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RESEARCHES ON TROJAN ASTEROIDS

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Abstract

The author's results on Trojan asteroids are summarized. First a theory of Trojan asteroids is described and then several applications of it in studying various perturbations of Trojans are shown. The main topics are: longperiodic libration around L_4 and L_5, variations of the mean motion, motion of the perihelion, critical inclination, an invariant relation of Trojan asteroids.

Резюме

В работе представлены результаты, полученные автором при исследовании астероидов группы Троянцев. Сначала описывается теория движения астероидов группы Троянцев, а затем дается несколько ее применений при изучении различных пертурбаций в движении этой группы. Главными темами исследования являются следующе: долгопериодические либрации вокруг L_4 и L_5, вариации среднего движения, движение перигелия, критическое наклонение, инвариантные соотношения для астероидов группы Троянцев.

1. Introduction

The Trojan asteroids are known as the first natural examples of the famous Lagrangian solutions of the three-body problem. (Others are among the recently discovered new satellites of Saturn.) A Trojan asteroid moves around the Sun nearly on Jupiter's orbit in such a way that the three celestial bodies are always at the vertices of equilateral triangles, at least in a first approximation. More detailed calculations have since long reveiled that these asteroids, named after the heroes of the mythological Trojan war, perform a long-periodic libration around the Lagrangian points L_4 or L_5 of the Sun-Jupiter system, which correspond exactly to Lagrange's equilateral solutions. This interesting type of motion and the mathematical problems connected with it have always challenged people working on problems of celestial mechanics and as a result of it now the literature is abundant in papers dealing with the problem of motion around L_4 or L_5 and especially with the motion of Trojans (see for example Szebehely [1967] and Hagihara [1975] for references).

The purpose of this paper is to show my results on Trojan asteroids. I refer to my papers as Papers I, II, ..., and X.

2. *A theory of Trojan asteroids*

First I describe a theory of Trojan asteroids on which the other results are based. The details of the theory are given in Papers II and V.

I studied the motion of Trojan asteroids in the framework of the three-dimensional elliptic restricted three-body problem. This means the assumptions that a Trojan asteroid is influenced only by the gravitational forces of the Sun and Jupiter, and the orbit of Jupiter is an ellipse. Then the following equations of motion can be derived

$$\frac{d^2r}{dv^2}-r\left(\frac{d\alpha}{dv}\right)^2-2r\frac{d\alpha}{dv}=\frac{1}{1+e_j\cos v}\left[r-\frac{1-\mu}{R_1^3}r+\mu\left(\frac{\cos\alpha-r}{R_2^3}-\cos\alpha\right)\right],$$

$$\frac{d}{dv}\left(r^2\frac{d\alpha}{dv}+r^2\right)=\frac{\mu r\sin\alpha}{1+e_j\cos v}\left[1-\frac{1}{R_2^3}\right], \tag{1}$$

$$\frac{d^2z}{dv^2}+z=\frac{z}{1+e_j\cos v}\left[1-\frac{1-\mu}{R_1^3}-\frac{\mu}{R_2^3}\right].$$

Here r, α, z are the cylindrical coordinates of the asteriod (Fig. 1), v is the true anomaly of Jupiter, e_j is the eccentricity of Jupiter's orbit, μ is the mass of Jupiter divided by the total mass of the Sun-Jupiter system and

$$R_1=\sqrt{r^2+z^2},\quad R_2=\sqrt{1+r^2-2r\cos\alpha+z^2}.$$

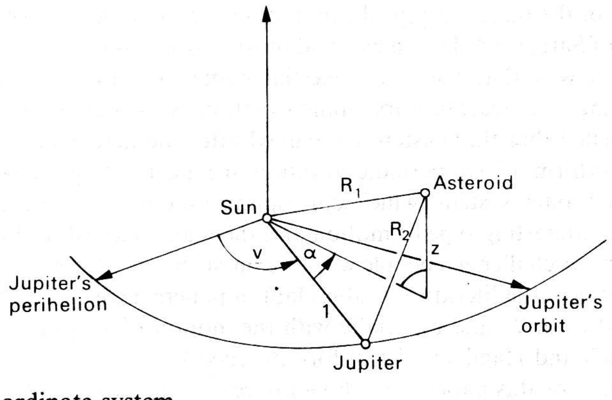

Fig. 1. The coordinate system

The coordinates r and α are polar coordinates in the orbital plane of Jupiter, α is counted from the direction of Jupiter, and z is perpendicular to Jupiter' s orbital plane. Both r and z are dimensionless, the instantenous Sun-Jupiter distance serving as unit distance.

To solve Equations (1) I applied the method of the multiple-variable expansions. (For a discussion of the method see the book of Kevorkian and Cole [1981].) Thus I looked for a solution of Equations (1) in the form of a three-variable asymptotic expansion

$$r = 1 + \sum_{n=1}^{N} \varepsilon^n r_n (v,u,\tau) + 0 (\varepsilon^{N+1}) ,$$

$$\alpha = \alpha_0 (u,\tau) + \sum_{n=1}^{N} \varepsilon^n \alpha_n (v, u, \tau) + 0 (\varepsilon^{N+1})) , \tag{2}$$

$$z = \varepsilon^{\frac{1}{2}} \left[\sum_{n=0}^{N} \varepsilon^n z_n (v,u,\tau) + 0 (\varepsilon^{N+1}) \right] ,$$

where

$$\varepsilon = \sqrt{\mu} , \quad u = \varepsilon (v - v_0) , \qquad \tau = \varepsilon^2 (v - v_0) \tag{3}$$

and v_0 is the epoch.

This is a generalization of Kevorkian's two-variable solution for the planar problem (Kevorkian, 1970). He studied the planar motion of Trojan asteroids assuming Jupiter's orbit circular and using two independent varables. In Paper I, I pointed out that to obtain a solution without secular terms in the third order, it is necessary to introduce a third variable too.

The reasons for the form (2) are the following.

1. The Trojans are in a 1:1 resonance with Jupiter. In case of a resonance the largest perturbations are proportional not to the perturbing mass but to the square root of it. Thus (2) is expanded according to the powers of $\varepsilon = \sqrt{\mu}$. Note, that in the Sun-Jupiter case $\mu = 0.000954$ and $\varepsilon = 0.030885$.

2. The unknown functions r_n, α_n, z_n in Equations (2) depend on the variables v, u, τ, representing three different time-scales of the motion of Trojan asteroids. The variable v corresponds to the orbital revolution around the Sun, u refers to the long-periodic libration around the Lagrangian points L_4 or L_5 and τ is connected with the motion of the perihelion. The respective periods are about 12, 148 and 3685 years (for an asteroid at L_4).

3. In the expansion of r the first term 1 corresponds to the fact that the Trojans are close to a circle with radius 1, having a centre at the Sun. L_4 and L_5 are also on this circle.

4. The leading term for α is $\alpha_0 (u, \tau)$. As it is not multiplied by ε it can reach large values. Actually, $\alpha_0 (u)$ describes the main part of the long-periodic libration of large amplitude around L_4 or L_5.

5. The coordinate z is assumed to be proportional to $\varepsilon^{\frac{1}{2}}$ so that the solution is valid for large inclinations occuring among the known Trojan asteroids.

An additional assumption for the solution of Equations (1) was that

$$e_j = \varepsilon e_1 ,$$

where the constant e_1 is not very large compared to unity.

Substituting Equations (2) into Equations (1) and taking into account that due to the relations (3) the total derivatives according to v have to be calculated as

$$\frac{dr}{dv} = \frac{\partial r}{\partial v} + \varepsilon \frac{\partial r}{\partial u} + \varepsilon^2 \frac{\partial r}{\partial \tau},$$

a system of partial differential equations can be derived for the unknown functions r_n, α_n, z_n from equating the coefficients of the same powers of ε on both sides of Equations (1). To 0 (ε^2) the new equations are

$$\frac{\partial^2 z_0}{\partial v^2} + z_0 = 0$$

$$\frac{\partial^2 r_1}{\partial v^2} - 2\left(\frac{\partial \alpha_1}{\partial v} + \frac{\partial \alpha_0}{\partial u}\right) = 3r_1 + \frac{3}{2} z_0^2 ,$$

$$\frac{\partial}{\partial v}\left(2r_1 + \frac{\partial \alpha_1}{\partial v}\right) = 0 .$$

$$\frac{\partial^2 z_1}{\partial v^2} + z_1 = -2\frac{\partial^2 z_0}{\partial v \partial u} + \left(3r_1 + \frac{3}{2} z_0^2\right) z_0 ,$$

$$\frac{\partial^2 r_2}{\partial v^2} + 2\frac{\partial^2 r_1}{\partial v \partial u} - \left(\frac{\partial \alpha_1}{\partial v} + \frac{\partial \alpha_0}{\partial u}\right)^2 -$$

$$-2\left[\frac{\partial \alpha_2}{\partial v} + \frac{\partial \alpha_1}{\partial u} + \frac{\partial \alpha_0}{\partial \tau} + r_1\left(\frac{\partial \alpha_1}{\partial v} + \frac{\partial \alpha_0}{\partial u}\right)\right] =$$

$$= 3r_2 + \frac{3}{2} r_1^2 + 3z_0 z_1 - \frac{15}{8}(2r_1 + z_0^2)^2 + 1 -$$

$$- e_1 \cos v \left(3r_1 + \frac{3}{2} z_0^2\right) + r_1\left(3r_1 + \frac{3}{2} z_0^2\right) -$$

$$- \cos \alpha_0 - 2^{-3/2}(1 - \cos \alpha_0)^{-1/2} ,$$

$$\frac{\partial}{\partial v}\left[r_1^2 + 2r_2 + 2r_1\left(\frac{\partial \alpha_1}{\partial v} + \frac{\partial \alpha_0}{\partial u}\right) + \frac{\partial \alpha_2}{\partial v} + \frac{\partial \alpha_1}{\partial u}\right] =$$

$$= -\frac{\partial}{\partial u}\left[2r_1+\frac{\partial \alpha_1}{\partial v}+\frac{\partial \alpha_0}{\partial u}\right]+\sin\alpha_0\left[1-2^{-3/2}(-\cos\alpha_0)^{-1/2}\right].$$

I derived the equations to $0(\varepsilon^3)$ and determined the solution for α_0, z_0, r_1, α_1, z_1, r_2, α_2 in Papers II and V. For example, the solution to $0\,(\varepsilon)$ is

$$z_0 = \lambda_0 \cos(v+v_0)\,,$$

$$r_1 = \varrho_1 \cos(v+\Psi_1)-\frac{1}{4}\lambda_0^2\cos 2(v+v_0)-\frac{2}{3}\frac{\partial\alpha_0}{\partial u}-\frac{1}{4}\lambda_0^2\,,$$

$$\alpha_1 = -2\varrho_1\sin(v+\Psi_1)+\frac{1}{4}\lambda_0^2\sin 2(v+v_0)+q_1\,,$$

where

$$\varrho_1\cos\Psi_1 = \varrho_{10}\cos(\alpha_0+\Psi_{10})+e_1\,,$$

$$\varrho_1\sin\Psi_1 = \varrho_{10}\sin(\alpha_0+\Psi_{10})\,,$$

$$\varrho_{10}\sin\Psi_{10} = -\varrho_{11}\sin(A_0\tau+\Psi_{11})-e_1\frac{A_2}{A_0}\,,$$

$$\varrho_{10}\cos\Psi_{10} = \varrho_{11}\cos(A_0\tau+\Psi_{11})+e_1\frac{A_1}{A_0}\,,$$

$$v_0 = \alpha_0-\frac{1}{2}A_3\tau+v_{01}\,,$$

and ϱ_{11}, Ψ_{11}, v_{01}, λ_0 are constants of integration. The solution for α_0 is shown in the next chapter. The parameters A_0, A_1, A_2, A_3 are given by the following expressions

$$A_0 = \frac{27}{2^3}+\frac{129}{2^6}l^2-\frac{87}{2^7}l^4+0\,(l^6)\,,$$

$$A_1 = -\frac{27}{2^4}-\frac{141}{2^6}l^2-\frac{1095}{2^{11}}l^4+0\,(l^6)\,,$$

$$A_2 = -\frac{27\sqrt{3}}{2^4}+\frac{45\sqrt{3}}{2^6}l^2+\frac{711\sqrt{3}}{2^{11}}l^4+0\,(l^6)\,, \tag{4}$$

$$A_3 = -\frac{3}{2}l^2+\frac{3}{2^5}l^4+0\,)l^6)\,,$$

where l is also a constant of integration.

Knowing the main perturbations in the coordinates r, α, z, those of the orbital elements can also be derived by applying the well-known formulas of the two-body problem. This was done in Paper V.

3. *Libration around* L_4 *and* L_5

The leading term α_0 in the expansion of α describes the main part of the long-periodic libration around L_4 or L_5. The equation which governes α_0 is (Paper II)

$$\frac{\partial^2\alpha_0}{\partial u^2}+3\sin\alpha_0\,[1-2^{-3/2}(1-\cos n\alpha_0)^{-3/2}]=0. \tag{5}$$

For moderate amplitudes of libration around L_4 occuring among the known Trojan asteroids the solution of Equation (5) is

$$\alpha_0=\frac{\pi}{3}+\frac{3\sqrt{3}}{2^3}l^2+\frac{13\sqrt{3}}{2^8}l^4+l\cos\Phi-$$
$$-\left(\frac{\sqrt{3}}{2^3}l^2+\frac{\sqrt{3}}{2^8 3^2}l^4\right)\cos 2\Phi+\left(\frac{5}{2^6}l^3-\frac{65}{2^{12}}l^5\right)\cos 3\Phi-$$
$$-\frac{25\sqrt{3}}{2^7 3^2}l^4\cos 4\Phi+\frac{1283}{2^{12}\cdot 3\cdot 5}l^5\cos 5\Phi+0\,(l^6)\,, \tag{6}$$

where

$$\Phi=\sqrt{\frac{27}{4}(1-\frac{3}{2^3}l^2-\frac{97}{2^9}l^4)}\,u+\delta\,, \tag{7}$$

and here l is a constant of integration and δ is a function of τ. For L_5 the solution (6) has to be applied with a negative sign.

It can be seen that α_0 is a periodic function of Φ having a maximum ($\alpha_{0\max}$) for $\Phi=0$ and a minimum ($\alpha_{0\min}$) for $\Phi=\pi$:

$$\alpha_{0\max}=\frac{\pi}{3}+\frac{\sqrt{3}}{2^2}l^2+\frac{11\sqrt{3}}{2^7 3}l^4+l+\frac{5}{2^6}l^3+\frac{77}{2^{10}\cdot 3\cdot 5}l^5+0\,(l^6) \tag{8}$$
$$\alpha_{0\min}=\frac{\pi}{3}+\frac{\sqrt{3}}{2^2}l^2+\frac{11\sqrt{3}}{2^7 3}l^4-l-\frac{5}{2^6}l^3-\frac{77}{2^{10}\cdot 3\cdot 5}l^5+0\,(l^6)$$

Φor a given l, α_0 librates between these two limits, the amplitude of libration being nearly l. The approximate period of libration T_L from Equation (7) is

$$T_L=\frac{T_J}{\varepsilon\sqrt{\frac{27}{4}\left(1-\frac{3}{2^3}l^2-\frac{97}{2^9}l^4\right)}}\,, \tag{9}$$

where T_J is Jupiter's orbital period. For $l=0-0.5$, $T_L=147.8-156.3$ years. This interval covers most of the known Trojans.

As a check of the accuracy of the solution (6) a comparison was made with the numerical integration of Chebotarev et al. (1974). Table I shows librational intervals of Trojan asteroids obtained by numerical integration of the planar, circular restricted three--body problem (second column) and from Equations (8) for appropriate values of l (third and fourth column).

Table I. Librational intervals of Trojan asteroids

Around L_4	Chebotarev et al. (1974)	l	From Equations (8)
588 Achilles	54°.63—65°.86	0.098	54°.63—65°.85
624 Hector	45.22—79.13	0.294	45.21—79.12
659 Nestor	49.07—73.11	0.209	49.07—73.11
911 Agamemnon	46.72—76.68	0.260	46.71—76.67
1143 Odysseus	51.37—69.95	0.162	51.36—69.94
1404 Ajax	44.01—81.21	0.322	44.00—81.21
1437 Diomedes	35.64—99.61	0.545	35.64—99.62
Around L_5			
617 Patroclus	53.96—66.65	0.111	53.96—66.65
884 Priam	49.71—72.20	0.196	49.71—72.20
1172 Aeneas	51.08—70.31	0.167	51.08—70.31
1173 Anchises	40.61—87.72	0.406	40.61—87.72
1208 Troilus	52.05—69.05	0.148	52.05—69.05

Another comparison was made (Paper VII) with Garfinkel's theory of Trojan asteroids (Garfinkel, 1977, 1980). The comparison refers to the normalized period of libration T_N which is obtained from T_L by dividing it with $T_J/\varepsilon \sqrt{\frac{27}{4}}$ this latter being the value of T_L for $l = 0$. From Equation (9):

$$T_N \doteq \frac{1}{\sqrt{1-\frac{3}{2^3}l^2-\frac{97}{2^9}l^4}} = 1+\frac{3}{2^4}l^2+\frac{151}{2^{10}}l^4+0\,(l^6)\,. \tag{10}$$

A relation can be found between l and the parameter α_0 of Garfinkel's solution (do not mistake it with α_0 in Equations (2), (5), (6) as

$$l^2 = \frac{8}{3^2}\alpha_0^2+\frac{2}{3^3}\alpha_0^4+0\,(\alpha_0^6)\,.$$

The substitution of this into Equation (10) leads to

$$T_N = 1+\frac{1}{6}\alpha_0^2+\frac{169}{1296}\alpha_0^4+0\,(\alpha_0^6)\,,$$

which is Garfinkel's result (Garfinkel, 1980).

As in Equation (7) δ depends on τ, this modifies the period of libration. Determining the $\delta\,(\tau)$ function (Paper V) a better approximation for T_L can be derived

$$T_L = \frac{T_J}{\varepsilon\sqrt{\frac{27}{4}\left(1-\frac{3}{2^3}l^2-\frac{97}{2^9}l^4\right)}}\left[1+\frac{1}{3}i^2\left(1+\frac{l^2}{4}\right)\right]. \tag{11}$$

Here i is the orbital inclination. It can be seen from Equation (11) that with increasing i the period of libration increases. Bien and Schubart (1983) found the same result by numerical integration.

4. *Long-periodic variations of a and n*

The main perturbations of the orbital elements of Trojan asteroids were derived in Paper V. The main variations in the semi-major axis a and in the mean motion n are

$$a = a_J\left(1-\frac{2}{3}\varepsilon\frac{\partial\alpha_0}{\partial u}\right),$$

$$n = n_J\left(1+\varepsilon\frac{\partial\alpha_0}{\partial u}\right): \tag{12}$$

Here the index J refers to Jupiter's elements. From Equations (6) and (7) it can be derived that

$$\frac{\partial\alpha_0}{\partial u} = \left(-\frac{3\sqrt{3}}{2}l+\frac{9\sqrt{3}}{2^5}l^3+\frac{345\sqrt{3}}{2^{11}}l^5\right)\sin\Phi+$$
$$+\left(\frac{9}{2^3}l^2-\frac{53}{2^8}l^4\right)\sin 2\Phi+\left(-\frac{45\sqrt{3}}{2^7}l^3+\frac{1125\sqrt{3}}{2^{13}}l^5\right)\sin 3\Phi+$$
$$+\frac{25}{2^6}l^4\sin 4\Phi-\frac{1283\sqrt{3}}{2^{13}}l^5\sin 5\Phi+0\,(l^6)\,. \tag{13}$$

Thus it can be seen that a and n vary periodically around the mean values a_J and n_J with the period of libration T_L. The amplitude of the variation can be easily calculated from Equations (12) and (13). For this, one should determine the extremes of $\partial\,\alpha_0/\partial u$. It follows from Equation (5) that $\partial\alpha_0/\partial u$ is at an extreme when $\alpha_0 = \pi/3$ or—$\pi/3$. For a given l, from Equation (6) one can calculate (by iteration) that value of Φ for which $\alpha_0 = \frac{\pi}{3}$. If Φ_0 is a solution, so is $-\Phi_0$, and these give through Equation (13) the extremes of $\partial\alpha_0/\partial u_0$ Table II shows again a comparison with the results of Chebotarev et al. (1974), obtained by numerical integration.

Table II. Variation of the mean motion of Trojan asteroids: $\Delta n = n_{\max} - n_J$

Around L_4	Chebotarev et al. (1974)	From Equations (12) and (13)
588 Achilles	2″.36/day	2″.35/day
624 Hector	7.03	7.02
659 Nestor	5.01	5.00
911 Agamemnon	6.23	6.22
1143 Odysseus	3.88	3.88
1404 Ajax	7.69	7.68
1437 Diomedes	12.83	12.74
Around L_5		
617 Patroclus	2.66	2.66
884 Priam	4.69	4.69
1172 Aeneas	4.02	4.00
1173 Anchises	9.65	9.63
1208 Troilus	3.55	3.55

5. *Motion of the perihelion*

The main perturbations of the eccentricity e and of the longitude of the perihelion $\tilde{\omega}$ (which is counted from Jupiter's perihelion) can be written as (Paper VIII)

$$\Psi_1 = \left(a - c\sin\chi\right)\frac{5}{8}\kappa\sin\gamma + \left(b - c\cos\chi\right)\left(1 + \frac{1}{4}\kappa + \frac{5}{8}\kappa\cos\gamma\right).$$

$$\Psi_2 = \left(a - c\sin\chi\right)\left(1 + \frac{1}{4}\kappa - \frac{5}{8}\kappa\cos\gamma\right) + \left(b - c\cos\chi\right)\frac{5}{8}\kappa\sin\gamma. \tag{14}$$

Here

$$\Psi_1 = e\cos\tilde{\omega},\ \Psi_2 = e\sin\tilde{\omega}, \tag{15}$$

$$a = -e_J \frac{A_2}{A_0}, \quad b = -e_J \frac{A_1}{A_0}, \quad c = \varepsilon \varrho_{11}, \quad \kappa = i^2 \tag{16}$$

$$\chi = A_0 \tau + \Psi_{11}, \quad \gamma = A_3 \tau - 2\nu_{01}.$$

The perturbations of e and $\tilde{\omega}$ were studied first in the case $\kappa = 0$, that is in the planar case, in Papers II, III, IX. When $\kappa = 0$, Equations (14) can be interpreted geometrically as shown in Figure 2. The endpoint of the vector (Ψ_1, Ψ_2) is on a circle with radius c having its centre at the point (b, a). This circle, called after Bien and Schubart (1983) the "Ψ_1, Ψ_2 curve", is described by the vector $(-c \cos \chi, -c \sin \chi)$ rotating uniformly around the centre (b, a). This centre corresponds to $e = e_J$, $\tilde{\omega} = 60°$. Figure 2 shows two possible motions of the perihelion: circulation and libration. It can be shown that the perihelion librates if

$$c < \sqrt{a^2 + b^2}. \tag{17a}$$

and circulates if

$$c > \sqrt{a^2 + b^2}. \tag{17b}$$

The condition for the libration of the perihelion can also be expressed as

$$e_{\max} < 2e_J \left[1 - \frac{7}{2^2 3} I^2 + \frac{5203}{2^8 3^3} I^4 - 0\,(I^6) \right], \tag{18}$$

where $e_{\max}$ is the maximum value of the eccentricity.

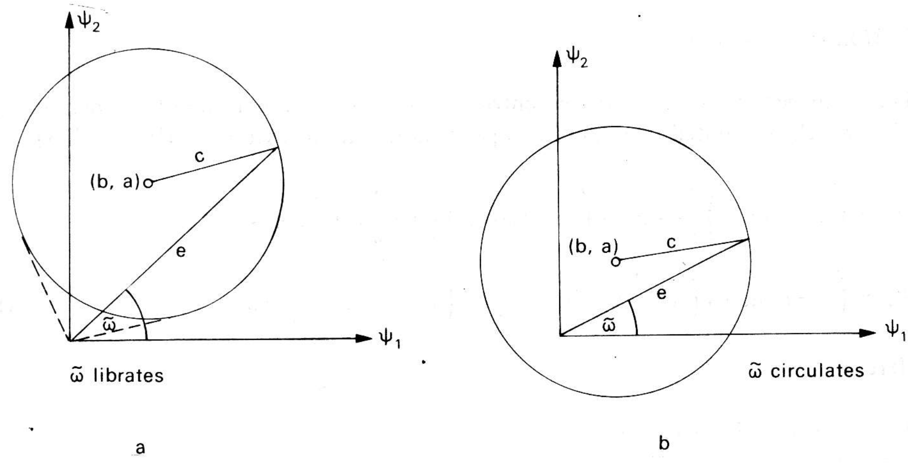

Figure 2. Two possible motions of the perihelion

It is important to remark that the possibility of the libration of the perihelion of Trojan asteroids is due to the ellipticity of Jupiter's orbit. If $e_J = 0$ is assumed, from Equations (14) only the circulation of the perihelion follows. This agrees with the result of Kozai (1984) in the circular case.

Equations (14)—(18) give an easy way to determine the motion of the perihelion of Trojan asteroids. Table III shows the list of the known Trojan asteroids having librating perihelion as well as their librational intervals (Papers III and IX). These were found from among 35 known Trojans. In the first column the letters PL refer to the Palomar-Leiden objects (van Houten et al. 1970).

Table III. Trojan asteroids with librating perihelion

Around L_4	$\tilde{\omega}$	Around L_5	$\tilde{\omega}$
911 Agamemnon	27°.4—86°.1	1871 Atyanax	291°.3—331°.3
1437 Diomedes	28.8—72.3	1872 Helenos	287.7—329.6
1583 Antilochus	28.4—78.2	1870 Glaukos	279.4—323.4
PL 6541	−24.5—130.5	1867 Deiphobus	262.9—356.1
PL 6629	−14.5—106.8		
PL 6540	17.8—88.1		
PL 4655	19.8—87.0		
PL 6581	26.0—73.6		
PL 4572	31.4—69.7		
PL 6591	42.2—62.2		

For the asteroids in the first column, the libration of the perihelion was confirmed by a numerical integration of the planar, elliptic restricted three-body problem (Paper IV). The asteroid PL 4572 was also shown to have librating perihelion by Bien (1980a).

The period of the libration of the perihelion is approximately

$$T_{e,\tilde{\omega}} = \frac{T_J}{\varepsilon^2 A_0} \tag{19}$$

For $l = 0$—0.5, $T_{e,\tilde{\omega}} = 3685$—$3241$ years. $T_{e,\omega}$ is also the period of the main variation of the eccentricity. Paper III gives the lower and upper limits of e for several known Trojan asteroids, obtained from Equations (14) with $K = 0$. Paper IV also gives these limits obtained by numerical integration.

In Paper IX initial conditions for the libration of the perihelion were determined. For an asteroid, which is exactly at L_4, $c = 0$, $e = e_J$ and $\tilde{\omega} = 60°$. This corresponds to the Lagrangian solution of the three-body problem. The asteroid moves around the Sun along an orbit similar to Jupiter's but rotated by 60 degrees. If the asteroid undergoes a small perturbation it leaves L_4 and its orbit begins librating around the Lagrangian equilibrium orbit. The parameter c can be considered as the measure of the perturbation. With increasing c the amplitude of the libration increases and having reached the value π it turns into circulation. Initial conditions for the libration of the perihelion were determined in two different domains of the phase space. Putting an asteroid into L_4 and starting it in a given direction with increasing (from zero) velocity, a critical velocity can be determined at which the libration of the perihelion turns into circulation. The critical velocities in different directions form a critical velocity curve around L_4 inside which all initial velocities result in the libration of the perihelion. The other region consists of the points around L_4 in which zero initial velocity leads to perihelion-libration. Similar investigations were made by McKenzie and Szebehely (1981) and by Szebehely and Premkumar (1982) in the Earth-Moon system but for libration around L_4.

The case $K \neq 0$ was studied in Paper VIII. It was shown that due to the non-zero orbital inclination, the "Ψ_1, Ψ_2 curve" changes nearly into an ellipse with eccentricity $e \approx i\sqrt{2.5}$. This result confirms the numerical results of Bien (1980b) and Bien and Schubart (1983). The ellipse rotates with the angular velocitiy and period of the ascending node T_{Ω} (>60000years). The centre of the ellipse moves on a circle with radius $r = 5K\sqrt{a^2+b^2}\,/\,8$ around the point ($b[1+K/4]$, $a[1+K/4]$). The period of this motion is $T_{\Omega}/2$. Recently, the motion of the centre of the "Ψ_1, Ψ_2 curve" was studied by Schubart and Bien (1984) by a numerical method and they also obtained this value for the period.

5. *Critical inclination of Trojan asteroids*

The perturbations of the ascending node Ω and of the inclination i were studied first in Paper V. By a further development of the theory, in Paper X an improved solution was derived for the main perturbation of Ω. According to this solution the main perturbation in Ω is

$$\Omega = \left[-\frac{3}{2^2} l^2 + \frac{3}{2^6} l^4 + \sin^2 i \left(\frac{3}{2^4} + \frac{35}{2^7} l^2 \right) \right] \tau . \tag{20}$$

It follows from Equation (20) that Ω decreases if $i < i_c$ and increases when $i > i_c$. Here i_c is the critical inclination corresponding to the value of i for which the co-efficient of τ in Equation (20) is zero:

$$i_c = 2l \left[1 - \frac{3}{2^5} l^2 + 0\,(l^4) \right] \tag{21}$$

in radians. Thus the critical inclination depends on the parameter l which characterizes the amplitude of libration around L_4. It can be seen that i_c increases with l. The existence of the critical inclination was pointed out by Bien and Schubart (1983) by numerical integration. The above solution explains the critical inclination analytically.

The existence of the critical inclination affects also the behaviour of the "Ψ_1, Ψ_2 curve". As the ellipse rotates with the same rate as Ω, it rotates backwards if $i < i_c$ and forwards if $i > i_c$.

6. *An invariant relation of Trojan asteroids*

The stability of the motion of celestial bodies can be studied in several ways. When the model of the circular restricted three-body problem is applicable the Jacobi integral can be used to determine regions of possible motions and stability. However, the Jacobi integral does not exist in the elliptic restricted three-body problem which is a better approximation when the motion of Trojan asteroids is investigated. In the planar, elliptic case the Jacobi integral is substituted by the following relation (Szebehely, 1967)

$$\left(\frac{dx}{dv}\right)^2 + \left(\frac{dy}{dv}\right)^2 = \frac{2U}{1+e\cos v} - 2e\int\frac{U\sin v}{(1+e\cos v)^2}\,dv - C, \tag{22}$$

where x, y are Cartesian coordinates of the body of negligible mass, $U(x, y)$ is the potential function of the problem, e is the eccentricity of the relative orbits of the primaries, v is the true anomaly of one of the primaries and C is constant. As U depends on x and y the integral in Equation (22) can be calculated only when the solution for x and y is known. Note, that for $e = 0$, Equation (22) turns into the Jacobi integral.

As the Jacobi integral has an important role in determining regions of possible motions and stability, the discussion of Equation (22) and the question of an invariant relation in the elliptic problem have been the subject of several papers (Delva and Dvorak, 1979, Vrcelj and Kiewiet de Jonge, 1978, Williams and Watts, 1978, Delva, 1983).

In Paper VI, I calculated the integral in Equation (22) by using my solution for the Trojan asteroids. Studying the motions in three dimensions, I derived the following relation

$$\frac{1}{2}\left[\left(\frac{dr}{dv}\right)^2 + r^2\left(\frac{d\alpha}{dv}\right)^2 + \left(\frac{dz}{dv}\right)^2\right] =$$
$$= \frac{1}{2}r^2 - \mu r\cos\alpha + \frac{1-\mu}{R_1} + \frac{\mu}{R_2} - C^*. \tag{23}$$

This relation is formally identical with the Jacobi integral written in cylindrical coordinates. However, C^* is not a constant but a slowly changing function of the time

$$C^* = -(D_1+\cos\alpha_0)\, e_J\, c\cos(A_0\tau+\Psi_{11}) - \\ -(D_2+\sin\alpha_0)\, e_J c\sin(A_0\tau+\Psi_{11}) - \\ -e_J^2\left(\frac{A_1}{A_0}\cos\alpha_0+\frac{A_2}{A_0}\sin\alpha_0\right)+0\left(e^2 e_J\right)+C, \tag{24}$$

where

$$D_1 = \frac{1}{2}-\frac{83}{2^4 3}\, l^2-\frac{1193}{2^8 3^3}\, l^4+0\,(l^6),$$

$$D_2 = \frac{\sqrt{3}}{2}+\frac{91\sqrt{3}}{2^4 3^2}\, l^2-\frac{11093\sqrt{3}}{2^8 3^4}\, l^4+0\,(l^6),$$

and C is a constant.
Equation (24) shows the main effects of Jupiter's orbital eccentricity e_J on the Jacobi integral. It can be seen that C* suffers long-periodic variations corresponding to the periods T_ι and $T_{\bullet,\tilde{\omega}}$. In Paper VI upper limits for the terms of Equation (24) were also derived.

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References

Bien, R. 1980 a. Astronomy and Astrophysics, *81,* 255.
Bien, R. 1980b. Moon and Planets, *22,* 163.
Bien, R. Schubart, J. 1983. in V. V. Markellos and Y. Kozai (eds.), "Dynamical Trapping and Evolution in the Solar System", D. Reidel Publ. Co., Dordrecht, Holland, 153–161
Chebotarev, G. A., Belyaev, N. A., Eremenko, R. P. 1974. in Y. Kozai (ed.), „The Stability of the Solar System and of Small Stellar Systems", D. Reidel Publ. Co., Dordrecht, Holland, 63–69.
Delva, M., Dvorak, R. 1979. Astronomy and Astrophysics, *77,* 252.

Delva, M. 1983. in V. V. Markellos and Y. Kozai (eds.), "Dynamical Trapping and Evolution in the Solar System", D. Reidel Publ. Co., Dordrecht, Holland,. 317—323
Érdi, B. 1977. Celestial Mechanics, *15,* 367. (Paper I)
Érdi, B. 1978. Celestial Mechanics, *18,* 141. (Paper II)
Érdi, B. 1979. Celestial Mechanics, *20,* 59. (Paper III)
Érdi, B., Presler, W. H. 1980. Astronomical Journal, *85,* 1670. (Paper IV)
Érdi, B. 1981. Celestial Mechanics, *24,* 377. (Paper V)
Érdi, B. 1982. in B. A. Balázs and V. Szebehely (eds.), "Dynamical Astronomy", Eötvös University Publication, Budapest, 17–36. (Paper VI)
Érdi, B. 1983. Celestial Mechanics *30,* 3. (Paper VII)
Érdi, B., Váradi, F. 1983. in C. I. Lagerkvist and H. Rickman (eds.), "Asteroids, Comets, Meteors", Uppsala Universitet, Uppsala,. 155—159. (Paper VIII)
Érdi, B. 1983. in V. V. Markellos and Y. Kozai (eds.), "Dynamical Trapping and Evolution in the Solar System", D. Reidel Publ. Co., Dordrecht, Holland, pp. 165—176. (Paper IX)
Érdi, B. 1984. Celestial Mechanics *34,* 435 (Paper X)
Garfinkel, B. 1977. Astronomical Journal, *82,* 368.
Garfinkel, B. 1980. Celestial Mechanics, *22,* 267.
Hagihara, Y. 1975. Celestial Mechanics Vol IV. Japan Society for the Promotion of Science, Tokyo.
Kevorkian, J. 1970. in G. E. O. Giacaglia (ed.), "Periodic Orbits, Stability and Resonances", D. Reidel Publ. Co., Dordrecht, Holland, 286—303.
Kevorkian, J., Cole, J. D. 1981. Perturbation Methods in Applied Mathematics, Springer-Verlag, Berlin, Heidelberg, New York.
Kozai, Y. 1984. in A. Berger (ed.) "The Big Bang and Georges Lemaitre", 207—215 D. Reidel Publ. Co.
McKenzie, R., Szebehely, V. 1981. Celestial Mechanics, *23,* 223.
Schubart, J., Bien, R. 1984. Celestial Mechanics, *34,* 443.
Szebehely, V. 1967. Theory of Orbits, Academic Press, New York and London.
Szebehely, V., Premkumar, R. 1982. Celestial Mechanics, *28,* 195.
van Houten, C. J., van Houten-Groeneveld, I., Herget, P., and Gehrels, T. 1970. Astronomy and Astrophysics Supplement Series, *2,* 339.
Vrcelj, Z., and Kiewiet de Jonge, J. H. 1978. Astronomical Journal, *83,* 514.
Williams, C. A., Watts, J. G. 1978. in V. Szebehely (ed.) "Dynamics of Planets and Satellites and Theories of Their Motion", D. Reidel Publishing Company, Dordrecht, Holland, 333—337.

VARIATION OF THE SOLAR CONSTANT AND ITS CONNECTION WITH THE SOLAR ACTIVITY

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Abstract

The measurements of the Nimbus-7 and Solar Maximum Mission satellites indicated a few hundreths percent per year systematic downward trend in the 1 A. U. total solar irradiance. Beside this slow decrease both satellites also indicated small amplitude variations of the solar constant on time scale from days to weeks. It seems that this latter variation of the solar constant is linked to the solar rotation period via the effect of solar active regions. Beside the measurements of the satellites the statistical analysis of the daily observations of the Smithsonian Institution from 1923 to 1952 also suggests that the solar constant changes in the order of a few hundredths percent, according to the magnetic activity of the Sun.

This work investigates the connection of the age, state of development and magnetic structure of the active regions to the variations of the solar constant measured by the Nimbus-7 and SMM satellites. Our results show that the large decreases of the solar constant occur when newly formed and quickly developing sunspot groups with complex structure can be seen on the solar disc, to which usually extended and connected facular fields belong. In those cases when old, simple sunspot groups and their facular fields were dominant on the solar disc the value of the solar constant seemed to slightly increase, or these could reduce the effect of the young and complex sunspot groups.

Резюме

Солнечная постоянная определяется как величина энергии, приходяшейся на единицу поверхности, перпендикулярной к направлению солнечного излучения на верхней границе атмосферы при среднем расстоянии Земля-Солнце в полном интервале спектра. Определение солнечной постоянной, а также выявление ее изменений в последине десятилетия стало центральной проблемой исследований, поскольку новейшие климатические модели указывают на то, что сотя солнечная постоянная и мала, ее непрерывное изменение может оказывать влияние на глобальный тепловой баланс земной атмосферы и может приводить к еффектам, изменяющим климат (Eddy, 1977).

Поскольку непрерывные измерения для определения солнечной постояной начались в начале века, а измерения вне пределов атмосферы, на которые не влияют атмосферные возмущения, – лишь в середине семидесятых только связанные с солнечной активностью изменения солнечной постоянной.

Анализ суточных наблюдений, проведенных в Смитсоновском институте с 1923 по 1952 год, показал, что в величине солнечной постоянной наблюдаются изменения с периодом около 28 дней с амплитудой δ S/S $\sim 7 \times 10^{-4}$. Эти изменения в суточной части временной шкалы связаны с магнитной активностью Солнца (Foukal és Vernazza, 1979). Измерения, проведенные с помощью спутников Нимб-7 и СММ, указывают на непрерыное уменьшение солнечной постоянной с величиной несколько сотых процента в год. Наряду с этим медленным уменьшением наблюдаются также колебания величины солнечной постоянной, достигающие нескольких сотых и нескольких десятых процента во временной шкале от нескольких дней до нескольких недель соответственно. Hickey et al., 1982; Willson, 1982 a, b). Повидимому, эти последние связаны с активными областями, периодические связаны с активными областями, периодически появляющимися на Солнце.

В настоящей работе исследуется связь между изменениями солнечной постоянной и солнечной активностью на основании результатов измерений спутников Нимб-7 и СММ, а также с использованием данных каталогов NOAA's BOULDER Solar Geophysical Data и Солнечные данные, Бюллетень.

I. Introduction

The solar constant is one of the most basic quantities of the astrophysics and meteorology because its value characterizes the solar energy flux reaching the Earth. The solar constant is defined as the quantity of solar energy at normal incidence outside the atmosphere at mean Sun-Earth distance. The correct determination of the solar constant and its variation became the main interest of the researchers in the last decades because according to the latest climatic models the slow but continuous change of the solar constant could influence the global heat-budget of the Earth's atmosphere, and it could trigger climate modifying effects (*Eddy,* 1977.).

Since the continuous measurements for the determination of the solar constant started at the beginning of this century and measurements free from the disturbing effect of the Earth's atmosphere (that is outside the atmosphere) have been available since the middle of the seventies thus we are able to study only the variation of the solar constant in its relation to the solar activity.

The analysis of the daily observations of the Smithsonian Institution between 1923 and 1952 indicate that there is a variation with about 28 days period, at a level of Δ S/S $\sim 7 \times 10^{-4}$ on time scale of days connected to the magnetic activity of the Sun (*Foukal* and *Vernazza,* 1979). The Nimbus-7 and the Solar Maximum Mission satellites measured a few hundredth percent per year systematic downward trend in the 1 A. U. total solar irradiance during their period of measurements. Beside this slow decrease one could observe a few hundredths or tenths of a percent fluctuation of the solar constant on the scale of days to weeks (*Hickey et al.*, 1982., *Willson*, 1982a, b.). It seems that these later mentioned, short time changes are connected to solar active regions.

This paper investigates the connection between the variation of the solar constant and the phenomena of the solar activity on the basis of the measurements of the Nimbus-7 and SMM satellites, and of the data of the Catalogues "NOAA's Boulder Solar Geophysical Data" and "Solnechnye Dannye, Byulleten' (Solar Data)".

II. Results of the Measurements of the Solar Constant

The different measurements of the solar contant indicate short period, from a few days to weeks, changes in the order of a few hundredths and tenths of a percent connected to the active regions of the Sun. The measurements of the Smithsonian Institution executed between 1923 and 1952 do not show changes above 0.17 rms in the wavelength ranges 340 to 2400 nm. But the statistical analysis of the Smithsonian data indicates an about 28 days period variation in the order of $\Delta S/S \sim 7 \times 10^{-4}$ on the scale of days connected to the magnetic activity of the Sun (*Foukal* and *Vernazza*, 1979.).

The measurements of the Nimbus-7 satellite between November 16, 1978 and August 11, 1981, in the first 1000 days of its operation, indicated a systematic decrease of the solar constant in the order of 0.025% per year (*Hickey et al.*, 1982). The SMM/ACRIM radiometer also showed a similar 0.04% per year systematic decrease in the value of the solar constant between February and December of 1980 (*Willson*, 1982a, b). The cause of this slow decrease is not exactly known as yet and because the available data sets cover only a short time interval one is not able to decide whether this is a continuous decrease or it is due to the decreasing phase of a periodical variation. Besides the amplitude of this variation is too small that it is close to the error-margin of the measurements even of the most modern high-stability instruments, thus it is hard to separate them from the different instrumental effects. Beside this slow decrease both satellites indicated a decrease in the order of a few hundredths and tenths of a percent related to the solar active regions corresponding to the rotation of the Sun (*Hickey et al.*, 1982 *Willson*, 1982a, b *Smith et al.*, 1982). A strong connection has been established between the decreases of the solar constant and the maxima of the 10.7 cm flux intensity, the Zurich sunspot number and the projected areas of the sunspots. The degree of the correlation was always higher in the case of the 10.7 cm flux intensity and the sunspot areas, than in the case of the sunspot number (*Willson*, 1982b., *Smith et al.* 1982). The reason of this partly is that the sunspot number is only an empirical index of the solar activity and in many cases there is a phase delay between the sunspot number and the total sunspot area. On the other hand, as we will see later on the basis of our investigations it seems that the largest decreases of the solar constant take place when newly formed and quickly developing sunspot groups with complex structure occur on the solar disc.

The biggest surprise in the data of the Nimbus-7 satellite was the two largest decreases in August 1979 and July 1981 for which the amplitudes and duration were substantially larger and longer than in any other cases. Unfortunately the time of these decreases were outside of the measuring period of the SMM. At that time the parameters of the solar activity showed only small maxima but in both cases equatorial corona holes crossed over the central meridian of the solar disc (*Hickey,* 1981, *Smith et al.,* 1982)

The values of the different periods of the decreases in the total solar irradiance observed by both the radiometers of the Nimbus-7 and SMM satellites as well as of the solar activity parameters are summarized in Table I. The obtained values of the periods indicate that the solar active regions can modify the value of the solar constant in accordance with the period of rotation of the Sun, through the combination of the radiaton deficit caused by the sunspots and the excess in radiation due to the faculae (*Willson,* 1982b, *Sofia et al.* 1982). The decreases in the solar irradiance in connection with the corona holes could be a significant factor of the decreases of the solar constant through a process which changes the transmittivity above the photosphere (*Smith et al.,* 1982.).

Table I

The periods of the irradiance values and different solar activity parameters calculated on the basis of the measurements of the Nimbus-7 and SMM satellites

Solar parameters	Nimbus-7 measuring period: Nov. 16, Aug. 11, 1978	SMM measuring period: April–October 1980
solar constant	30 days	24.1 days
10.7 cm flux	31 days	27 days
Zurich sunspot number	27 days	28.1 days
sunspot areas	—	25.1 days
facula areas	24 days	—

III. The relationship between the variation of the solar constant and the solar active regions

This chapter investigates the relationship between the large irradiation decreases indicated by the Nimbus-7 and SMM satellites and the ages, state of developments and magnetic conditions of the active regions. Our calculations use the data from the first 411 days of operation of the Nimbus-7 satellite between November 16, 1978 and December 31, 1979, and the normal operation period of the SMM satellite from February to December of 1980. The irradiance records observed by both the radiometers of the Nimbus-7 and SMM satellites were taken from Hickey (1982) and Willson (1982b) digitizing the published curve by the Hewlett-Packard HP 9864A Digitizer of the Debrecen Heliophysical Observatory. The parameters of the solar

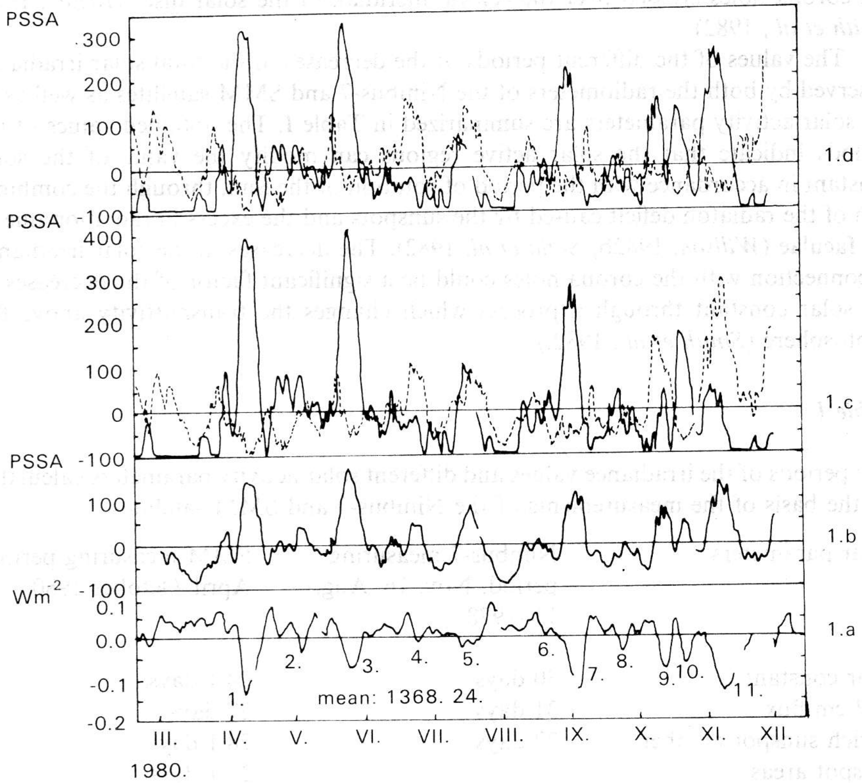

Fig. 1 The devations of the radiation values from their mean measured by the SMM/ACRIM radiometer (1. a after *Willson* 1982b.) compared to the deviations from the mean of the projected sunspot areas during the first 300 days of the normal operation period of the SMM satellite. Fig. 1 b shows the areas of all the spots, the full line on Fig. 1 c shows the areas of the young spots, the broken line shows the areas of the old spots. The full line on 1 d indicates the areas of the quickly developing sunspot groups with complex structure, while the broken line indicates the areas of the old spots with simple structure.

activity were taken from the Catalogues "NOAA's Boulder Solar Geophysical Data" and the "Solnechnye Dannye, Byulleten' (Solar Data)".

To obtain information about the connection of the ages of the active regions and the decreases in the solar constant we classified the sunspot groups of the active regions according to the following:

a.) *Young sunspot groups:* newly formed groups or some new groups in returning active regions.

b.) *Old sunspot groups:* spots observable in active regions without new areas.

Fig 1. a shows the irradiance records of the SMM/ACRIM radiometer between February and December of 1980 (*Willson,* 1982b) compared to the projected areas of all the spots (Fig. 1b), the projected areas of the young spots (Fig. 1 c full line), and the projected areas of the old spots (Fig. 1 c broken line) calculated on the basis of the Solnechnye Dannye. From Fig. 1 we can separate 11 smaller or larger decreases in the value of the solar constant. It can be seen that at the time of the dips 1, 2, 3, 5, 7, 8 and 10 in the solar irradiance the projected areas of the young spots were large. However, there is no good connection between the irradiance dips 4, 6, 9 and 11. and the projected areas of the young spots. On the other hand, the projected areas of the spots especially in the case of the dips 9. and 11. showed a large maximum (*Pap,* 1984). While the amplitudes of the dips 4. and 6. were too small, inside the margin of the measurement error, the amplitudes of the dips 9. and 11. were large, namely the irradiance decrease in November 1980 was the second largest in the sequence and its duration was the longest in the measuring period of the SMM satellite. At the time of the 9. irradiance dip sunspots with rather large areas (its number in the Solnechnye Dannye, Byulletin was 484) and HR 17 188 (S. D. 494) appeared at the beginning of October. These were the third and fourth recurrence of the HR 17 117 and the second recurrence of the HR 17 120 and 17 127. The areas of these groups grew very rapidly, their magnetic structures were rather complex, moreover the umbrae of the opposite polarities were in the same penumbrae, that is they had delta configuration. At the time of the eleventh decrease in November also two quickly developing spots occurred on the solar disc with complex structure in the HR 17 244 (S. D. 541) and 17 255 (S. D. 548), which were the recurrence of the HR 17 181 and 17 188. These later Hale Regions were the main causes of the sixth irradiance dip.

Fig. 2. shows the irradiance records of the Nimbus-7 satellite during the first 411 days of its operation between November 16, 1978 and December 31, 1979 (Fig. 2 a) compared to the projected areas of all the spots, while on Fig. 3 to the projected areas of the young spots (Fig. 3 b full line) and to the projected areas of the old spots (Fig 3 b broken line). Fig. 3. a also shows the irradiance decreases observed by the Nimbus-7 satellite during the above mentioned measurement period. Because for the radiometer of the Nimbus-7 satellite the measurement errors were larger than for the SMM/ACRIM radiometer and because of the uncertainities of digitizing the curve only the decreases with amplitudes larger than 0.1% were considered as real changes. These were concentrated to 12 December 1978, 18 February, 5 and 16 June, 12 and

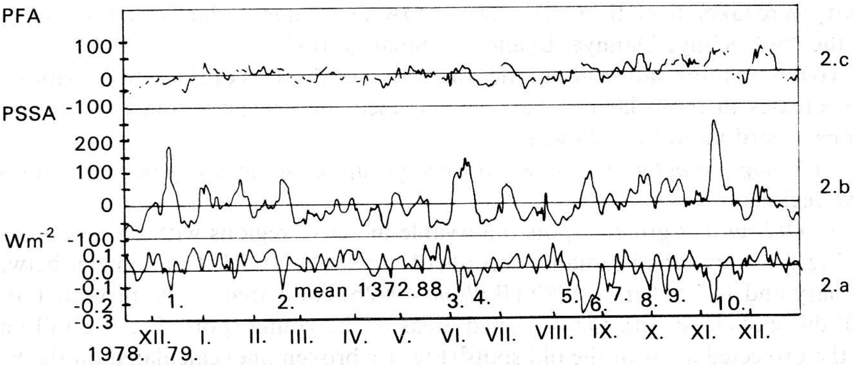

Fig. 2 The deviation (from the mean) of the radiation values (Fig. 2 a) compared to the projected areas of all the spots (Fig. 2 b) and the areas of all the faculae (Fig. 2 c) after the measurements of the Nimbus-7 during the first 411 days of its operation from 1978 November 16, to December 31, 1979.

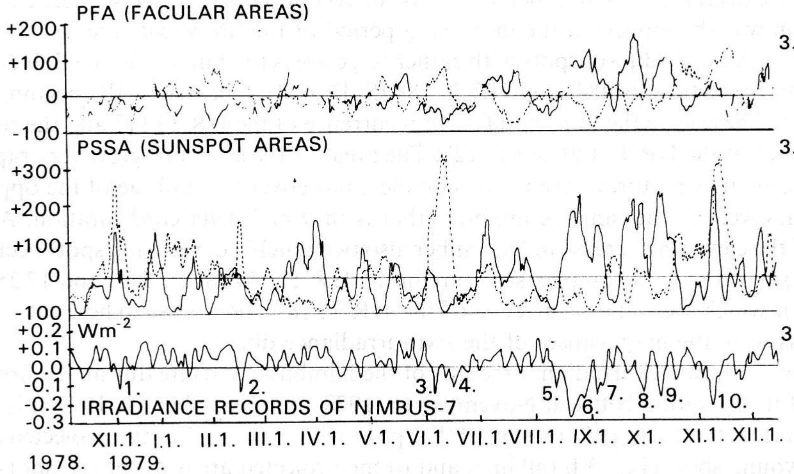

Fig. 3 The radiation values (Fig. 3 a) measured by the Nimbus-7 satellite during the first 411 days of its operation from November 16, 1978 to December 31, 1979 compared to the projected areas of the young spots (Fig. 3 b full line) and to the projected areas of the old spots (Fig. 3 b broken line). The full line on Fig. 3 c shows the projected areas of faculae appearing in young active regions, the broken line shows the projected area of the faculae occuring in old active regions.

20 August, and 4 and 30 September, 10 October and 8 November 1979. It can be seen from Fig 3 that except the second and fourth decreases in the solar irradiance all the others correspond to smaller or larger maxima of the projected sunspot areas of the young spots. During these two decreases the areas of the old spots were large, while at the time of the first, third and tenth decreases beside the young spots the projected areas of the old spots had maximal values, too. In these cases two groups could be noticed with complex structure and rapidly growing areas. These groups occured in the case of the first irradiance dip in the 15 697 (S. D. 390) and the 15 700 (S. D. 389) McMath Regions — which were the third rotation of the regions 15 654 and 15 651 —, and in the case of the second decrease in the 15 654 and 15 651 —, and in the case of the second decrease in the 15 823 (S. D. 70) and 15 830 (S. D. 74) McMath Regions, which were the third rotation of 15 772 and the fourth rotation of the 15 777.

At the time of the third decrease quickly developing sunspot groups with complex structure occurred in the 16 051 (S. D. 250) and 16 052 (S. D. 251) McMath Regions, which were the sixth rotation of 15 990, and the fourth and second rotation of 15 987 and 15 996, and at the time of the fourth decrease in the 15 065 (S. D. 268) and 15 067 (S. D. 267) McMath Regions, which were the second rotation of the regions 16 008 and 16 014. In November of 1979, at the time of the tenth decrease a great number of old spot groups with complex structure and fast development were observable on the solar disc. The more important ones of these occurred in HR 16414B (S. D. 530), 16 419 (S. D. 537) and 16 418 (S. D. 535). The first two were the third and second rotations of 16 357, the last was the second rotation of 16 365.

If in our classification of spots we take into account the sate of development and the magnetic structure of the spots beside their ages we get the following classes:

c.) Newly formed and quickly developing sunspot groups with complex structure, inside which the areas of the individual spots can grow by a factor of ten in a few days. The spots of opposite polarities are mixed strongly within the groups (gamma configuration) and the umbrae of opposite polarities were in the same penumbrae (delta configuration)

d.) Old spot groups with simple structure and normal magnetic polarity conditions. According to the above classification we sorted the sunspot groups for both of the investigated periods. On Fig. 1. d and on 4.b the full line indicates the projected areas of the spots of the classification d. On the base of these Figures we can conclude that the large decreases of the solar constant took place when newly formed and quickly developing sunspot groups with complex magnetic structure occurred on the solar disc. When the old sunspots with simple structure were dominant the value of the solar constant seemed to increase slightly or these spots could reduce the effect of the quickly developing spots of complex structure (*Pap,* 1984.)

On the basis of the Solar Geophysical Data Catalogue we investigated the facular areas in connection with the variation of the solar constant for the first 411 days of the measuring period of the Nimbus-7 satellite. Fig. 2. c shows the total the area of all the faculae compraed to the value of the solar constant measured by the Nimbus-7 satellite and to the total area of all the spots. The full line on Fig. 3. c indicates the areas of faculae surrounding young spots and the broken line shows the same in the case of the old spots. The full line of Fig. 4. c represents the areas of faculae surrounding the new and quickly developing sunspot groups with complex structure, and the broken line shows the areas of the faculae in the remaining old active regions. Unfortunately, mainly in the first part of the investigated period, because of the incompleteness of the measured data it is hard to get unambiguos conclusions considering the areas of the faculae. But on the basis of our studies it seems that the areas of faculae surrounding the spots increased together with the areas of the spots. From Fig 3. and 4. it can be seen that at the time of the large irradiance decreases observed by the radiometer of the Nimbus-7 satellite the areas of faculae of the new active regions as well as of the active regions containing quickly developing sunspot groups with complex structure were large, too. Similarly, when the old groups with complex structure were dominant on the solar disc, the areas of the faculae surrounding them also showed a maximum. This connection is supported by the result of the

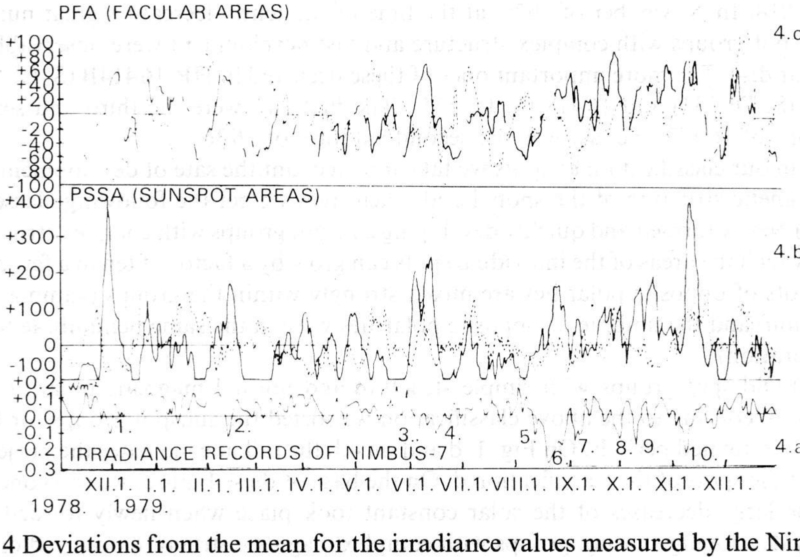

Fig. 4 Deviations from the mean for the irradiance values measured by the Nimbus-7 satellite during the first 411 days of its operation between November 16, 1978 and December 31, 1979 compared to the projected areas of the young quickly developing sunspot groups with complex structure (Fig. 4 b full line) and to the areas of the remaining old spots with simple structure (Fig. 4 b broken line). The full line on Fig. 4 c shows the areas of faculae appearing in active regions containing quickly developing complex spots, the broken line shows the areas of the remaining old faculae.

linear correlation calculation for the spot and facular areas. The value of the correlation coefficient between the areas of the faculae and all the spots considering the complete data set was 0.63, between the areas of the faculae and the quickly developing spotgroups with complex structure was 0.63 too, while for the areas of the old spots and the area of the faculae surrounding them was 0.46.

On the basis of these facts it seems that we have to revise the conception that the decreases of the solar constant are due to the combination of the radiation deficit caused by the sunspots and the radiation excess caused by the faculae. Our investigations suggest that the variation of the solar constant is mainly connected to the age, state of development and magnetic structure of the active regions. It seems that the presence of quickly varying magnetic fields of the young and complex active regions would be able to stop the convection or to reduce its efficiency, while the magnetic field of the old active regions with simple structure could provide more intensive energy transport into the photosphere by the convection. In this way the sunspots and faculae surrounding them could be the common symptoms of such a physical process which takes place in the deeper regions of the Sun and in which the magnetic fields of active regions could modify the energy flux transported to the surface by the convection, thus causing the variation of the solar luminosity.

IV. Discussion

Both the Nimbus-7 and SMM satellites indicated a systematic downward trend in the order of a few hundredths percent per year in the 1 A. U. total solar irradiance (*Hickey et al.*, 1982, *Willson*, 1982a, b). Beside this slow decrease of the solar constant, dips of the order of a few hundreths and tenths of a percent have been found on a time scale of days and weeks in both the Nimbus-7 and SMM satellite records. During the common measuring period the decreases of the solar constant observed by two different radiometers show such a good agreement that the solar origin of the decrease could not be doubted. The strong correlation between the solar constant variation and the solar activity parameters, as well as the period analysis indicate that the solar active regions can modify the value of the solar constant according to the rotation period of the Sun (*Willson*, 1982b, *Smith et al.*, 1982). Beside the measurements of the satellites the statistical analysis of the Smithsonian data also suggests that the value of the solar constant varies at the level of $\Delta S/S \sim 7 \times 10^{-4}$ on the scale of a few days connected to the magnetic activity of the Sun (*Foukal* and *Vernazza*, 1979).

We have investigated the connection between the variation of the solar constant and the different solar activity phenomena during the first 411 days of the Nimbus-7 satellite from November 1978 to December 1979 and during the normal operation period of the Solar Maximum Mission from February to December 1980. Our study shows that the value of the solar constant decreased significantly when new and quickly developing sunspot groups with complex structure were seen on the solar disc.

On the other hand, it seems that at the time when old sunspot groups with simple structure were dominant the value of the solar constant increased slightly or these old groups could reduce the effect of the young and complex groups. The investigation of the facular fields, surrounding the sunspots indicates that the areas of the faculae increased together with the areas of the spots, and at the time of the large decreases of the solar constant the areas of the faculae surrounding the new and complex sunspot groups were large, too. Similarly, when the old, simple spots predominated the areas of the faculae surrounding these spots also showed maxima. Thus it seems, that the state of development, the age and magnetic structure of the active regions containing spots and faculae have to be considered principally in the study of the variation of the solar constant and this varation cannot be explained simply with the combination of the radiation deficit due to the spots and the radiation excess due to the faculae.

It seems that the magnetic fields of the active regions containing new and quickly developing sunspot groups with complex structure and surrounding faculae fields would be able to stop the convection or could reduce its efficiency, which could give an explanation to the deficit observed in the emitted total energy flux. On the other side, the magnetic fields of the active regions containing simple old spots and faculae surrounding them can no longer stop the convection or reduce its efficiency, moreover it seems that in these places the convection could transport more energy flux to the photosphere.

Another very important question is what happens with the radiative energy deficit caused by the rapidly varying active regions with complex magnetic structure. Is it storaged in the convection zone and reradiated later as the active regions become older, or is it emitted immediately in form of flares or in other forms of the corpuscular radiation?

Finally it has to be noted that it is a very important task to determine which spectral regions could be connected to the decreases of the solar constant. It has been known for a long time, that there are significant changes in the short wavelength intervals of the solar spectrum in connection with the solar activity but such a small fraction of the total energy flux arrives in these spectral ranges that it can only modify the value of the solar constant at a level of 10^{-4}–10^{-6}. On the other side, the fact that the ground based measurements, which refer to the wavelength range of 340 to 2400 nm because of the selective transmittance of the terrestrial atmosphere, indicates a variation of the solar constant in magnitude and time scale similar to that of the satellite measurements, could suggest that the important part of the variations takes place in the near ultraviolet and visible part of the spectrum. This is very probable because the energy arriving in the U. V. and visible spectral ranges is emitted from the photosphere where the sunspots occur. The study of this question is a very important task, since the major part of the solar energy arriving in these spectral bands determines the energy budget and photochemical reactions of the terrestrial atmosphere, thus directly could influence the wheather of the Earth.

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References

Eddy, J. A. 1977. Climate and changing Sun. Climatic Change, *1.*: 173–190.

Foukal, P., Vernazza, J. 1979. The effect of magnetic fields on solar luminosity., Astrophysical Journal, *234.:* 707–715.

Hickey, J. R., Alton B. M., Griffin, F. J., Jackbowitz, H., Pellegrino, P., Smit, E. A. 1982. Observations of the solar constant and its variations emphasis on Nimbus-7 results. Proceedings of the IAMAP Third Scientific Assembly, 1981, Hamburg, Boulder Colorado, USA,: 10–17.

Hickey, J. R. 1982. Private communications

Pap, J. 1984. Modulation of solar constant by active regions during 1980. Astronomische Nachrichten, 305, 1.: 13–16.

Smith, E. A. Hickey, J. R., Vonder Haar, T. H. 1982. The nature of short period fluctuations in solar irradiance observed by Nimbus-7 satellite. Proceedings of the IAMAP Third Scientific Assembly, 1981. Hamburg, Boulder Colorado, USA,: 18–28.

Sofia, S., Oster, L., Schatten, K. 1982. Solar irradiance modulations by active regions during 1980. Solar Physics *80:* 87–98.

Willson, R. C. 1982.a. Observation of total solar irradiance variaton in ballon, rocket and satellite experiments. Proceedings of the IAMAP Third Scientific Assembly, 1981. Hamburg, Boulder Colorado, USA,: 3–8.

Willson, R. C. 1982.b. Solar irradiance variations and solar activity. Journal of Geophysical Research, *87.:* 4 319–4 326.

FLARE STARS IN THE APPARENT CELESTIAL NEIGHBORHOOD OF η TAURI I.

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"It has been estimated that more photographs of the Pleiades have been taken by astronomers than of any other object in the stellar universe. Similarly, it is no exaggeration to say that more refined observations of all kinds have been made of the Pleiades than any other distant object."
— Otto STRUVE —

Abstract

As part of the international flare-search program 868 photometric plates were taken of the neighborhood of η Tauri with radius 2° 22′. On these plates 39 flare stars were identified, 26 of them were the author's discoveries. The most relevant properties of these objects are introduced here, together with the maps for easy identification. The inconsistency in the notation of the flare stars is discussed, and the chronological ordering of the objects and flare-ups discovered at the Eötvös University and a possible rationalization of the reordering of the Konkoly numbers are suggested.

Analysing the sources of the observed flares it became apparent that most of them belong to the stellar cluster, thus presumably the majority of the flare stars are cluster members, too. This means that the number of stars belonging to the Pleiades could reach at least 2000, and that so far only 15–16 per cent of the members are known.

The results of the photometric study will be published in the continuation of this paper.

Резюме

В рамках международной программы по исследованию вспыхивающих звезд автором было сделано 868 фотометрических снимков в окрестности звезды η Tauri с радиусом 2° 22′. На этих снимках было идентифицировано 39 вспыхи-

вающих звезд, из которых 26 было открыто нами. В работе приводятся наиболее важные данные, относящиеся к этим объектам, а также карты, облегчающие их идентификацию. Обсуждаются также несоответствия, встречающиеся при обозначении вспыхивающих звезд, и предлагается способ каталогизации открытых в Университете им. Этвеша объектов и вспышек в зависимости от времени, а также одна из возможных и целесообразных перегруппировок чисел Конкоя.

При анализе источников обнаруженных вспышек было обнаружено, что большинство из них принадлежит к звездному скоплению. На основании этого можно предположить, что большиство вспыхивающих звезд также принадлежат скоплению. Это означает, что число звезд, принадлежащих скоплению Плеяд, составляет по меньшей мере две тысячи, и таким образом, лишь 15–16% из звезд этого скопления известны в настоящее время.

Результаты фотометрических исследованний будут опубликованы во второй части настоящей работы.

Introduction

In 1924 E. Hertzsprung by chance photographed the sudden brightness increase of a star of the constellation Carina. (Now this object is called DH Carinae.) He noticed the phenomenon, and tried to give an explanation. According to his opinion the cause of the quick brightness increase was due to the impact of an asteroid into the star. But the frequency and time-development of similar events observed in the forties (Van Maanen, 1940: WX UMa, 1945: YZ CMi, Carpenter, 1947: UV Ceti etc.) and the reoccurences of the phenomenon in the case of the same stars made this naive hypothesis to be rejected. However, the truth is that the real physical causes of this phenomenon, called the flare activity, have not been found yet. Maybe that is why the study of flare stars is still a popular field for the astrophysicists of the seventies and the eighties.

At rest these variables, called UV Ceti-type after their well known representative, are red dwarfs with very low energy output. Their spectra contain emission lines, and in most of the cases they can be classified as dM0.5e - dM6.5e. Because their absolute visual magnitudes are between $+10^{M}$ and $+18^{M}$ with a few exception, only the ones in the immediate solar neighborhood can be observed with photoelectric photometers and spectrographs mounted onto small or medium sized telescopes. But there are hardly more than fifty of that type (Petit, 1958, Joy, 1960, Kunkel, 1965) and there is only a dozen, which flare up with frequency that it would be worthwhile to observe them continuously photometrically.

Fortunately at the beginning of the fifties it was already discovered (Haro and Morgan, 1953) that these peculiar stars seem to cluster in certain parts of the sky. Objects with similar properties to that of UV Ceti were identified in the Orion nebula and its close neighborhood, though at first they were considered as a separate class of the variable stars, and therefore they were called as flash- not flare-stars. Since the very young group of stars, the so called Orion association — presumably to which the majority of these variables belong (Haro 1976) — is so far from the Solar system that the individual photoelectric observation of its red dwarfs would be wasteful, photographic methods are used for the observation and the registration of the actual value of the apparent brightness of these stars. The photometric observations are made in the ultraviolet, blue, sometimes in visual and red range of the electromagnetic spectrum with large field reflectors, mostly Schmidt telescopes. This way about 20 square degree area of the sky can be detected simultaneously. To study the time-development of the change in brightness, it is necessary to use such exposure times for the plates, which are not longer than 5 to 10 minutes. It is also important to minimize the deadtime between the measurements. For that purpose most of the observatories use the method of multiple exposures, that is 4 to 12 exposures are taken onto the same plate, sliding the plate alongside with a small amount between each exposures.

According to the above described method the researchers studied quite a few groups of stars and galactic clusters after the Orion association, and discovered that the representatives of this type of the variables can be recognised in them. There are two limitations of their detection. First, the galactic clusters almost without exception can be found in the Milky Way, where the interstellar absorption is the strongest, second the extraordinarily low brigtness of the considered type of the variable stars. In the last three decades, since 1952 flares have been also found in the NGC 2264 (Rosino, 1957, Haro, 1968, Petit, 1958, Haro, 1976), in the NGC 7000 (Haro, Chavira, 1973, Rosino, 1976, Erastova and Tsvetkov, 1974), in the Coma Berenices cluster (Haro and Chavira, 1964), in the Hyades (Haro, 1968), in the dark clouds of the constellation Taurus — TDC-1, TDC-2 — (Haro and Chavira, 1965, Tsvetkova 1984), in the Praesepe (Haro and Chavira, 1965, Jankovics, 1973, Jankovics, 1975, Oganjan et al. 1982), and last but no least, in the Pleiades (Johnson and Mitchell, 1958., Haro, 1963, Rosino and Pigatto, 1969, Ambartsumian et al. 1971, Mirzoyan et al. 1977, Balázs et al. 1973, Szécsényi-Nagy, 1975, Rosino and Szécsényi-Nagy, 1978, Melikian et al. 1981).

From the investigation of the clusters and associations it could be concluded that these objects gather primarily in the supposedly young star aggregations, while they could be hardly found in older clusters. Considering that the data obtained by photographic methods could be evaluated and interpreted statistically, our aim was to collect such homogeneous observational evidences, which give adequate base for statistical conclusions. Thus we had to study such part of the sky, which could be observed for a relatively long time with our instruments, that is an area of at least $+15°$ in declination, and crossing the meridian at midnight in winter. This area had to contain a suitably populated cluster reasonably close to the Sun with sufficiently large apparent diameter. This way the Pleiades became our choice, which is — in addition — located 24° south of the galactic equator.

1. The discovery of the flare stars of the Pleiades

Though the Pleiades is the oldest known open cluster studied in details (Alter et al. 1970, Ruprecht et al. 1981) its flare stars were discovered relatively late. The cluster is reasonably close to the Sun, its distance modulus is all in all 5.5 magnitude (Becker, Fenkart, 1971), so it was generally accepted that each of its members were already catalogued. Therefore in the fifties nobody took the job in hand of the search for additional members. As for the early spectral type members — in the central regions of the cluster —, they were entirely identified by that time (Hertzsprung, 1947) but not the extremely dim red dwarfs there. Nevertheless the flare stars originate from these.

First Johnson and Mitchell took note of an object within the limits of the cluster, established by Hertzsprung, which had shown a sudden and dramatic increase in brightness. (In his catalogue Hertzsprung marked it by the number 1306, hereinafter designated as H II 1306, Hertzsprung, 1947) They interpreted the phenomenon as a flare up, and concluded that more flare stars might be located in that area. Through the systematical photometric investigation of the Pleiades, Haro proved that Johnson and Mitchell's conclusion had been correct. Already in the sixties Haro identified about 50 active stars in the area of the cluster (Haro, 1963, 1968).

Here we have to call the readers' attention, that only in the cases of the few brightest, earliest spectral type stars one can decide whether they are members of the cluster or not. That is why we emphasized that flare stars were observed in the area of the cluster, and not say in the Pleiades itself. Later we will return to the question of cluster membership.

2. Observations

In Hungary the observations started in January of 1969. Their purpose was to find and recognize as much as possible from among the flare stars hidden in the Pleiades and its apparent celestial neighborhood. This program was a contribution to an international one for the persuasion of the late László Detre, who then was the director of the Konkoly Observatory. Besides the Hungarian astronomers, the researchers of the Astrophysical Observatory at Asiago, the Astronomical Institute of the University of Padua (Italy), the Astrophysical Observatory at Byurakan (USSR, Armenian Rep.), the Tonantzintla Observatory (Mexico) participated in it from the beginning. Later the astronomers of the Astrophysical Observatory at Abastumani (USSR, Georgian Rep.), the National Astronomical Institute of the Academy of Bulgaria and the Observatory at Sonneberg (GDR) joined. In the beginning Béla Balázs, later the author and László Patkós participated in the program from the Department of Astronomy of the Loránd Eötvös University. The first flare discoveries appeared in two publications (Ambartsumian et al. 1969, and Balázs, Vardanian, 1970.).

The photographic observations were executed by a Schmidt telescope of 600 mm aperture, f/3 aperture ratio, with 900 mm mirror diameter. The field of view is circular and its angular diameter is 4° 45′. Kodak plates (16 × 16 cm^2) were used for the exposures, this way 17.5 square degree parts of the sky were photographed. In the Schmidt-camera, made by Zeiss (Jena) the sharp image is formed on a spherical calotte shaped surface, therefore the plates had to be deformed during the exposures to make them fit to the focal surface. Though in some cases the plates broke, this method had an advantage. Namely, — avoiding the correction lens — we could use the exceptional transmittance of the telescope in the ultraviolet up to its maximum. It has particular importance in the observation of flare phenomena since the sudden brightness increase mainly is due to the essentially increased ultraviolet energy output compared to their neutral state. For this we tried to execute the observations in this range of the electromagnetic spectrum, and only the U range of the objects' emission were detected. To get this range an UG2-type Schott filter of 2 mm thickness was used in front of the emulsion (Johnson, 1955.). The astroclimatic circumstances, and the fact that already at about 15 kms from the observatory, which is situated at 950 m above the sea level, there are well-lit settlements allowed one and a half hour integrated (accumulated) exposure time. To keep the background fog density at an acceptable level—if nothing disturbed the observations—most of the cases each of the plates were exposed for 80 minutes. Since we hoped to find the flare stars between extremely dim and the top of that red dwarf stars, the exposures had to be such that even 16–17 magnitude objects would have been identifiable. Thus we chose 10 minutes to be the exposure time. Longer exposures are not worthwhile, because to get the time-development of a flare event it is essential to obtain the brightness increase of the outburst on more than one exposure. Considering that a flare phenomenon very rarely lasts longer than one hour—most of the cases only 30–40 minutes—the 10 minutes seemed to be the optimal exposure time. Between each exposure we had to interrupt the path of the light for 30 seconds, thus the 80 minutes effective exposure time photographs cover $83^{m}.5$ time intervals.

At the beginning of the program—and temporarily in 1976—we did not have the necessary UV filter, therefore the plates (mostly Kodak 0-a-0 emulsions) were exposed without filter. According to the above reasoning, in these cases the plates were exposed 8 times for 4 minutes, also with 30–40 seconds interruptions. The time in these breaks were used to move the telescope in the direction of increasing right ascensions, in a way that on the plate the angular distance between the first and the second image was 25″, while only 15″ between the others. At the mountain station in Mátra (Piszkéstető) of the Konkoly Observatory the seeing is usually 2″–3″, which is not really favourable if we characterize the plates with the apparent brightness of the most dim object possible to observe yet. But considering the very sharp, pointlike image of the used telescope, which in case of ideal atmospheric circumstances would make hard the measurement of the photographic plates, we could even be grateful to the atmosphere doing us a favour.

Starting an exposure sequence we set the optical axis of the telescope to the Alcyone (η Tauri), similarly to our colleagues participating in the international program. At the time of the observations the mean equatorial coordinates of this object were $\alpha = 3^h\, 46^m\!.0$ and $\delta = +24°\, 02'$. The Alcyone is very close to the virtual centre of the cluster—moreover it is a third magnitude object—thus this choice seemed to be very advantageous in more respect. If the wheather was satisfactory we made series of exposures of the Pleiades as long as the cluster remained closer than 60° to the zenith. This way we could make four or five plates one night. Due to the restrictions caused by the built of the telescope, we had to wait 3–5 minutes between the exposures of two plates, depending on the hour angle of the Pleiades. However these time intervals were short enough that the flares we could detect with our equipment would not be unobserved. Every plate (except for the previously mentioned ones we used 103-a0 Kodak emulsion to detect the ultraviolet radiation) was developed in D19 developer suggested by the manufacturer, according to the specification.

In the course of the program 868 exposures were registered on 110 plates, with altogether 4416 minutes exposure time. The time interval covered by these observations was 4848 minutes, which counting the time necessary to change the plates, is equivalent to 85 hours.

3. *The evaluation of the observational material*

The negatives were visually studied, comparing them in pairs by the "Sternplatten-komparator" made by Carl Zeiss, Jena. The series of points, which seemed to change, fluctuate in brigtness were measured by a Becker type iris photometer. (The datails of the photometric measurements will be discussed in the continuation of this paper.) Those objects were considered as flare stars, of which the brightness changed at least $0^m\!.8$ in the detected spectral range, during the studied time interval. An additional requirement was that the trace of the flare-ups had to be identified at least on two image points, to eliminate the possibility of erroneous discoveries due to observational errors. In the studied time interval 39 objects satisfied these criteria, but no one of these 39 stars had shown two or more flashes.

The equatorial coordinates of the objects, identified as flare stars were determined in three steps. First with the help of the above mentioned comparator we have measured their Cartesian coordinates. This measurement resulted in data with 0.05 mm precision. The reading error had the same uncertainity as the one due to the seeing. The next step was the determination of the cartesian coordinates of the reference stars. To achieve as precise results as possible with the Turner method (Smart, 1931), we chose the reference stars to represent the whole plate well (Fig. 1).

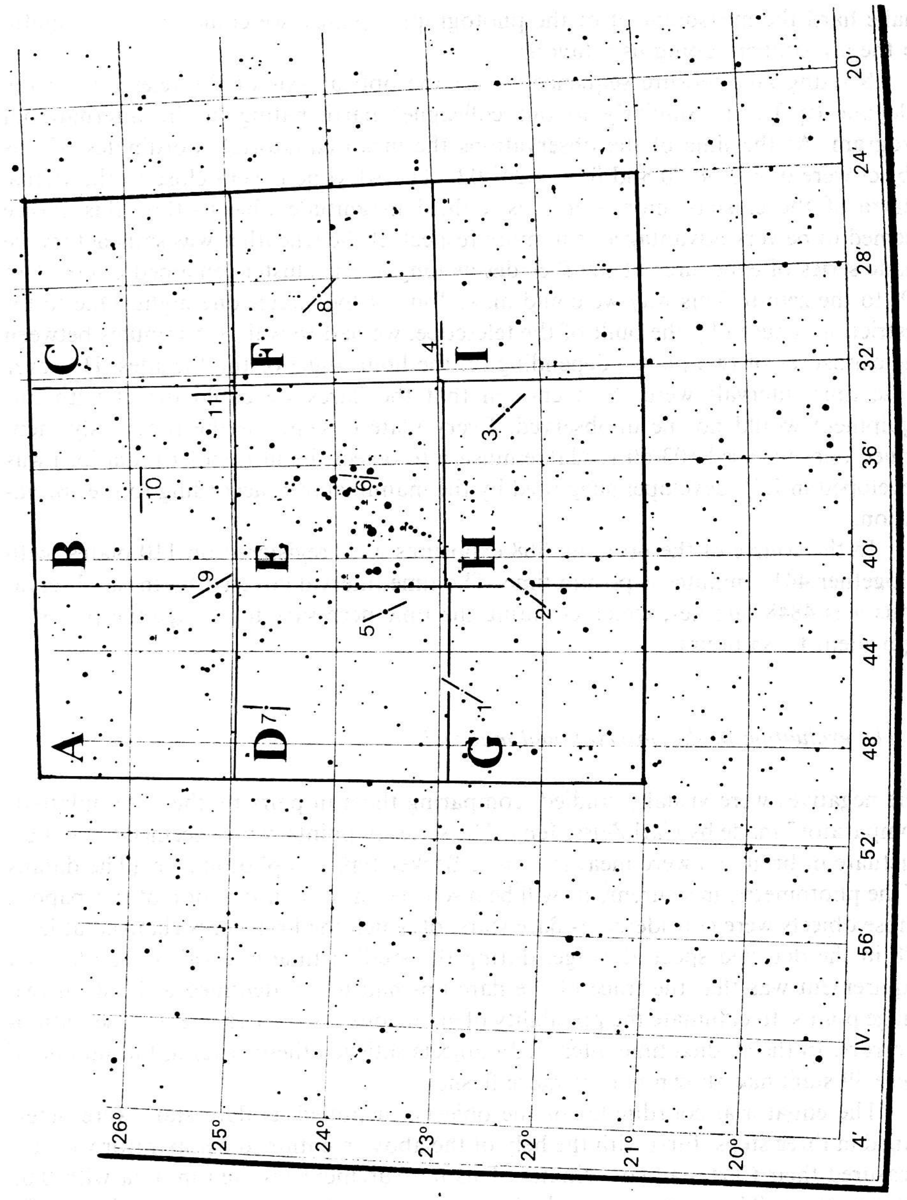


Fig. 1 Location of plates A,…I.

Since the projection of the Schmidt camera we used to obtain the plates is essentially free from radial distortions, the reference objects were chosen close to the edge of the field. The eleven stars used for the measurements and computations are:

1 — BD +22° 593	2 — BD +22° 575	3 — BD +22° 532
4 — BD +22° 524	5 — BD +23° 570	6 — BD +23° 508
7 — BD +24° 595	8 — BD +24° 520	9 — BD +25° 621
10 — BD +25° 608		11 — BD +25° 591

Knowing the exact equatorial coordinates of the above stars and the focal length of the instrument (f = 1809 mm, Nagy, 1980) and the measured x,y values we calculated the plate constants, and with the help of these constants the equatorial coordinates of the objects of unknown position. The obtained values (rounded according to international standards) were calculated to the epoch of 2000.0, taking the precession into consideration. Our results are consistent with the values published by others, those results have been calculated very often to the epoch of 1900.0.

The data necessary for the identification of the observed flare stars can be found in Table I. In its first column the letter "E" refers to the eponym of the University (Loránd *E*ötvös), it stands together with the serial number. The purpose of introducing such new nomination was that the usual abbreviations, made after the geographical location of the institutes were already taken (B or Bu), moreover it seemed not to interfere with any other in the close future. The objects were ordered according to the moment of their flashes.

The second and the third columns contain the right ascension and the declination of the objects, calculated to the epoch of 2000.0. The precision of the first is a tenth of a minute, of the second is an arc minute.

TABLE I

Eötvös catalogue number	$\alpha_{2000.0}$	$\delta_{2000.0}$	Sign of the map	Serial number	Discoverer
E 1	$3^h\ 50^m.9$	+25° 36′	A	5	P.L.+
E 2	$3^h\ 52^m.0$	+25° 02′	D	10	P.L.+
E 3	$3^h\ 48^m.3$	+25° 15′	E	13	P.L.
E 4	$3^h\ 44^m.5$	+24° 41′	E	12	P.L.
E 5	$3^h\ 42^m.2$	+24° 06′	E	7	Sz.–N.
E 6	$3^h\ 48^m.4$	+22° 33′	H	4	Sz.–N.
E 7	$3^h\ 45^m.6$	+22° 59′	H	2	Sz.–N.
E 8	$3^h\ 38^m.9$	+24° 25′	F	1	Sz.–N.
E 9	$3^h\ 47^m.5$	+24° 22′	E	6	Sz.–N.
E 10	$3^h\ 52^m.3$	+24° 40′	D	3	Sz.–N.

TABLE I (cont.)

Eötvös catalogue number	$\alpha_{2000.0}$	$\delta_{2000.0}$	Sign of the map	Serial number	Discoverer
E 11	$3^h\ 47^m.2$	+25° 02′	E	3	Sz.–N.
E 12	$3^h\ 44^m.9$	+25° 22′	E	2	Sz.–N.
E 13	$3^h\ 49^m.2$	+22° 53′	H	3	Sz.–N.
E 14	$3^h\ 42^m.7$	+24° 01′	E	8	Sz.–N.
E 15	$3^h\ 50^m.0$	+25° 08′	D	1	Sz.–N.
E 16	$3^h\ 43^m.2$	+25° 24′	E	1	Sz.–N.
E 17	$3^h\ 49^m.1$	+23° 45′	E	10	Sz.–N.
E 18	$3^h\ 53^m.9$	+25° 21′	A	1	Sz.–N.
E 19	$3^h\ 45^m.3$	+23° 07′	H	1	Sz.–N.
E 20	$3^h\ 52^m.6$	+25° 29′	A	3	Sz.–N.
E 21	$3^h\ 56^m.3$	+23° 55′	D	9	Sz.–N.
E 22	$3^h\ 50^m.6$	+23° 02′	G	2	Sz.–N.
E 23	$3^h\ 52^m.0$	+24° 00′	D	8	Sz.–N.
E 24	$3^h\ 51^m.2$	+24° 25′	D	5	Sz.–N.
E 25	$3^h\ 44^m.0$	+25° 51′	B	1	Sz.–N.
E 26	$3^h\ 53^m.4$	+25° 31′	A	2	Sz.–N.
E 27	$3^h\ 55^m.9$	+23° 04′	G	1	Sz.–N.
E 28	$3^h\ 45^m.0$	+24° 46′	E	4	Sz.–N.
E 29	$3^h\ 53^m.9$	+25° 56′	A	1	Sz.–N.
E 30	$3^h\ 43^m.2$	+24° 39′	E	5	Sz.–N.
E 31	$3^h\ 52^m.0$	+24° 16′	D	7	Sz.–N.
E 32	$3^h\ 52^m.3$	+24° 34′	D	4	Sz.–N.
E 33	$3^h\ 43^m.0$	+23° 32′	E	11	Sz.–N.
E 34	$3^h\ 48^m.7$	+23° 47′	E	9	Sz.–N.
E 35	$3^h\ 50^m.6$	+21° 55′	G	3	Sz.–N.
E 36	$3^h\ 50^m.5$	+24° 24′	D	6	Sz.–N.
E 37	$3^h\ 44^m.8$	+25° 47′	B	2	Sz.–N.
E 38	$3^h\ 48^m.6$	+22° 25′	H	5	Sz.–N.
E 39	$3^h\ 50^m.6$	+24° 53′	D	2	Sz.–N.

+: The plate was taken by Béla Balázs

To make easier the identification of the stars we publish the map of the investigated area on 9 pages with sufficiently large magnification. (The plates are magnifications of the corresponding page of the National Geographic Society—Palomar Observatory Sky Survey [NGS—POSS] in red.) These plates are marked by the letters A, B, ... I (see in the supplement) in their North—East corner, and on each of them the flare stars are distinguished by numbers. Thus in the fourth and the fifth columns of Table I one can find the signs of the map and the serial number of the given star on that map. The last column stands for the initials of the discoverer of the flare event P.L. = László Patkós or the abbreviation of the family name of the discoverer Sz.–N. = Szécsényi-Nagy. As usual in the observational astronomy the plates were evaluated by the observers themselves. The exceptions are marked (Patkós, working on his dissertation evaluated Balázs's data).

4. Discussion

Comparing our data with the literature it turned out that one third of the observed flare events (exactly 13) was produced by flare stars discovered by others already. (See Table II and the corresponding first remark!) The reason why we have enlisted them in the Eötvös catalogue is that in most of the cases it can be proved only years later that somebody had already discovered them. This is the result of the fact that most discoverers characterize the objects only by approximate coordinates, thus practically preventing the certain identification. According to the practice todays identifying maps are published with the paper only if the researcher or the research group have already collected at least a dozen flare star observations. We follow that practice.

To eliminate the possibility of misunderstandings due to the above circumstances, to make easier and more certain the identification of individual flare stars we have compiled and now publish Table II. Here we give additional serial numbers of the flare stars observed by us (or us *also!*) based on the publications of the researchers of the four observatories continuously participating in the long study of flare activity of red dwarfs.

It is to be noted that the Mexican colleagues have compiled more than one list of the flare stars found in the area of the Pleiades. From among these we only give the numbers from the most complete catalogue (Haro et al., 1982) in the column of Tonantzintla Observatory. Additional informations about the flare stars discovered at Tonantzintla can be found in the above mentioned publication, or in its detailed references.

It is worth to accentuate some problems connected to the notations in the publications about flare star observations in our country, and in earlier papers using these publications as references.

The flare stars discovered by the Schmidt telescope of the Astronomical Research Institute of the Hungarian Academy of Sciences (earlier known as Astronomical

Observatory)—which is referred to as "Konkoly Observatory" after its founder in international circles—are distinguished by a letter "K" in front of their serial number. Unfortunately the K numbers of different authors given to the individual discoveries are ambiguous.

a) There are flare stars with more than one flare-ups recorded by the above mentioned instrument. According to the adopted nomenclature these objects, of course, are included leastways twice in the Konkoly list seeing that this latter is not a catalogue of the flare stars but that of observed flare events (e.g. E 16 = 2, Balázs, Patkós 1972 and also = K 27, Szécsényi-Nagy 1974; or E 33 = K 22, Balázs et al. 1973 and also = K 44, Rosino, Szécsényi-Nagy 1978 respectively).

b) There are such K serial numbers—sometimes marked by an asterisk in order to point to the ambiguity of the nomination—which are ordered to *different objects* by our foreign colleagues (e.g. K*1 = CPFS 139, K*1 = CPFS 157, K*1 = CPFS 226 and K*1 = CPFS 227 or K*3 = CPFS 32, K*3 = CPFS 289, K*3 = CPFS 415 and K*3 = CPFS 508 too etc.—these catalogue numbers are the serial numbers of the active stars in the work of Haro et al. 1982, "A *C*atalogue of the *P*leiades *F*lare *S*tars").

c) Some of the Konkoly serial numbers (K1, K2, ... K13) were left out of the list to make the unambigous ranging possible for the flare-ups observed by Hungarian astronomers, and published previously (Balázs et al. 1973). Consequently we deemed the following coordinations (identifications) advisable:

K1 = B 129 (KB 129), K 2 = B 130 (KB 130)—(Ambartsumian et al. 1970, Haro et al. 1982)

K 3 = 1 (H II 1094), K 4 = 2, K 5 = 3, K 6 = 4 (H II 1061)—(Balázs, Vardanian 1970)

TABLE II

Eötvös catalogue number	Notations of Asiago	Byurakan	Konkoly	Tonantzintla
E 1	A 64 (Pigatto, Rosino 1971)	B 211 *D* (Ambartsumian et al.1971)	4 (Balázs, Patkós 1972)	412
E 2			5 *D* (Balázs, Patkós 1972)	447
E 3			6 *D* (Balázs, Patkós 1972)	317

Eötvös catalogue number	Notations of Asiago	Byurakan	Konkoly	Tonantzintla
E 4		B 179 *D* (Ambartsumian et al.1971)	7 (Balázs, Patkós 1972)	150
E 5			K 14 (Balázs et al. 1973)	68 *D*
E 6	A 108 *D* (Pigatto 1973)		K 15 (Balázs et al.1973)	318
E 7		B 414 (Ambartsumian et al.1973)	K 16 *D* (Balázs et al.1973)	191
E 8		B 415 (Ambartsumian et al.1973)	K17 *D* (Balázs et al.1973)	15
E 9			K 18 (Balázs et al.1973)	273 *D*
E 10		B 416 (Ambartsumian et al.1973)	K 19 *D* (Balázs et al. 1973)	455
E 11		B 417 (Ambartsumian et al.1973)	K 20 *D* (Balázs et. al.1973)	250
E 12	A 71 (Pigatto, Rosino 1971)		K 21 (Balázs et al.1973)	169 *D*
E 13		B 455 (Mirzoyan et al. 1976)	K 24 *D* (Szécsényi-Nagy 1974)	356
E 14		B 456 (Mirzoyan et al. 1976)	K 25 (Szécsényi-Nagy 1974)	80 *D*
E 15		B 457 (Mirzoyan et al. 1976)	K 26 *D* (Szécsényi-Nagy 1974)	379
E 16		B 458 (Mirzoyan et al. 1976)	K 27 (Szécsényi-Nagy 1974) 2 *D* (Balázs, Patkós 1972)	98

TABLE II (cont.)

Eötvös catalogue number	Notations of			
	Asiago	Byurakan	Konkoly	Tonantzintla
E 17		B 459 (Mirzoyan et al. 1976)	K 28 (Szécsényi-Nagy 1974)	354 *D*
E 18		B 460 (Mirzoyan et al. 1976)	K 29 *D* (Szécsényi-Nagy 1974)	476
E 19		B 461 (Mirzoyan et al. 1976)	K 30 *D* (Szécsényi-Nagy 1974)	187
E 20		B 462 (Mirzoyan et al. 1976)	K 31 *D* (Szécsényi-Nagy 1975)	459
E 21		B 463 (Mirzoyan et al. 1976)	K 32 *D* (Szécsényi-Nagy 1975)	507
E 22		B 464 (Mirzoyan et al. 1976)	K 33 *D* (Szécsényi-Nagy 1975)	405
E 23		B 465 (Mirzoyan et al. 1976)	K 34 *D* (Szécsényi-Nagy 1975)	442
E 24			K 35 *D* (Szécsényi-Nagy 1975)	421
E 25		B 503 (Mirzoyan et al. 1981)	K 36 *D* (Rosino, Szécsényi-Nagy 1978)	132
E 26			K 37 *D* (Rosino, Szécsényi-Nagy 1978)	472
E 27		B 504 (Mirzoyan et al. 1981)	K 38 *D* (Rosino, Szécsényi-Nagy 1978)	503
E 28		B 505 (Mirzoyan et al. 1981)	K 39 *D* (Rosino, Szécsényi-Nagy 1978)	172
E 29			K 40 *D* (Rosino, Szécsényi-Nagy 1978)	475

TABLE II (cont.)

Eötvös catalogue number	Notations of Asiago	Byurakan	Konkoly	Tonantzintla
E 30		B 118 *D* (Ambartsumian et al. 1970)	K 41 (Rosino, Szécsényi-Nagy 1978)	103
E 31		B 506 (Mirzoyan et al. 1981)	K 42 *D* (Rosino, Szécsényi-Nagy 1978)	443
E 32	A 95 (Pigatto, Rosino 1972)	B 115 *D* (Ambartsumian et al. 1970)	K 43 (Rosino, Szécsényi-Nagy 1978)	454
E 33		B 418 (Ambartsumian et al. 1973)	K 22 *D* (Balázs et al. 1973)	90
		B 507 (Mirzoyan et al. 1981)	K 44 (Rosino, Szécsényi-Nagy 1978)	
E 34		B 508 (Mirzoyan et al. 1981)	K 45 *D* (Rosino, Szécsényi-Nagy 1978)	336
E 35		B 509 (Mirzoyan et al. 1981)	K 46 *D* (Rosino, Szécsényi-Nagy 1978)	408
E 36		B 510 (Mirzoyan et al. 1981)	K47 *D* (Rosino, Szécsényi-Nagy 1978)	402
E 37		B 511 (Mirzoyan et al. 1981)	K 48 *D* (Rosino, Szécsényi-Nagy 1978)	163

TABLE II (cont.)

Eötvös catalogue number	Notations of Asiago	Byurakan	Konkoly	Tonantzintla
E 38	A 85 (Pigatto, Rosino 1972)		K 49 (Rosino, Szécsényi-Nagy 1978)	325 *D*
E 39		B 512 (Mirzoyan et al. 1981)	K 50 *D* (Rosino, Szécsényi-Nagy 1978)	407

Remarks:

— letter "D" marks the observatory first observing the flare up of the object

— objects E 16 and E 33 got two serial numbers on the different Konkoly lists. Both were discovered by the researchers of this observatory, the smaller of the Konkoly numbers refers to the discovery

— due to a misunderstanding the object E 33 was taken into the list twice at the Byurakan Observatory, though each object is allowed to appear only once on that list, not like in the Konkoly list where every flare event gets a serial number

K 7 = 1, K 8 = 2, K 9 = 3, K 10 = 4, K 11 = 5, K 12 = 6, K 13 = 7 — (Balázs, Patkós 1972)

Unfortunately this proposition never has become a really popular one and it resulted in two troublesome outcomes. Firstly there are obscurities of the designations (as explained under b) and secondly in the papers dealing with flare-ups detected in the Pleiades field there are no references at all to the flare events K 8, K 9,... K 13. In such a way these catalogue numbers were omitted from the lists.

d) Finally it is lucky that there are such flare observations (K 14,... K 23, Balázs et al. 1973, K 24,.... K 30, Szécsényi–Nagy 1974, K 31,.... K 35, Szécsényi–Nagy 1975 and K 36,.... K 50, Rosino, Szécsényi–Nagy 1978) the ranging of which are unanimous both according to the discoverers and other authors (Ambartsumian et al. 1973, Parsamian 1976, Mirzoyan et al. 1977, 1981, Jones 1981, Stauffer 1982 and Haro et al. 1982) too.

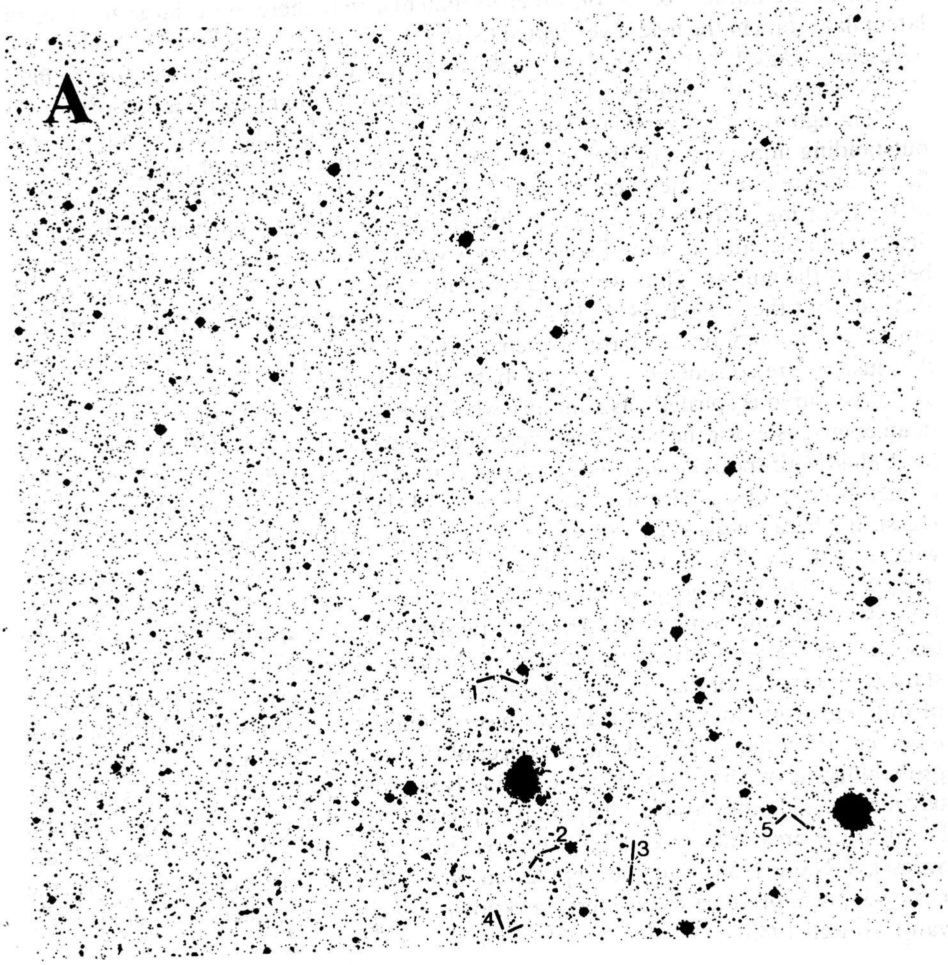
5. *Summary*

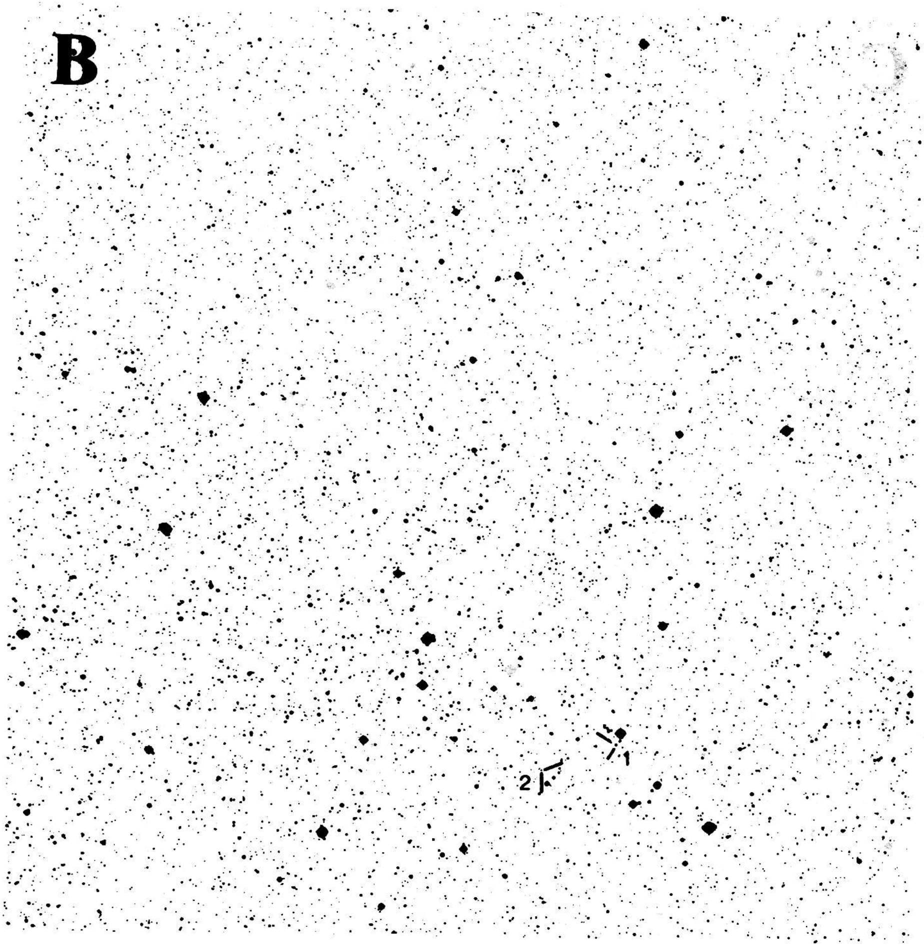
On the base of the given results it can be concluded that the 85 hours long observations made possible to detect 39 flare events. That means that the described method gives almost exactly the same results as the one of the researchers at Byurakan (in average they needed $2.^h20$ to detect a flare-up—Ambartsumian et al., 1973—we needed $2.^h18$), and somewhat better than the one at Asiago (there $2^h\,40^m$ was necessary to register an event–Pigatto, Rosino 1972). The difference is due, not to the difference of size and aperture ratio of the telescopes at Asiago (though one of them is slightly larger, the other is quite smaller than the telescope at Piszkéstető) but to the fact that instead of the plates, which are extremely expensive, though perfectly suitable to the purposes, Kodak Tri-X sheet films were used. The sensitivity of this emulsion type is worse—mainly because of the reciprocity failure—than the sensitivity of the special astronomical emulsions.

The fact that the one-third of the detected flare-ups occured on such objects, which were not known as flare stars from earlier observations, supports the conclusion of the author, based on other arguments, that there are a large number of latent flare stars in the field investigated (Szécsényi–Nagy 1978, Szécsényi–Nagy 1979, Szécsényi–Nagy 1983). On the other hand accepting the earlier estimates for the flare star population, the number of the returning flare-ups ought to be in majority.

Though the discovered or studied objects are extremely dim, because of the outstanding importance of the problem there were efforts to determine whether the flare stars are cluster members or not. According to the result of the investigations of Hertzsprung, that we have already mentioned, the brighter cluster members were distinguishable, and in case of some objects we could safely decide that they did not belong to the cluster. Thus we could concluded that the object E 17 belongs to the Pleiades, but the E 23, E 34, E 36 and the E 39 are not members of the cluster. The others, in majority on the base of their relative position to the known members of the cluster were considered as very probable cluster members. Fortunately there was an "adventureous spirited" astronomer who gave the probability of being a member of an open cluster for the newly discovered flare stars (Jones 1981). In his investigation he studied with special attention whether a correlation exists between the probability of membership of the flare stars and the place of the discovery. For us his results are reassuring because the stars chosen from the Konkoly list are members of the cluster with probability of 0.73. Only the observers of Tonantzintla have better results than that (0.75). The average probabilities for the other three observatories: Asiago 0.56, Byurakan 0.38 and Sonneberg 0.01. The question of membership is important in the case of flare stars because the validity of a theorem of the birth and evolution of the stars can be proven or disproven by the abundance of these restless stars in the clusters of different ages. In the literature we have found probabilities of membership altogether for 15 stars (38%) of the 39 object of the Eötvös catalogue. 10 of these have probability higher than 0.75, they are probably members, the remaining 5 are possibly not members. If the sample adequately represents the flare stars observed and still latent in the area, than it could mean (Szécsényi–Nagy 1979, Szécsényi–Nagy 1983, Szécsényi–Nagy 1984) that the population of the Pleiades reaches 2000 against the todays known, or at least considered as known 329 cluster members (Pels et al. 1975, van Leeuwen 1983).

The author wishes to thank the leaders of the Konkoly Observatory for making possible for him the use of the instruments of their institute, and Professors L. V. Mirzoyan, L. Rosino and G. Haro for their personal interest and their useful questions and advises in the consultations, thus contributing to the success of the described researches.

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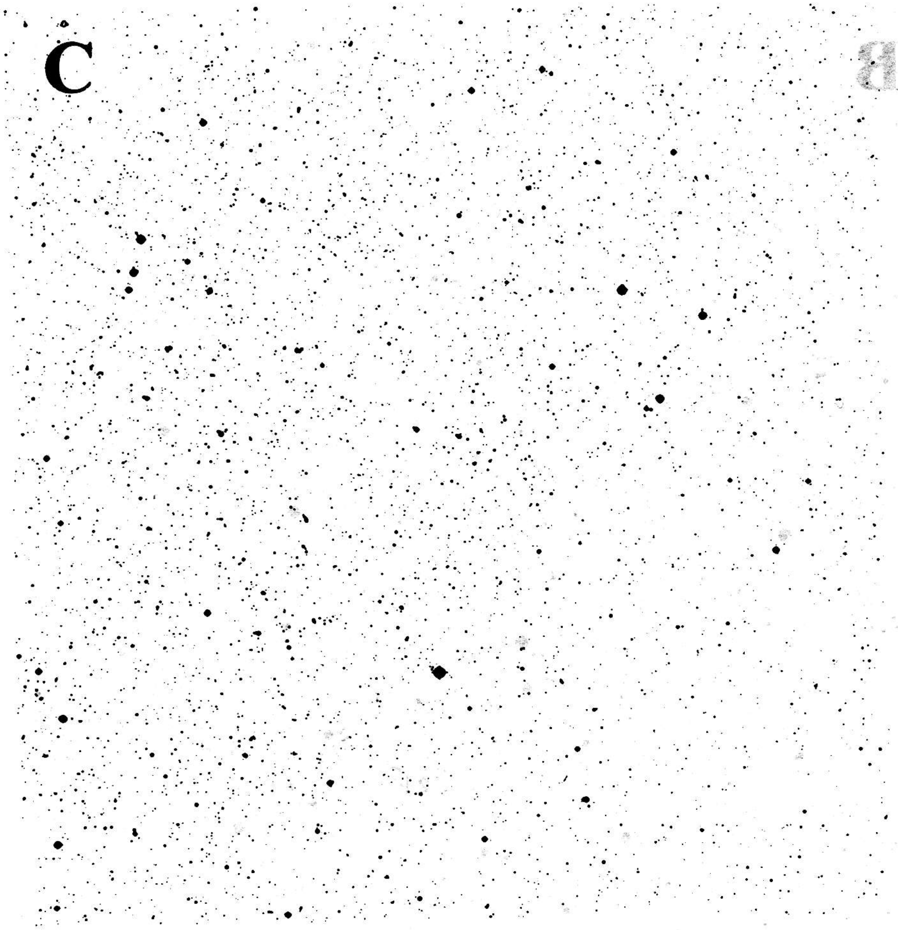
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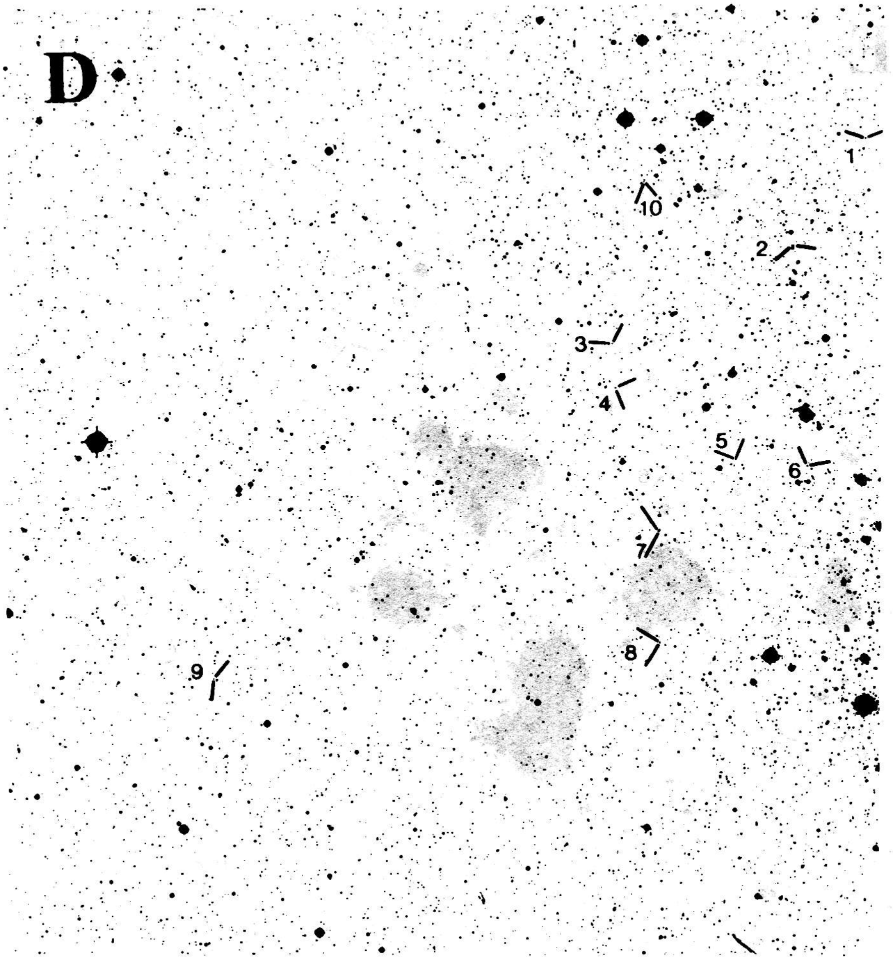
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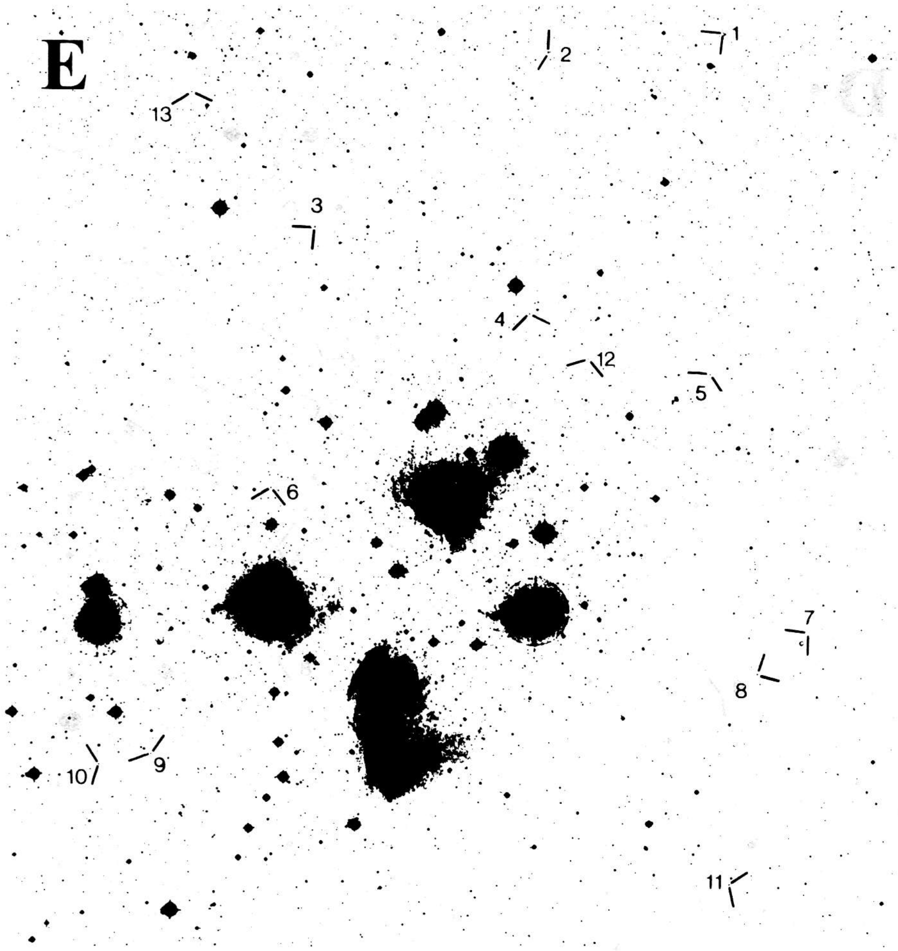
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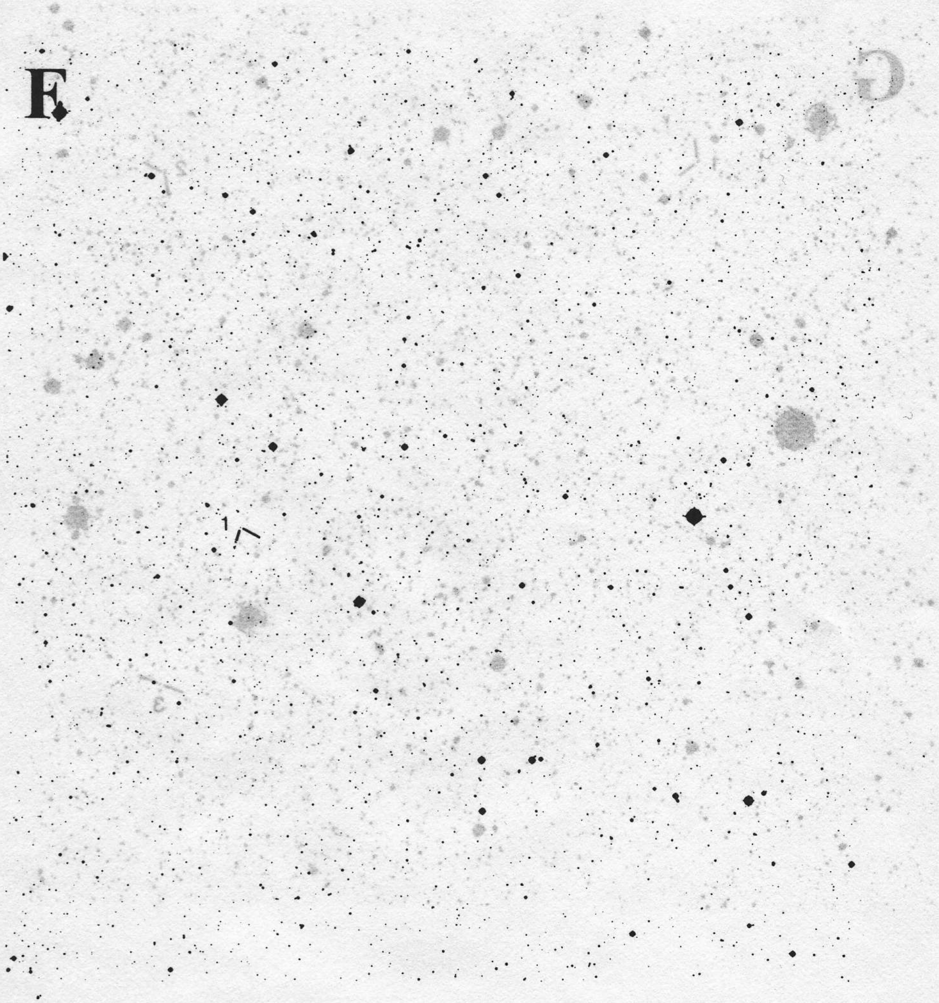
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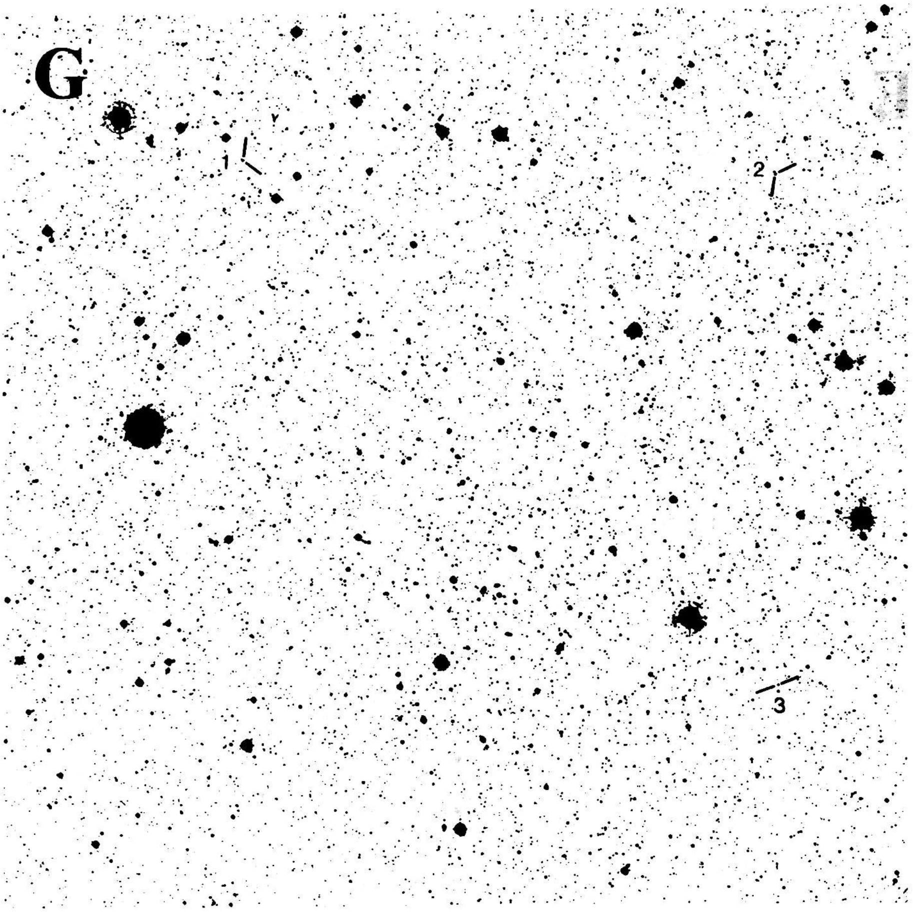
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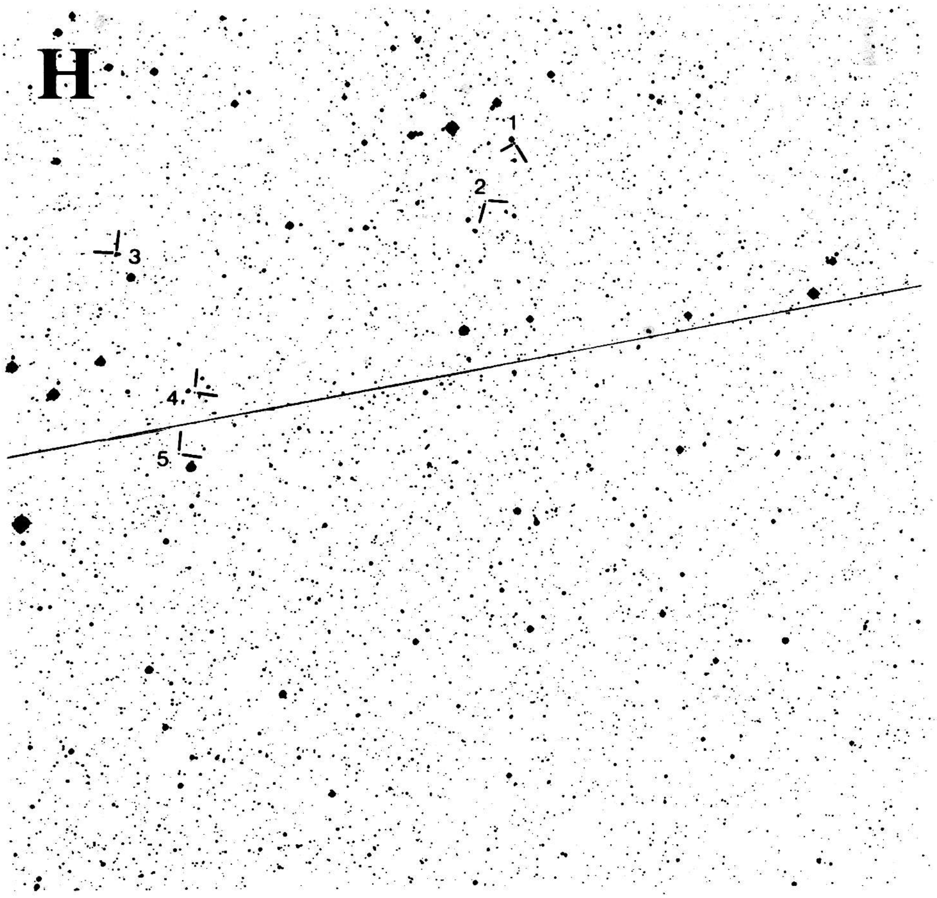
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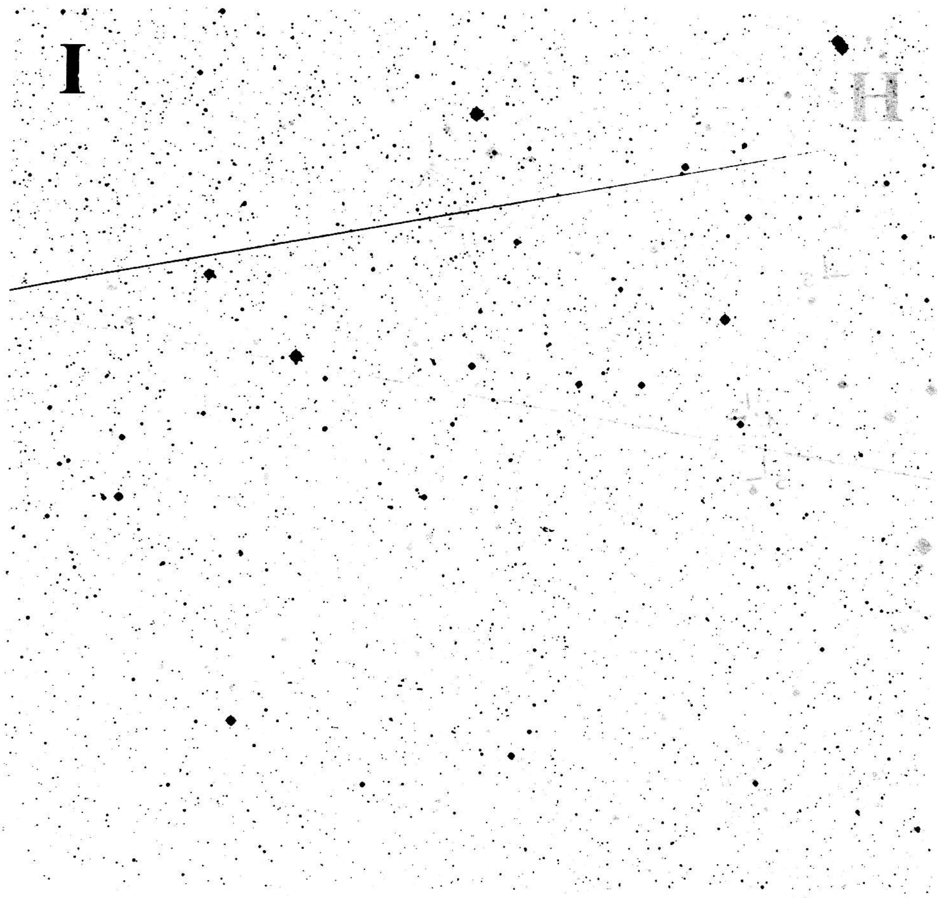
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References

Alter, G., Ruprecht, J., Vanýsek, V. 1970. Catalogue of Star Clusters and Associations — Second edition, Eds. G. Alter, B. Balázs, J. Ruprecht. Akadémiai Kiadó, Budapest.

Ambartsumian, V. A., Mirzoyan, L. V., Parsamian, E. S., Chavushian, H. S., Erastova, L. K. 1970. Astrofizika, *6,* 7.

Ambartsumian, V. A., Mirzoyan, L. V., Parsamian, E. S., Chavushian, H. S., Erastova, L. K. 1971. Astrofizika, *7,* 319.

Ambartsumian, V. A., Mirzoyan, L. V., Parsamian, E. S., Chavushian, H. S., Erastova, L. K., Kazarian, E. S., Ohanian, G. B., Jankovics, I. 1973. Astrofizika, *9,* 461.

Balázs, L. G., Vardanian, R. A. 1970. I.B.V.S., No. 493.

Balázs, L. G., Patkós, L. 1972. I.B.V.S., No. 688.

Balázs, L. G., Kun, M., Szécsényi-Nagy, G. 1973. I.B.V.S., No. 803.

Becker, W., Fenkart, R. 1971. Astron. and Astroph. Suppl. *4,* 241.

Erastova, L. K., Tsvetkov, M. K. 1974. I.B.V.S., No. 909.

Haro, G. 1963. Bol. Obs. Tonant. y Tac., *3,* 118.

Haro, G. 1964. IAU—URSI Symposium No. 20 (Canberra, 1963), eds. J. F. Kerr and A. W. Rodgers (Canberra; Australian Academy of Science), 30.

Haro, G. 1968. Stars and Stellar Systems, Vol. VII. Ed. by B. M. Middlehurst and L. H. Aller, The Chicago University Press, 141.

Haro, G. 1976. Bol. Instituto Tonantzintla, Vol. 2, No. 1, 3.

Haro, G., Chavira, E. 1964/1965, Vistas in Astronomy, Vol. 8, eds. A. Beer and K. A. Strand (London; Pergamon Press), 89.

Haro, G., Chavira, E., González, G. 1973. Bol. Instituto Tonantzintla, Vol. 1, no. 1, 3.

Haro, G., Chavira, E., González, G. 1982. Bol. Instituto Tonantzintla, Vol. 3, no. 1, 3.

Haro, G., Morgan, W. W. 1953. Ap. J. *117,* 73.

Hertzsprung, E. 1947. Ann. Leiden Obs., Vol. XIX, No. 1A.

Jankovics, I. 1973. I.B.V.S., No. 840.

Jankovics, I. 1975. Flare activity of red dwarf stars in the Praesepe field (theses — in Russian), Yerevan.

Johnson, H. L. 1955. Ann. d'Astrophys., *18,* 292.

Johnson, H. L., Mitchell, R. I. 1958. Ap. J., *128,* 31.

Jones, B. F. 1981, Astron. J., *86,* 290.

Joy, A. H. 1960. Stars and Stellar Systems Vol. VI. 563.

Kunkel, W. 1967. An Optical Study of Stellar Flares, Texas Univ., Austin.

Melikian, N. D., Jankovics, I., Kelemen, J. 1981. I.B.V.S., No. 2019.

Mirzoyan, L. V., Chavushian, H. S., Erastova, L. K., Ohanian, G. B., Melikian, N. D., Natsvlishvili, R. Sh., Tsvetkov, M. K. 1977. Astrofizika, *13,* 205.

Mirzoyan, L. V., Chavushian, H. S., Ohanian, G. B., Hambarian, V. V., Gharibdjanian, A. T., Melikian, N. D., Natsvlishvili, R. Sh. 1981. Astrofizika, *17,* 71.

Nagy, S. 1980. priv. comm.
Ohanian, G. B., Jankovics, I., Kelemen, J. 1982. I.B.V.S., No. 2149.
Parsamian, E., 1971. Astrofizika, *7,* 3.
Parsamian, E., 1976. Astrofizika, *12,* 235.
Pels, G., Oort, J. H., Pels–Kluyver, H. A. 1975. Astron. and Astroph., *43,* 423.
Petit, M. 1958. Contr. Asiago Obs., No. 95.
Pigatto, L. 1973. I.B.V.S., No. 776.
Pigatto, L., Rosino, L. 1971. IAU Colloquium on Variable Stars Bamberg, No. 100, 116.
Pigatto, L., Rosino, L. 1972. Contr. Asiago Obs., No. 273.
Pigatto, L., Rosino, L. 1973. Contr. Asiago Obs., No. 296.
Rosino, L. 1957. Contr. Asiago Obs., No. 95.
Rosino, L. 1976. Variable stars (in: Trans. IAU, Vol. 16A, Part 2.)
Rosino, L., Pigatto, L. 1969. Contr. Asiago Obs., No. 231.
Rosino, L., Szécsényi–Nagy, G. 1978. I.B.V.S., No. 1528.
Ruprecht, J., Balázs, B., White, R. E. 1981. Catalogue of Star Clusters and Associations Supplement 1, ed. B. Balázs (Budapest: Akadémiai Kiadó), Part B1.
Smart, W. M. 1931. Textbook on Spherical Astronomy, Cambridge University Press, Cambridge.
Stauffer, J. R. 1982. Astron. J., *87,* 899.
Szécsényi–Nagy, G. 1974. I.B.V.S., No. 898.
Szécsényi–Nagy, G. 1975. I.B.V.S., No. 996.
Szécsényi–Nagy, G. 1983. Star Clusters and Associations and their Relation to the Evolution of the Galaxy (Praha, 1983), eds. J. Ruprecht and J. Palouš (Praha, Czech. Acad. Sci.), Publ. Astron. Inst. No. 56, 60.
Szécsényi–Nagy, G. 1986. Symposium on Flare Stars and Related Objects (Byurakan, 1984), ed. L. V. Mirzoyan, Publ. House of the Acad. of Sci. Yerevan, 101—115.
Tsvetkova, A. G. 1985. Priv. comm.
van Leeuwen, F. 1983. The Pleiades, Sterrewacht Leiden, Royal Greenwich Observatory.