maximum and in the region approximately from 30$^o$ S to 30$^o$ N, MIR rather often was below the F -region maximum. This paper describes the ionograms obtained in these conditions and their preliminary analysis.

Radiowave reflections from the ionospheric plasma and reflections from the Earth's surface are observed with the MIR Ionospheric Sounder. The group delay and amplitude of pulses after their passage from MIR up to the ionospheric maximum (topside or space bottomside sounding) and also down to the Earth and back (a double transionospheric sounding) are recorded.

The equipment (Danilkin, 1999) can store ionospheric information during MIR passes over various regions of our planet. The orbital inclination was 52 degrees. The MIR station ionosonde can also simultaneously transmit ionospheric information about zones over which it flies. A special 137 MHz telemeter transmitter was used for this purpose.

Instrumentation:

| | |
|---|---|
| Frequency band | From 0,3 up to 15.95 MHz |
| Number of sounding frequencies | 338 |
| Sounding pulse duration | 133μs |
| Intervals of sounding | 50 kHz |
| Output power | Not less than 250 W |
| Sounding range | Up to 1800 km |
| Virtual distance accuracy | 10 km |

The main ionospheric parameters (critical frequency in F layer, foF2, height of the maximum, hmaxF, and F layer half-thickness, q) were estimated (Danilkin and Viseman, 1997). Ionograms were used for the MUF determination. These data were the basis for a mathematical model of the ionosphere and for the calculation of  radio communication parameters.

The experiments on board the MIR station were conducted in very difficult conditions for radiosounding:

- The station was contaminated in the electromagnetic sense. There was much noise and interference;
- The station was rotating. Therefore the positions of the ionosonde antennas almost always were far from ideal for radiosounding;
- The station dimensions were such that almost the entire station was a passive antenna for the ionosonde, however the parameters of this antenna were not known

In such conditions the ionograms were noisy and it can be difficult to detect the signal.

Figure 1 shows the size and arrangement of various blocks of MIR station and arrangement of the ionosonde antenna.

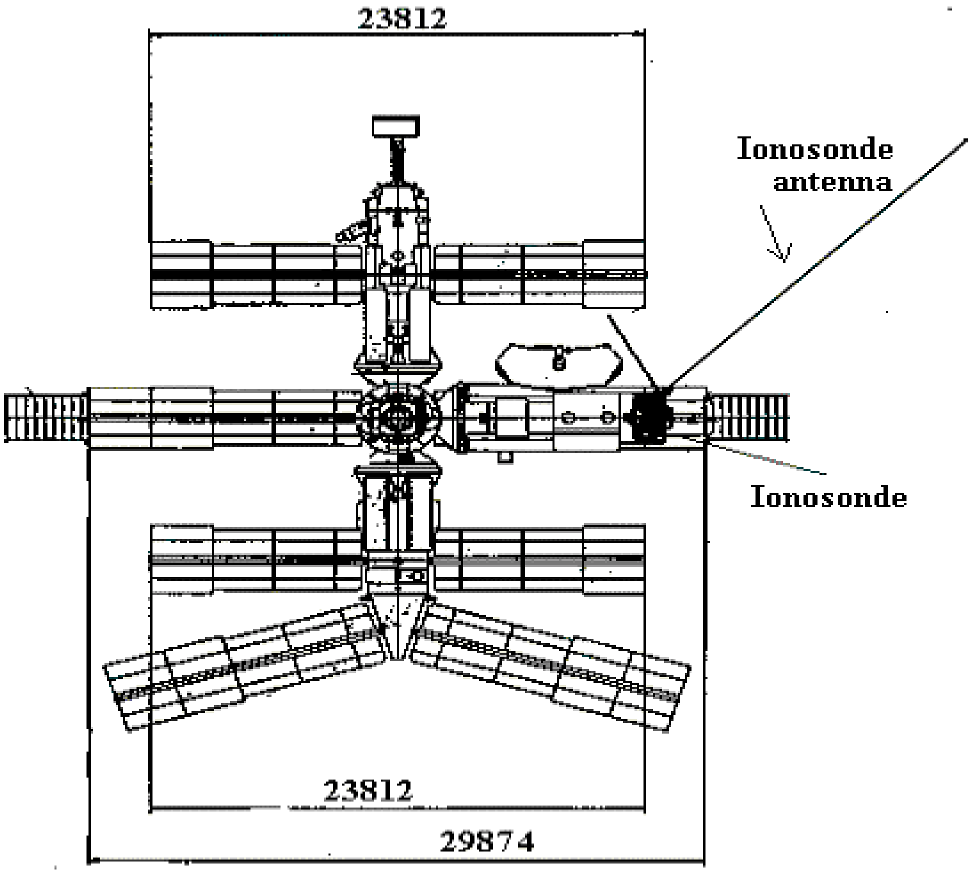


**Figure1.** The MIR station mainframes and the location of the ionosonde antenna.

## 2 The ionogram description and principal explanation

Among the ionograms recorded there are a large number of new ionograms. Figure 2 shows a portion of one such ionogram.  Other parts of the ionogram are excluded as superfluous, there being no ionospheric reflections. To reveal the ‘ionospheric signal’ in Figure 2 a sketch where the important details are shown and noise and interference are ignored accompanies the ionogram.

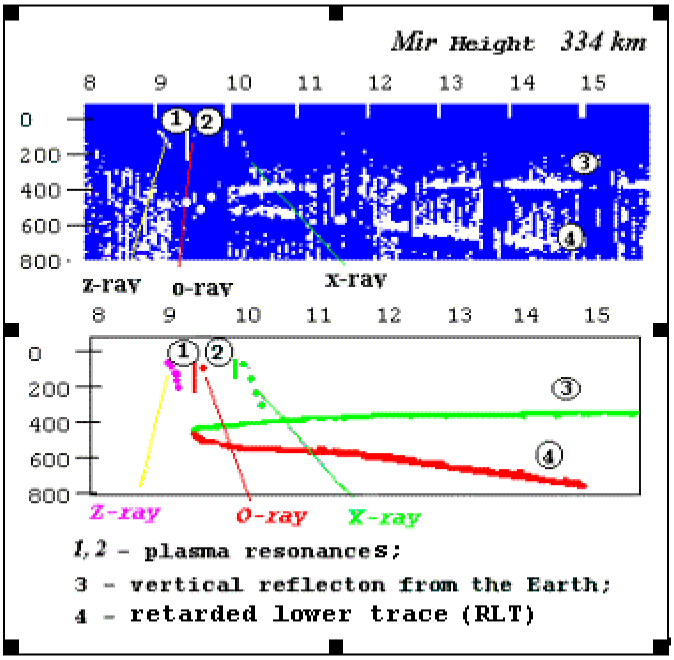


**Figure 2.** The top part of figure shows the real new ionogram received from 334 km satellite height. The bottom part of figure is a rough sketch, which is shown what ionogram details the author considers essential to the subsequent analysis

One can see that MIR is located below the ionospheric maximum. The trace reflected from the ground is fairly typical for topside sounding signals. However its lowest frequency is equal not to the ionospheric critical frequency (as it always is for at topside sounding), but to the plasma frequency in the vicinity of MIR, the latter fact being the strongest confirmation that MIR is below the height of layer maximum. Note that the frequency of the inflection point of the reflection from the ground is equal to the plasma frequency in the vicinity of MIR, also confirmed by the plasma resonance denoted in Figure 2 by numeral 1. Very short reflection traces from the ionosphere above MIR are also seen: z, o, and x are the reflection traces of the z, ordinary, and extraordinary components, respectively. The group delay (retardation) of the lower trace (RLT) is larger (see Fig. 2) than that of the signals reflected from the ground. The frequency range of RLT observed is higher than the F2-layer critical frequency at the MIR location. In such situations, hypothesising the presence of large-scale irregularities of the electron concentration in the region of the main ionospheric maximum makes it possible to offer an explanation for the typical features of RLT in terms of the "returning" terminology trajectories concept. RLT are formed due to the refraction of signals of different frequencies at a sharp lateral electron concentration gradient of the ionospheric irregularity. This refraction precedes or follows the oblique reflection of the signals from the ground and returning of the signals to the point of the MIR location.

The figure 3 illustrates this idea.

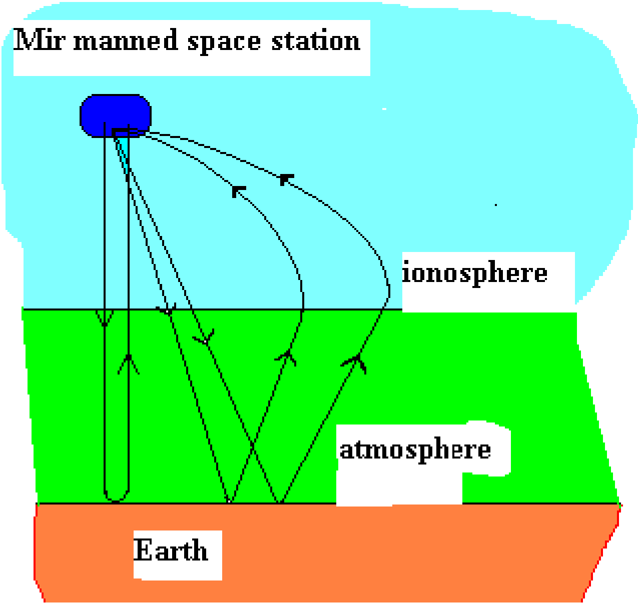


**Figure 3** shows the principle for the occurrence of RLT (see text) on ionograms, observed when the satellite is lower than the maximum of the F2 layer.

The calculations in the scope of the solution of the problem of fitting parameters of such irregularities of the simplest form to provide coincidence of the calculated and observed group delays of RLT have shown a presence of sharp positive gradients of the electron density. On the whole, the entire spectrum of ionograms with RLT indicates the very large dimensions of the irregularities.

## 3 New ionograms registered in various places of the globe

The number of ionograms showing RLT exceeds the quantity of "nomal" ionograms observed when MIR was below the F2 ionospheric maximum. They were obtained under different geophysical conditions and for various parts of the Earth. Table 1 presents information about the ionograms with the RLT obtained on board MIR station.

Table 1

| N | Time of Observation, Start Finish | Beginning. Geographical Coordinates. Latitude Longitude | Finish. Geographical Coordinates Latitude Longitude | MIR Height (км) |
|---|---|---|---|---|
| **3.1.1 3 March 1999** | | | | |
| 1 | 0942:44 | -4.81 89.22 | -4.81 89.22 | 349 |
| **3.1.2 10 March 1999** | | | | |
| 2. | 0401:13 0403:13 | -20.36 -67.99 | -26.18 -73.25 | 361 |
| **3.1.2.1 31 March 1999 – 01 April 1999** | | | | |
| 3. | 1655:48—1702:44 | -24.03 -82.08 | -2.97 -65.66 | 344 |
| 4. | 1830:17—1835:36 | -14.95 -97.7 | -0.07 -86.87 | 344 |
| 5. | 2004:15—2306:55 | -7.17 -115.15 | +1.12 -109.27 | 345 |
| 6. | 2304:46—2307:22 | -14.39 -167.01 | -6.39 -161.09 | 344 |
| 7. | 0213:14—0217:26 | +2.94 +159.02 | +15.87 168.55 | 345 |
| 8. | 0513:39—0514:41 | -4.68 +107.15 | -1.47 +109.42 | 344 |
| **3.1.2.2 21 April 1999** | | | | |
| 9. | 0524:03—0524:51 | +51.61 +68.33 | +51.81 +73.50 | 346 |
| 10 | 0714:26—0718:26 | +15.12 +125.41 | +2.81 +134.45 | 350 |
| **3.1.2.3 05 May 1999** | | | | |
| 11 | 1803:53—1806:49 | -44.37 +56.29 | -37.87 +68.13 | 372 |
| 12 | 1808:41—1808:57 | -33.12 +74.49 | -32.41 +75.34 | 369 |
| 13 | 1936:07—1939:35 | -43.14 +35.56 | -35.01 +48.83 | 370 |
| **06 May 1999** | | | | |
| 14 | 1825:44 1830:32 | +18.02 +115.83 | +31.82 +128.98 | 354 |
| 15 | 1832:08 1832:57 | 36.02 134.23 | +38.05 +137.15 | 355 |
| **3.1.2.4 02 June 1999** | | | | |
| 16 | 1935:53 1936:41 | +35.05 +65.06 | +32.95 +67.69 | 352 |

To describe the event thoroughly, the table contains several groups of ionograms on various days of this type that have been observed. On 31 March 1999, a diurnal series of observations was conducted from 0949 UT to 0930 UT on the following day. This group is shown to demonstrate the quantitative side of the phenomena. During the period mentioned 6 groups of ionograms of the type described were observed (see the top part of Table 1). They were predominantly observed in the latitude range from 20$^o$ S to 20$^o$ N. However, MIR sometimes was below the F2-layer maximum even orbiting at high latitudes. Line 8 in Table 1 provides information on such a case. Lines 9 and 10 are shown to illustrate especially long periods of observations of the ionograms considered. These lines show that the region forming the extra trace is extended in space and is a structure of the global scale.

While RLT on ionograms are very similar, nevertheless, ionograms from different places around the globe show some differences. To illustrate this, an ionogram series is shown in Figures 4 – 9, according to the data in the table №1.

Each of the following figures (4 to 9) consists of three parts:

- the top frame of each figure is a MIR ionogram;
- the middle frame shows the trajectory of MIR station superposed against the appropriate region of the Earth. The red point shows the position of MIR station at the moment the ionogram was recorded;
- the bottom frame is author's interpretation of the ionogram in the top frame.

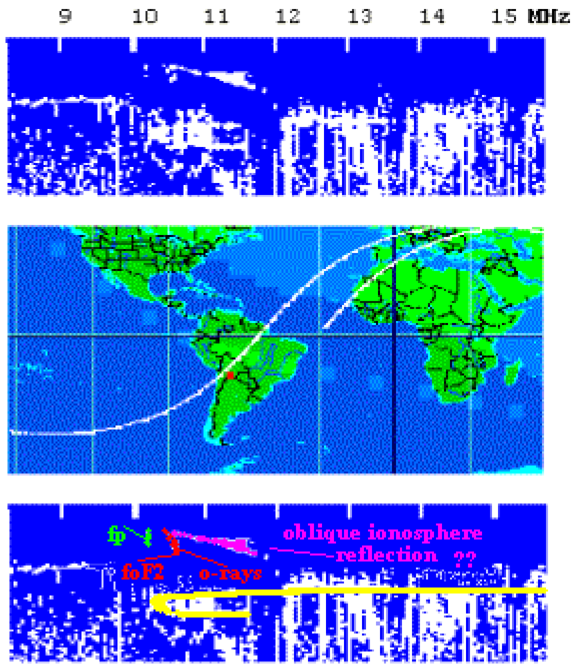


**Figure 4.** The direct reflection from the Earth (yellow), and also the RLT trace (yellow, also) is clear on this ionogram. Due to a clear plasma resonance (green) it is possible to identify a point of inflexion. The traces of an ordinary rays are seen satisfactorily (red) and it is possible to determine the critical frequency foF2. The reflections of the extraordinary waves are not visible. In their place, traces of, apparently, inclined reflection (pink) are visible. It is not possible to decide if this is ordinary or extra-ordinary propagation..

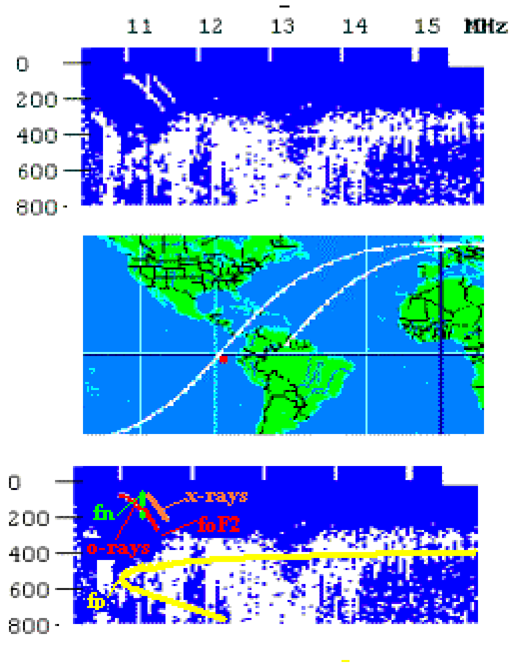


**Figure 5.** The ground reflections (yellow) are weak but it is possible to see them within the noise. The extra-ordinary-ray cutoff frequency (green) are clearer.  It is apparent that the RLT is present and proceeds higher in frequency than the critical frequency. The of ordinary and extraordinary rays traces are visible and it is possible to determine critical frequencies with an insignificant error.

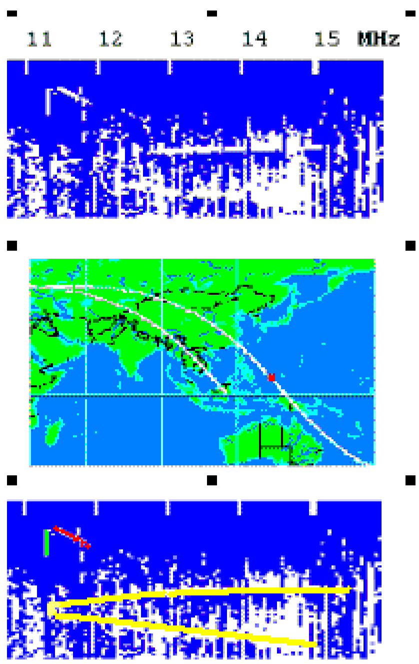


**Figure 6.** The ordinary ray reflections, the plasma resonance and inflexion point are all just visible. It is clear that the RLT proceeds lower in frequency than foF2. The ordinary component critical frequency cannot be seen clearly, but it can be estimated to within 0,5 MHz

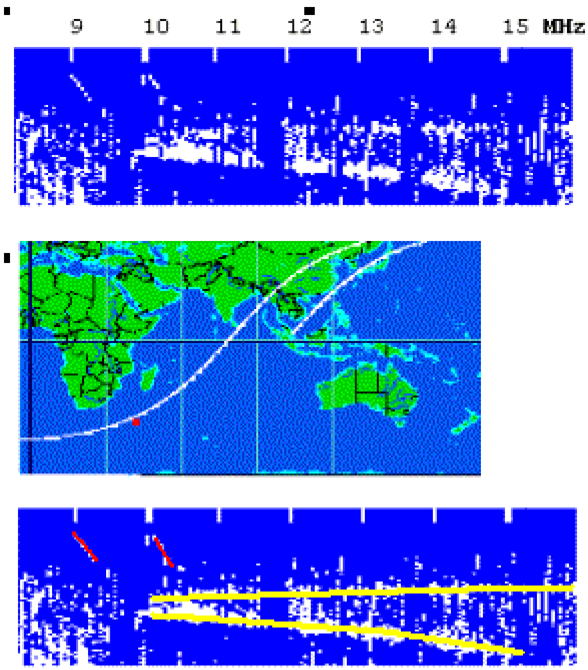


**Figure 7.** Ionospheric reflections are visible, but it is difficult to determine a type of waves present. Apparently, we can see a z-wave and x-wave. The critical frequencies, resonance and inflexion point are not visible. However, the vertical trace of reflection from the Earth and RLT is very clear. The RLT proceeds farther in frequency than foF2 and it is stronger, than the vertical reflection from the Earth.

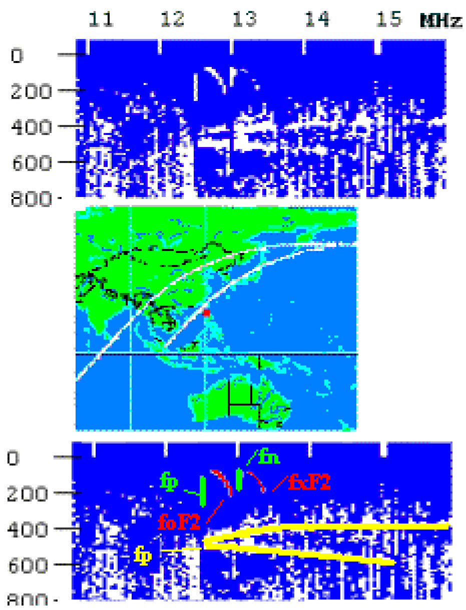


**Figure 8.** The plasma resonance, x-component cutoff-frequency, and inflexion point are clearly visible. Both the critical frequencies are determined. Also it is apparent that the RLT proceeds lower in frequency than foF2. The difference of group delays between reflection from the Earth and RLT on this ionogram is less than on the previous. It suggests further structure of a lateral wall of ionospheric irregularity

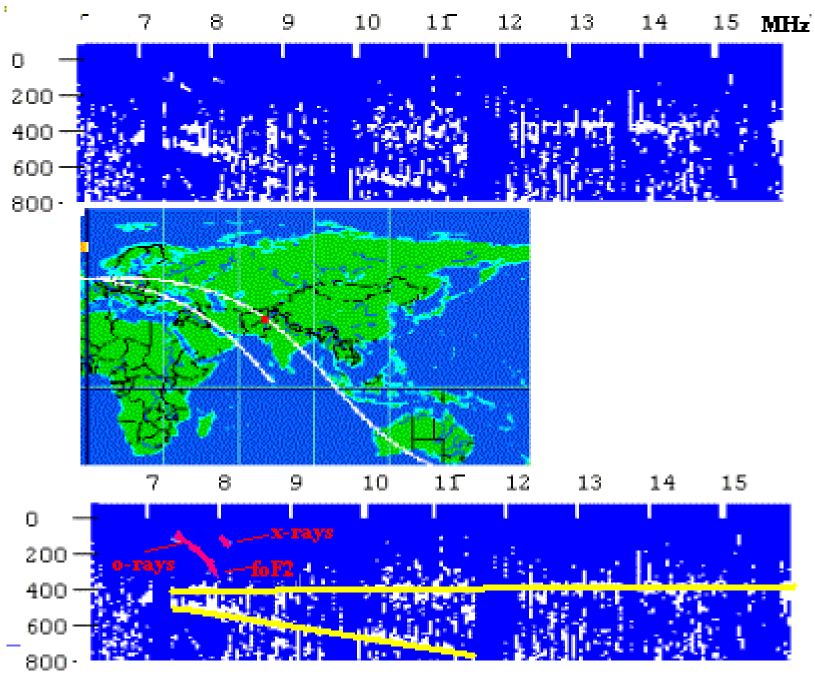


**Figure 9.** The z- and x- ionospheric reflection traces, inflexion point, the plasma resonance and cutoff frequency are practically not visible. However, the ordinary component, foF2, Earth reflections and RLT are seen clearly and the RLT group delay is greater than in the previous figure.

## 4 Conclusion

1. When ionograms were recorded when MIR was located below hmF2, the ionosphere maximum, off-vertical ionospheric irregularities were observed.
2. At least part of these irregularities have to have very large spatial sizes, as the duration of the RLT (Retarded Lower Trace) in time and in space suggests.

## 5 References

Danilkin N.P.,1994, Transionospheric radiosounding, JATP, v.56, n.11, p.1423

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