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FLASH SPECTRUM OBSERVATIONS AROUND THE BALMER JUMP

I. VINCE and A. KUBIČELA
Astronomical Observatory, Volgina 7, 11160 Belgrade-74, Yugoslavia
E-mail ivince@aob.aob.bg.ac.yu

Abstract. In this paper the theoretical background for analysis of the observed Balmer jump and an observational equipment for flash spectra observation during the second and third contacts of solar eclipse are presented.

1. INTRODUCTION

Total solar eclipses give an opportunity of high spatial resolution observations of the solar chromospheric spectrum during the two flash phases using fast electronic cameras as detectors. In low spectral resolution observations (higher degree of illumination of the spectrum) the frequency of observations could be as high as 20-30 Hz, that corresponds to spatial resolution of about 10-20 km. On the other hand, low spectral resolution observation can be used in the case of a continuous spectrum. The observation of the Balmer jump (an abrupt step in continuum level), from which the electron temperature can be obtained, satisfies these conditions. Because of that we introduce it into our observational program for the 11th August 1999 solar eclipse expedition as an experiment for high spatial resolution determination of chromospheric electron temperature.

2. THEORETICAL BACKGROUND

The intensity of continuum radiation in vicinity of wavelength 364.6 nm is enhanced. It is caused by Balmer continuum, which is the result of electron recombination to the second energy level in hydrogen atoms.

Theoretical considerations show that the radiation power (P) can be expressed by

$$P(\nu)d\nu = N_{HII}N_eE_{eff}d\nu,$$

where N_{HII} is the number density of ionized hydrogen, N_e is the number density of electrons, and E_{eff} is the effective emission coefficient. This coefficient is the sum of all free-bound and free-free transition radiative coefficients.

Emission coefficient depends on the electron temperature (T) of the gas. For instance, in the case of hydrogen atom the volume emission coefficient of free-bound transition is given by (Bray and Lunkhead, 1974, pp 154)

$$E_\nu = Const.g_{fb}n^{-3}N_{HII}N_eT^{-\frac{3}{2}}e^{\frac{h(\nu_n-\nu)}{(kT)}},$$

where g_{fb} is the Gaunt factor for a given energy level of atom, n is the principal quantum number, ν_n is the frequency at Balmer limit, ν is any other frequency higher or equal with ν_n, h is the Planck constant. In Balmer continuum n=2, g_{fb} =0.876, and the value of the constant depends on the used units (in CGS Const=2.15×10^{-32}).

If $\nu = \nu_n$, the emission coefficient depends on the product of electron and proton density, and on temperature. As above the temperature minimum level the source of electrons are almost only hydrogen atoms one can suppose that the number of electrons is equal to the number of protons. Then the emission coefficient is proportional to the product of square of electron density and temperature.

The Balmer jump is defined by $D = log(H_{\nu<\nu_n}/H_{\nu>\nu_n})$, where $H_{\nu<\nu_n}$ is the radiation flux at lower frequency and $H_{\nu>\nu_n}$ at higher frequency than the frequency of the Balmer limit.

If we suppose that the continuum radiation flux depends on ff and fb transitions in hydrogen atoms under thermodynamical equilibrium, then the Balmer jump can be expressed as (see, e.g., Emerson, 1997)

$$D = log \frac{g_{ff} + 2(\frac{\kappa_1}{kT}) \sum_{i=3}^{\infty} i^{-3} g_{fb}^{i} e^{(\frac{\kappa_i}{kT})}}{g_{ff} + 2(\frac{\kappa_1}{kT}) \sum_{i=2}^{\infty} i^{-3} g_{fb}^{i} e^{(\frac{\kappa_i}{kT})}},$$

where κ is the ionization potential of energy level i. In this case D depends only on electron temperature. So, by observing the Balmer jump we can get the electron temperature, and from emission coefficient of Balmer continuum, knowing the electron temperature, we can calculate the electron (proton) density.

The observations do not give the emission coefficient but its line-of-sight integral value:

$$I_\nu(x) = \int_{-\infty}^{+\infty} E(x,y) e^{-\tau_\nu(x,y)} dy,$$

where x and y are the coordinates of a chromospheric element, τ is its optical depth.

If the observed intensity we express as (Bray and Loughhead, 1974, pp 150)

$$I_\nu(x) = \sum_i a_i e^{-\beta_i x},$$

the emission coefficient is

$$E_\nu(x) = \frac{1}{(2\pi R)^{\frac{1}{2}}} \sum_i a_i \beta_i^{\frac{1}{2}} e^{-\beta_i x},$$

where β is the intensity gradient with height and R is the solar radius. From the observed intensity distribution with height we can get the gradient, then the emission coefficient and finally the electron (proton) density.

3. FLASH SPECTROGRAPH

According to the mentioned research program it has been decided to construct a slitless grating spectrograph for the observation of the flash spectrum. It is a portable Newtonian instrument equatorially mounted, with an objective grating and a CCD camera as a radiation receiver. Of course, the camera has to be fast (capable to capture several full frames per second) and sufficiently sensitive in the wavelength interval 300 nm to 400 nm.

A 110 mm diameter 1140 mm focal length primary mirror has been combined with a 25 mm diagonal flat to form an off-axis Newtonian type reflector (Figure 1.). The off-axis arrangement is applied to make use of the whole grating aperture. The dispersion of about 2 to 4 nm/mm would be desirable. This is satisfied with a grating 51×51 mm size with 150 lines/mm. It can be used either in the first or in the second order to yield the suitable dispersion and a linear spectral resolution slightly higher than the resolution of the receiving CCD chip. Also, no spectral order separation measures would be necessary except, perhaps, for some filtering in the second order - depending on the spectral sensitivity of the CCD radiation receiver.

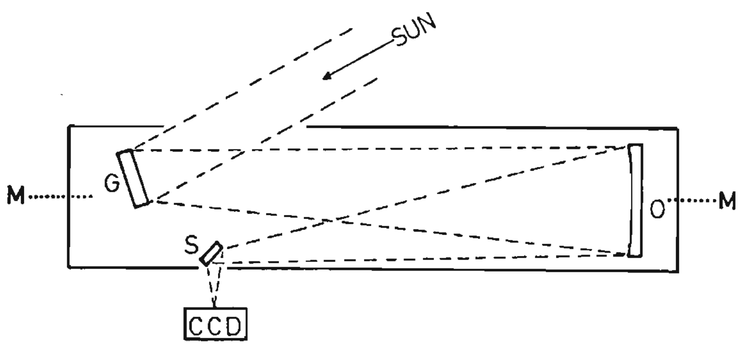

Fig. 1. Optical arrangement of the spectrograph. G - diffraction grating, O - objective mirror, S - secondary flat mirror, CCD -radiation receiver, SUN - direction from the observed point at the solar limb (O_2 or O_3 in Figure 2.), M ... M - rotational axis of the spectrograph (direction toward the points M_2 or M_3 in Figure 2.)

A 30 times magnifying finderscope with a Sun-protecting filter is attached to the main tube of the spectrograph. Its optical axis is parallel to the light rays incoming to the grating. This direction subtends an angle of about 30^o to the geometrical axis of the telescope tube. Actually, this angle is for $\kappa = 0.^o507$ greater than the sum of the incidence and the diffraction angle of the grating.

To align the direction of the spectral dispersion plane with the radial direction at the observed points of the second and third contacts at the solar disk, the main spectrograph tube can be rotated around the geometrical axis of the tube for preselected angular increment.

3. 1. ROTATION IN POSITION ANGLE

It seems normal to assume that, during the flash observation, the direction of spectral dispersion projects itself at the solar disk in radial direction. The easiest mechanical way to achieve transition in the position angle from the second to the third eclipse contact is to rotate the whole spectrograph tube around the axis of its cylindrical body. If proper bearings of the tube and a suitable angular scale (relative position angle) are provided, the necessary rotational increment between the tube positions of the second and the third eclipse contacts can be precalculated and engaged during the observation.

In the most frequent case when the two eclipse contacts (2nd and 3rd)fall at the opposite, east and west sides with respect to the terrestrial central meridian of the solar disk, The desired rotation of the spectrograph tube in position angle can be found consideration the relations in Figure 2. In this figure points S_2 and S_3 are the centers of the solar disk at the instants of the second and the third eclipse contacts respectively. The corresponding contact points at the solar limb are O_2 and O_3. These are the points where the spectrograph optical axis is aimed at times of the eclipse contacts, t_2 and t_3. At the same instants the rotational axis of the spectrograph tube is supposed to intersect the celestial sphere at points M_2 and M_3 respectively. P is the celestial North Pole and Z is the Zenith. Apparent solar radius is ρ and P_2 and P_3 are the position angles of the points O_2 and O_3 respectively (the heavy arcs along the corresponding solar limbs).

The desired rotational angular increment, ΔP, represents the angle necessary for the spectral dispersion plane at the instant t_2, namely O_2M_2, to rotate into position O_3M_3 at the instant t_3.

In the case of an equatorially mounted, and well oriented spectrograph, one can achieve ΔP rotation by rotating the spectrograph in the following way. First, one rotates the spectrograph around point M_2 counterclockwise for the angle P_2' (direction of spectral dispersion M_2S_2 being radial at the solar disk now becomes pointing northward, M_2P) then aims the spectrograph tube toward point M_3 (with spectral dispersion still oriented toward north, M_3P), and finally rotates the spectrograph around point M_3 for the angle P_3' counterclockwise returning the direction of spectral dispersion again into the radial position at the solar disk, M_3S_3. Namely, $\Delta P = P_2' + P_3'$. Here P_2' is the angle PM_2S_2 and P_3' is the angle PM_3S_3.

In the case of a well oriented alt-azimuth instrument, after the observation of the second eclipse contact, we similarly disintegrate ΔP in two increments taking instrumental vertical direction (M_2Z in M_2 or M_3Z in M_3) as the constant orientation reference during the transition of the spectrograph is pointing toward M_2 into its pointing toward M_3. The overall rotation is then

$$\Delta P = P_2' + P_3' + q_3 - q_2,$$

where q_2 and q_3 are the paralactic angles at points M_2 and M_3 respectively. In either case the rotation ΔP has to be performed in the clockwise sense (looking toward the Sun).

All quantities needed for rotation of an equatorial spectrograph can be found from the corresponding spherical triangles PS_2M_2 and PS_3M_3 as follows

$$P_2' = \arcsin(\frac{\sin P_2 \cos \delta_0}{\cos \delta_2}),$$

where δ_2 is the declination of point M_2, and δ_o is the Sun's declination at the middle of the eclipse totality. Here we neglect the changes of this quantity during the totality (that is always less than one arc min h^{-1}). The former can be found as

$$\delta_2 = \arcsin(\sin \delta_0 \cos(\gamma + \rho) + \cos \delta_0 \sin(\gamma + \rho) \cos P_2).$$

Accordingly follow the relations

$$P_3' = \arcsin(-\frac{\sin P_3 \cos \delta_0}{\cos \delta_3})$$

and

$$\delta_3 = \arcsin(\sin \delta_0 \cos(\gamma + \rho) + \cos \delta_0 \sin(\gamma + \rho) \cos P_3).$$

In these relations γ depends on the grating montage and on its working regime as $\gamma = K + \alpha + \beta$, where $K = 0.^o507$ is given by the spectrograph construction and α and β are the incidence and diffraction angles at the grating.

After evaluating δ_2 and δ_3, one obtains the complete positions of the points M_2 and M_3 knowing the hour angles of the Sun, H_{02} and H_{03}, at the eclipse contact instants t_2 and t_3 respectively. Then the hour angles of M_2 and M_3 are $H_2 = H_{02} + \Delta H_2, and$ $H_3 = H_{03} - \Delta H_3$, where ΔH_2 and ΔH_3 are the hour angle increments within the spherical triangles M_2PS_2 and M_3PS_3 respectively. These angles can be found from the same triangles as follows

$$\Delta H_2 = \arccos(\sin \delta_0 \sin \delta_2 + \cos \delta_0 \cos \delta_2 \cos(\gamma + \rho)), and$$

$$\Delta H_3 = \arccos(\sin \delta_0 \sin \delta_3 + \cos \delta_0 \cos \delta_3 \cos(\gamma + \rho)).$$

The paralactic angles q_2 and q_3 one finds from the positional spherical triangles PM_2Z and PM_3Z. The relations are

$$\tan q_2 = \frac{\sin H_2}{\tan \varphi \cos \delta_2 - \sin \delta_2 \cos H_2},$$

and

$$\tan q_3 = \frac{\sin H_3}{\tan \varphi \cos \delta_3 - \sin \delta_3 \cos H_3}.$$

Here φ is the geographical latitude of the observer's location.

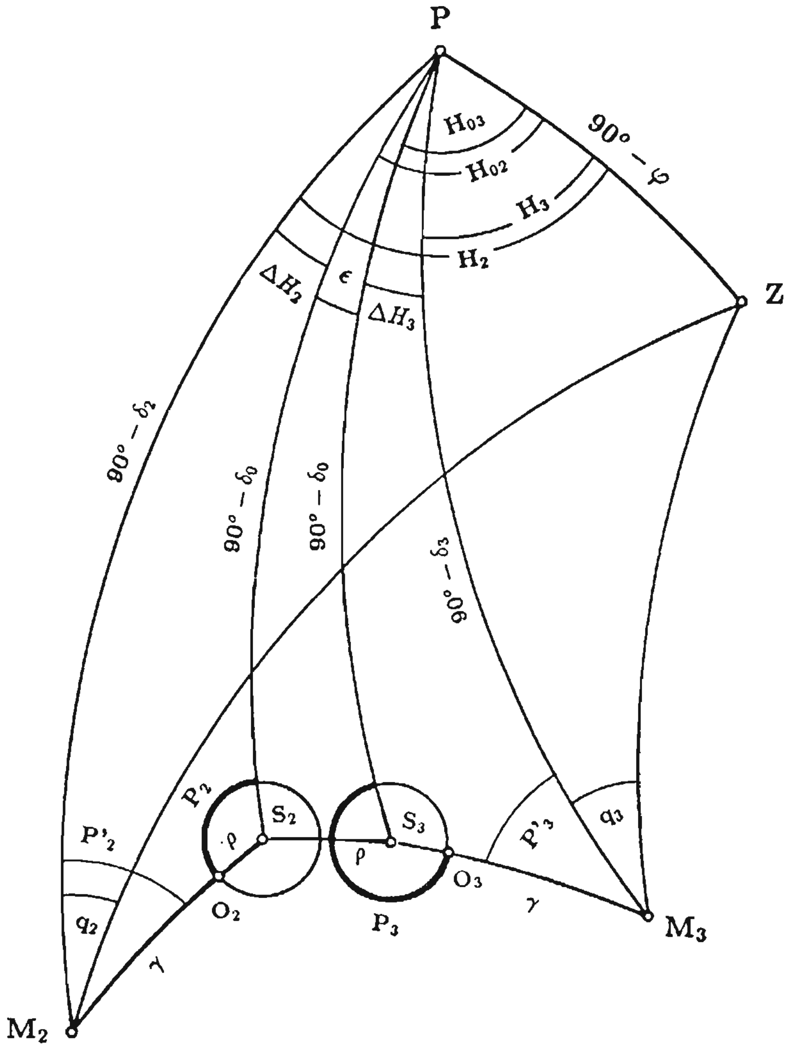

Fig. 2. Geometry of the spectrograph rotation. P - celestial North Pole, Z - Zenith, S_2 and S_3 - center of the solar disk at the instant of 2nd or 3rd eclipse contact, ρ - apparent radius of the solar disk, O_2 and O_3 - 2nd and 3rd contact points at the solar limb, M_2 and M_3 - points where the spectrograph rotational axis in succession intersects the celestial sphere, P_2 and P_3 - positional angles of the 2nd and 3rd eclipse contacts, γ - angular divergence of the spectrograph optical and rotational axes, H_{02}, H_{03} and δ_0 - solar equatorial coordinates.

References

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