Solar Service by SPOT, STOP, and RATAN-600

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Abstract. Solar service implies monitoring the Sun regularly or continuously in different wavelengths of the electromagnetic spectrum. The main purpose of such a service is to understand fundamental physical processes undergoing on the Sun and determine the parameters of coronal mass ejections (CMEs), flares, solar wind and etc., for practical applications by using data obtained by terrestrial or satellite telescopes. This paper briefly introduces the solar patrol optical telescope (SPOT) and solar telescope for operational prognoses (STOP) as two important systems which are sufficiently effective for ground based solar service. We also note the importance of the solar spectral polarization complex (SSPC) at RATAN-600, which is unique because of its ability to monitor the solar corona in a range of radio frequencies from 3 GHz to 17 GHz. Such spectral and polarization measurements with great resolution makes RATAN-600 a vital instrument for frequency tomography of the corona. Also, we demonstrate that such spectral measurements by SSPC allow us to estimate electron number densities at flaring sites.

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The Sun being the closest star is therefore capable of revealing a wealth of interesting and exotic physical phenomena, which are important to understand both from fundamental and practical points of view. Our star has so many mysteries that only a dedicated service which is otherwise called as the solar service or regular monitoring and observation in all possible wavelengths can help us resolve them. The more frequently we observe the better we can grasp the physical processes taking place on the Sun and model them. As a result, many space-borne telescopes such as YOHKOH, SOHO, TRACE, SDO and etc., were launched to observe the Sun in UV and X-ray wavelengths as these wavelengths are otherwise impossible to observe from the Earth.

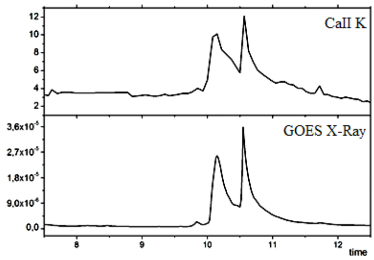

Fig. 1: Flare on 2013.10.24

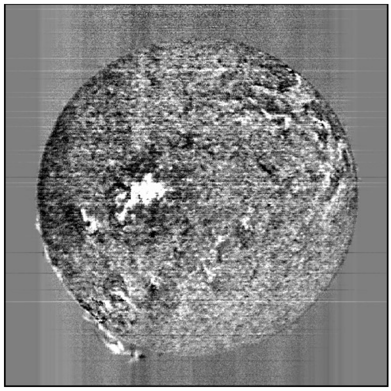

Fig. 2: CaII K (SPOT) Dopplergram of CME on 2014.11.09

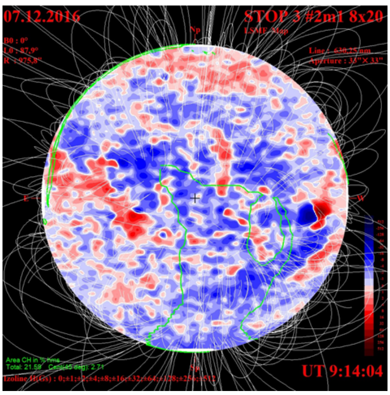

Fig. 3: Typical magnetogram of STOP showing extrapolated magnetic field lines and coronal holes

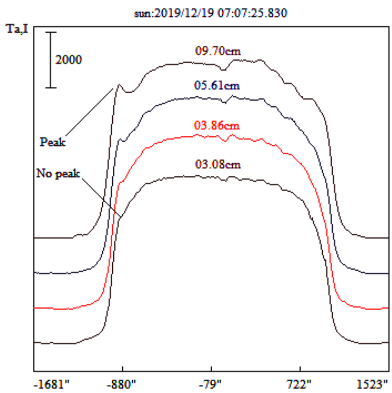

Fig. 4: Full disc 1D intensity profile in the radio spectrum taken by SSPC of RATAN-600

Given the proximity of the Sun, the effects of solar flares and CMEs cannot be exaggerated on the Earth's magnetosphere.Therefore, the need for solar service to help forecast such energetic phenomena is further augmented due to the rapid progress in satellite communications' technology, human space exploration like ISS (International space station), air travel and etc. Such a forecast can be made from ground based continuous solar monitoring in the well know wavelengths of CaII K and H-α,which form in the mid and upper chromospheres respectively. CaII K line is especially important because of its strong correlation with the hard X-ray flux during solar flares as shown in fig.1 and also bright features observed in this line depict regions with enhanced magnetic activity.

Keeping in view the need for the solar service and the high cost of the space borne telescopes, special ground-based telescopes such as SPOT and STOP are developed. Apart from being several times cheaper than their space counterparts they can easily be upgraded with new equipment and capabilities keeping in line with the modern developments in the instrumentation technology.

The scientific task of the SPOT is to observe various manifestations of solar activity, such as, plages, filaments, prominences, flares, CMEs, and etc. A classic example of a CME observed by SPOT in CaII K is shown in the fig.2. SPOT continuously registers images of the full solar disc in CaII K 3934 Å, H-α 6563 Å spectral lines. The optical resolution of the SPOT is about 1 arcsec for CaII K line and the telescope is designed to work continuously throughout the day in a semi-automatic mode with a lifetime of 25 years. Images in CaII K, H-α can be recorded once every minute. The most important feature of this telescope is that it can scan the Sun completely in a given wavelength interval and therefore makes it possible to extract dopplergrams from the spectral data. In this way one can estimate the kinematic parameters of the eruption events like CMEs. Also, dopplergrams allow us to investigate oscillations of filaments and prominences which thereby help us to use the data for prominence seismology. It was shown by Naga Varun (2018) that SPOT can successfully be used to give short term solar flare forecasts by analyzing the spectral profile of the CaII K line from the active regions. This proves that SPOT is a valuable instrument for solar service and space weather forecasting.

As most of the phenomena on the Sun take place due to intense magnetic activity, it is quite essential to have a continuous survey of the magnetic state of the Sun. This is done by STOP, which is essentially a magnetograph capable of measuring large scale magnetic fields on the photosphere along the line of sight with a resolution of 30 arcsec. Large scale magnetic fields are formed due to the imbalance in concentrated flux and more diffuse flux and are important because of their connection with the interplanetary magnetic field. Also, the space weather parameters near the Earth can be predicted by using the data of STOP with the help of Wang–Sheeley–Arge (WSA) semiempirical model (Tlatov et al. 2017). Apart from this the instrument also measures the distribution of Stokes parameters for polarization for various spectral lines which helps to estimate the full magnetic field vector. By using the potential field and force free field approximations, the magnetic field in the photosphere obtained by STOP is extrapolated to the corona and used to identify coronal holes on the solar disc as shown in fig.3. Coronal holes act as the centers for the fast-solar wind.

Another important instrument, that has been in use for solar service in the radio spectrum is the solar spectral polarization complex (SSPC) of RATAN-600 (Tokhchukova 2011; Bogod 2011). Although the Sun cannot be monitored from dawn to dusk by SSPC, the ability of observing from 3 GHz to 17 GHz with a frequency step of about 200 MHz helps to use frequency tomography to probe the solar corona. As an example, we can show from fig.4 that at lower frequencies there is a peak in the profile to the left of the Sun because of the active region but as we go upwards to higher frequencies, at some higher frequency the peak diminishes completely. This frequency can be taken as the cutoff frequency and by using the simple formula for the plasma frequency, we can calculate the average electron density of the flaring site. From fig.4, the cutoff frequency is therefore around 9.73 GHz, which therefore gives the electron number density of the flaring site as $1.17 \times 10^{12}/cm^3$.

At present SPOT continuously monitors the Sun in CaII K and H-α spectral lines from the Kislovodsk mountain solar station of the Pulkovo Astronomical Observatory since 2011 and has accumulated a wealth of observational data about solar flares, CMEs, filament oscillations and etc. Similarly STOP has been initiated at three different places namely Kislovodsk, Irkutsk and Ussuriysk. By installing such telescopes which are cheap and reliable at regular longitudes along the entire globe, we can have continuous monitoring of the Sun with sufficient redundancy to account for cloud coverage. In the very near future SSPC of RATAN-600, will be modernized to a new level, where individual active regions can be continuously monitored in the radio spectrum in search of quasiperiodic pulsations during solar flares. Therefore, SSPC supplements the data provided by the SPOT and STOP network for a better solar monitoring service.

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