**On the broadening of spectral lines for the investigation of neutron stars**

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**Abstract**

Solar electromagnetic energy of wavelength range 0.1-0.8 nm, emitted during occurrence of Solar flare events and often called soft X-ray radiation, penetrates deep into the Earth′s atmosphere, where causes abrupt and intense changes of ionized medium within altitude range 50-90 km that corresponds to lower Ionosphere.

**Introduction**

Broadening of spectral lines by collisions with charged particles or Stark broadening is significant for many important astrophysical quantities as for example modelling of stellar plasma, analysis and synthesis of spectral lines, it enters in the calculations of absorption coefficient, opacity, radiative transfer, abundance determination, acceleration of gravity etc. Stark broadening is the most important pressure broadening mechanism of spectral lines in the conditions of neutron star atmospheres and their environment.

However, when Stark broadening parameters of Fe XXV lines are needed for neutron star investigations, they are calculated very approximately, and without taking into account the magnetic field (see e.g., Paerels 1997, Madej 1989, Majczyna et al. 2005, Suleimanov et al. 2014). Usually very simple formula of Cowley (1971) or approximate formula from Griem (1974) book (cf. Chap. IV 6) are used.

In this contribution we calculated widths and shifts of Fe XXV spectral lines broadened by collisions with important charged constituents of neutron star atmospheres, electrons, protons and Fe XXVII ions. Calculations have been performed for a grid of temperatures and electron densities for plasma conditions of interest for neutron star atmospheres and their environments. Since such results are also of interest for Virtual Observatories, we will prepare them additionally for implementation in STARK-B database (Sahal-Brechot, et al. 2015), which is also a part of Virtual Atomic and Molecular Data Center - VAMDC (Dubernet et al. 2010).

**Analysis and results**

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Analysis was conducted for short path VLF signals, with GQD signal depicted in detail. Examples of monitored Solar flare signatures on GQD signal, during two very active days and some representative examples of recorded VLF perturbations, induced by Solar flare events of moderate intensity within period of interest, are given in Fig. 2.

Sluggishness of the Ionosphere in analyzed cases is of absolute amount up to 2 min, for main signal extremum, both in case of amplitude (D\_A) and phase delay (D\_P). Examples of monitored Solar flare signatures on GQD signal, during two very active days and some representative examples of recorded VLF perturbations, induced by Solar flare events of moderate intensity within period of interest, are given in Fig. 2.



Fig. 1. VLF signals (in red) registered in Belgrade (star) by AbsPAL receiver in period 2004-2009

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Table 3. Parameters characterizing GQD/22.1 kHz signal propagation conditions under influence of considered X-ray Solar ﬂare events of moderate intensity

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| ﬂare date(dd-mm-yy)timeUTclass | time(UT) | signalstate | ΔA(dB) | ΔP(o) | β(km-1) | H′(km) |
|
| 07-04-0608:03UTC9.7 | **07:59** | preﬂare | -0.89 | 2.52 | 0.33 | 72.5 |
| 08:01 | Pmax | -1.72 | 7.68 | 0.395 | 70.5 |
| **08:02** | ﬂare Amin1 | -2.62 | 4.93 | 0.45 | 69 |
| 08:04 | Amax1 | -1.98 | -1.69 | 0.335 | 71 |
| 08:05 | Pmin | -1.99 | -1.78 | 0.335 | 71 |
| 08:12 | Amin2 | -2.34 | 3.09 | 0.394 | 70 |
| 08:32 | Amax2 | -1.71 | 6.28 | 0.395 | 70.5 |
| 08:43 | Amin3 | -1.55 | 4.48 | 0.37 | 71 |
| **10:20** | postﬂare | -0.53 | 2.31 | 0.325 | 72.5 |

**Conclusions**

Propagation model based on Wait′s parameters and LWPC calculations can be used for VLF signal sub ionospheric propagation simulations both for unperturbed conditions [14, 17-19] and perturbed conditions due to Solar flare events. Complexity of D-region response to incident X-ray radiation from Sun and variation of Solar flare events′ characteristics themselves, is the reason that issue has been treated from many and diverse aspects primarily regarding flare peak irradiance in perturbed state, relaxation period, different flare classes and on the other hand mid, low-latitude ionosphere etc. In this paper, utilization of LWPC code routine was applied to selected VLF data from second half of the 23rd Solar cycle, mainly from 2004 to 2008, with goal to inspect Solar flare signatures on VLF signals of relatively short paths, emitted from European military transmitters towards Belgrade AbsPAL receiver station.

In case of GQD/21.1 kHz signal, series of perturbations forced by Solar flare events were thoroughly reviewed and inspected in detail throughout entire time evolution of flare influence. Few chosen events are presented in this paper, with corresponding propagation parameters′ variations related to soft X-ray Solar irradiance. The Earth-ionosphere waveguide was modeled during the entire duration of analyzed flare events′ influence on the lower Ionosphere. Results obtained from LWPC software through conducted modeling procedure are in good agreement with real VLF signal measurements. It can be concluded that modeled averaged waveguide states realistically depict real states of the ionospheric plasma environments held in certain time periods along GQD signal path, as perturbed by these flare events, but also in unperturbed preflare and recovered postflare states.

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