Multi-Wavelength Investigations of Solar Activity
Proceedings IAU Symposium No. 223, 2004
A.V. Stepanov, E.E. Benevolenskaya & A.G. Kosovichev, eds.

DOI: 10.1017/S1743921304006969

Space solar limbograph

Habibullo I. Abdussamatov
Pulkovo Observatory, Saint Petersburg, Russia

Observations of the Sun are always complicated by the thermal influence of the integral flux of its radiation on the optical-mechanical and photo-detecting units of the telescope. This influence manifests itself especially strong and can be even amplified while observing the Sun from the space, and mostly while observing its full disk. However, the existing optical solar telescopes produce an image of either full disk of the Sun or only one individual region. In the latter case, the radiation of almost full disk of the Sun is cut off from the telescope, and emission from a small region on its surface propagate through a small aperture on the optical axis of the telescope (see, for example, Popov (1988); Stix (1991). The third variant is a solar coronagraph, which constructs an image of the solar corona, cutting off radiation of the whole disk of the Sun, thus imitating a total solar eclipse (Lyott, 1939; Nikolsky 1966; Smartt 1998). This solution determines success of the solar experiment in the space, particularly, if it is connected with long-term high-precision photometric and coordinate measurements of temporal variations of the diameter and shape of the solar disk limb.

That is why, in 2000 we constructed and patented a new original solar telescope - an optical solar limbograph. Limbograph imitates an annular solar eclipse by the artificial Moon, which is mounted inclined to the optical axis at its intermediate focus after reflection of a beam by the primary mirror (Abdussamatov 2000). The projection L' of the major semi-axis L and the projection l' of the minor semi-axis l of the thermal-protective mirror (the "moon") onto the focal plane of the limbograph satisfy the relation: $L' = l' < R_\odot$, where $R_\odot$ is the radius of the Sun's image in the focal plane of the limbograph. The mirror after-focus aplanatic optical system of the limbograph with concave ellipsoidal shape of the both primary and secondary mirrors provides large angular field and reduction of aberrations (particularly, coma) throughout the whole working field of view with a diameter $2\omega^\circ = 0^\circ 35'$. The use of after-focus optical system is caused by the fact that in the limbograph it is necessary to have an intermediate image of the solar disk, in the plane of which the artificial "moon" is situated, which cut off a major part of radiation beyond the working beams. The telescopic optical system under consideration with two concave ellipsoidal mirrors, which is of Gregory system type, is more stable with respect to thermal influence (thermal distortions) than Cassegrain systems (Zakharchenko (1989)). Slightly smaller than the diameter of the solar image diameter of the artificial Moon provides constructing the image of the narrow boundary limb zone, limited by the edge of the field of view Ø$35'$ and of the artificial Moon Ø$31'$. Additional special openings on the "moon's" disk provide simultaneous construction of additional images of the individual photospheric regions, which are formed by the light beams going through these apertures in the disk of the "moon". As a result, the images of both the narrow ring of the Sun's limb, limited by the "moon's" edge, and given local regions of the Sun's surface in the zone of the "moon's" disk, can be simultaneously formed in the focal plane of the limbograph on the surface of photo-detector. They have diffraction resolution in all the points of the working field of view of angular diameter $2\omega^o = 0^o 35'$.

The optical system of the limbograph is constructed in the way that this artificial Moon does not produce any additional screening to that caused by the secondary mirror.

At the same time, the “moon” cuts off the unused radiation (constituting on the average about 93% of the solar disk flux) to the open space away from the limbograph, thus providing maximum thermo-protection of the optical elements after the primary mirror and of photo-detectors in its focal plane. A central part of the limbograph focal plane of the diameter Ø33′, where an image of the solar disk is constructed, is protected from direct solar light and micro-meteorites by means of a special screen in the plane of the secondary mirror. It is possible to rotate the “moon” about the optical axis of the limbograph. Taking into account that the openings are situated at different distances to the “moon’s” center, this allows to obtain image of any given region of the solar disk. Protection of the limbograph primary mirror against the powerful integral flux of solar radiation is performed by means of a specialized removable mirror filter – a plane-parallel quartz plate- mounted at its inlet pupil. A special light(spectrum)dividing multi-layered coating on the outer and inner surfaces of this plate reflects (to the open space) almost all radiation in the ultraviolet, infrared and a major fraction of radiation in the visual spectral domain, falling onto the inlet pupil of the limbograph except for a given working diapason with wavelength coverage of about 60 nm. As a result, the total flux of solar radiation falling on the primary mirror of the limbograph is diminished by a factor of about 100. Besides of that, this specialized, reflecting almost all ultraviolet radiation, coating on the outer, looking at the Sun, surface of the mirror filter minimizes degradation of the optical elements of the limbograph under the action of hard ultraviolet radiation of the Sun. Simultaneously, in addition to precise measurements of the form and diameter of the Sun, it is possible to get subsequent homogeneous data on the fine structure of the photospheric formations using the images of both the limb zones and individual regions, situated at different distances to the disk center. These data can be obtained with very high spatial and temporal resolution and with regularity, impossible for ground-based and stratospheric telescopes. This allows also to investigate a function of the limb darkening and variations of its profile with changes in the photosphere’s structure, solar diameter and a phase of the solar cycle. Continuous monitoring of the solar diameter and stellar calibration of the image scale will allow to determine for the first time the coordinates of individual formations in the fine structure of the photosphere in the regions under investigation with an accuracy, which will provide their precise identification and further study of dynamics of super-fine structure of these formations.

Thus, the limbograph restricts the image construction to the only necessary for such investigation limb zone and given individual regions of the solar disk by means of cutting off and throwing off to the open space all the rest unused flux form the solar disk using the “moon”. As a result, the limbograph can provide high-quality images during continuous long-term observations of the Sun and makes it possible to perform more precise and long-term photometric and coordinate measurements of the limb form, diameter and individual regions of the solar disk and investigate their temporal variations.

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https://doi.org/10.1017/S1743921304006969 Published online by Cambridge University Press