PROGRAM OF SMALL SATELLITES APPLICATION FOR OBSERVATION OF SMALLSIZED FRACTIONS OF SPACE DEBRIS

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1. Annotation.

Available ground optic and radar facilities are not capable to observe small sized fragments (less than 10 cm) of space debris, being a serious danger for manned flights safety and long-term automatic space vehicles.

New generation of space electrooptic sensors, installed onboard small space vehicles may unable to successfully solve the problem.

At present possibilities of electrooptic instruments and small space vehicles for space debris observation are under consideration in Russia.

International co-operation program is proposed on creation of a space system for monitoring and warning of a danger of space debris fragments collision with some manned objects.

2. Estimation of Near-Earth Space Contamination by Small Space Debris Fractions (SSDF).

About 4000 launchers with various space vehicles were launched in near-Earth space during the period beginning from 1957 till the present time, Russian and American catalogues contain together about 8000 registered space objects of more than 10 cm and about 60% of the objects are space debris (SD). The registered objects are defined rather precisely in their orbital parameters, distribution density in space and the estimation is made of their collision probability with large manned orbital stations or unmanned space vehicles. According to D. Kessler /1,2/ annual probability of space objects (SO) collision with registered space objects from 600 to 1600 km is about $(1...5)\cdot 10^{6}$ $1/m^2$/year. Probability of a collision of larger SO increases proportionally to their cross-section area in m^2. It's obviously, that SO collision with large SD fragments may cause catastrophic consequences. The probability of a large SD collision may be significantly reduced if their orbital movement parameters are available and SO coordinate altitudes and its orbit inclination are properly selected.

However, SO significant damage may be caused by its collision with smaller SD fragments. Thus, during SO collision with a fragment from 1 to 10 cm in size (mass from 1.5 g to 1.5 kg) at velocity about 10 km/s destruction power will be from 1 Kjoule to 1 Mjoule accordingly.

Taking into account, that SSDF space distribution density, observed from the Earth, is several orders more, than that of the registered debris, a danger of SO collision with SSDF can not be ignored.

There are some reasons to suppose, that non-registered SSDF distribution almost fully coincided with registered SD fragments distribution, remained after SO destruction. That means, that the most intensively used orbits are the most contaminated by SSDF.

Table 1 illustrates a number of non-registered objects ratio to registered ones, obtained by means of estimations, made with the help of Russian SO catalogue. The table shows, that hazard SSDF density may exceed registered objects distribution density more than by 2-4 orders. Annual probability of SO collision with SSDF increases accordingly.

However, the above estimations as the estimations , made by some other authors, were obtained at a series of admittaines and they require direct experimental confirmation with space observation means application.

Table 1

unregistered objects dimensions range	from 10 to 14 cm.	from 4 to 10 cm.	from 2 to 4 cm.	from 1 to 2 cm.	from 0.4 to 1 cm.	from 0.2 to 0.4 cm.	from 0.1 to 0.2 cm.	from 0.07 to 0.1 cm.
Ratio of a number of objects with stated range of dimensions to a number of objects, registered by the Russian Centre	1.1	5	22	70	400	3000	19000	27000

3. SSDF Observation Probable Concepts.

3.1. Observations by means of ground facilities.

As it was said above, ground space control facilities of the USA, Russia and some other nations posses unlimited capabilities for SSDF observation. Powerful radars of millimetre range and large scanning telescopes, located on all the Earth continents are needed for permanent SSDF monitoring. However, such a concept realization requires extremely great expenses and a lot of time.

3.2. Observations with ground and space facilities application.

Combined using of available ground observation facilities and electrooptic and radar space means, located at the altitudes LEO1 (upto 1000 km), LEO2 (upto 2000 km) and in geostationary orbit promotes to SSDF observation task decision and permits to obtain a complete estimation of near space (NS) contamination, to define SD fragments dimensions, chemical composition and orbital parameters and to enlarge SD Catalogue on SSDF account.

However, orbital clusters of a significant number of SV, equipped with updated observation instruments are to be deployed in Space in order to provide small objects permanent observation, and to involve the most powerful ground computer complex.

The concept also requires very great expenses and a lot of time for realisation.

3.3. Earth remote sensing SV for SSDF observation

Many nations use Solar-synchronous orbits for Earth remote sensing (ERS). SSDF observation equipment could be installed onboard ERS SV, using their mass and power resources, thus gradually deciding the task of low orbits contamination estimation.

However, practical realisation of the above concept requires hard-labour, long-term and expensive co-ordination of space activities of some nations, ERS SV modification, acquisition, analysis and summarising of SSDF various information, obtained during different periods of time from various by their characteristics observation instruments. Finally, the concept realisation may appear more expensive and less efficient than the concept 3.4, proposed below.

3.4. SSDF observation, using one or several specific SV

The most attractive SSDF observation concept is in periodic (for example, once per Solar activity period) one or two small observation SV (SOSV) launch to the most contaminated low orbit altitudes.

Orbits of 1000 ... 850, 650 ... 600 km, inclination from 100 to 80°, and orbits of a specific interest of 500 ... 350 km, inclination 60 ...50°, where long-term manned orbital stations are located, are the most contaminated zones in low near-Earth orbits (LEO1).

Increased contamination by registered objects and SSDF may be observed in LEO2 area (upto 2000 km), in orbits of 1600 ... 1400 km with inclinations, close to Polar ones.

The experiment could be arranged in the following way. SOSV is launched in Solar - synchronous orbit of about 1500 km in altitude to monitor SSDF during the period of time, required for their distribution density true estimation for the given altitude.

Then SOSV is transferred in another Solar-synchronous orbit of about 1000 km and also observes SSDF. After that SOSV is transferred in orbit of 600 km in altitude and it slowly descends due to aerodynamic braking thus completing its SSDF observation. One SV is sufficient to estimate only SSDF distribution density. It could be a great jump in solving the problem of real danger, which SSDF presents for long-term manned and unmanned space flights.

More complete information on SSDF elements, including dimensions, configuration and SD fragments chemical composition may be obtained either by means of SOSV equipping by multispectral electronic instruments, radar or lidar, or by using two SV with electrooptic devices. This problem requires additional study to estimate expenses for realisation of each variant. However, the author of the given article considers the variant of using SOSV with electrooptic instruments more preferable.

It's advisable to note, that a real probability exists for solving the problem of space debris fragments catalogisation from 1 to 5 cm in orbits of 500 km. The concept is described in section 5 of the article.

SD observation concept realisation using space observation means may have further development. In particular, SOSV may be used in a joint flight with a large manned orbital station to warn its possible collision with a large unregistered object and to take necessary protection measures.

SOSV may be also used in geostationary orbit both for precising the orbit contamination and for its cleaning.
In our opinion, due to the fact, that the problem bears global character for space flights safety, the proposed concept realisation shall be performed

under UN aegis on the basis of SSDF observation International Program with participation of all the interested "space" nations.

4. SSDF Detective Characteristics and Jbservation Features

SSDF observation possibilities with the help of space electrooptic sensors were discribed in part 4.

Fig.1 presents reflecting characteristics of space debris fragments of 10, 1 and 0.1 cm in UV, visible and IR ranges.

Fig.2 illustrates, that observation of SSDF, lighted by Sun is better to carry out in spectral range 0.2 ... 1.0 mcm by electrooptic instruments with marginal sensivity (~ 10^{-17} W/m²·mcm·sr).

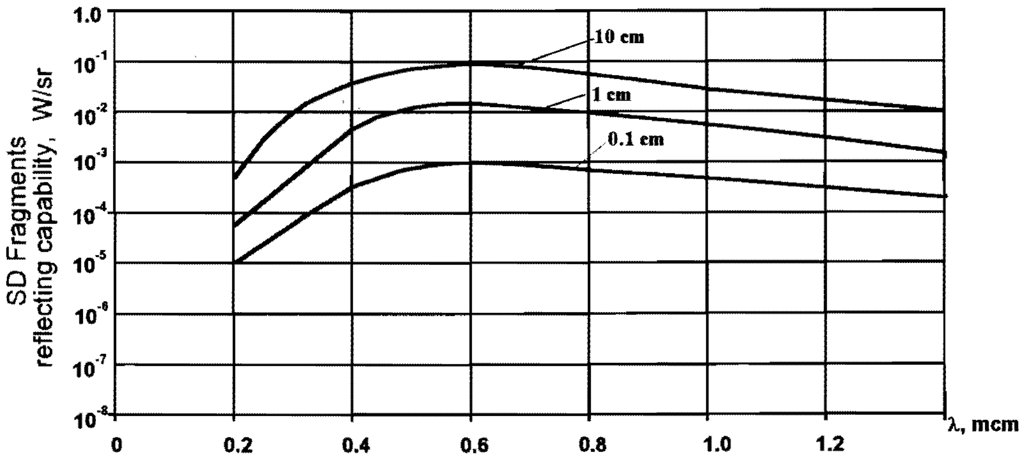


Fig. 1. SSDF reflecting characteristics

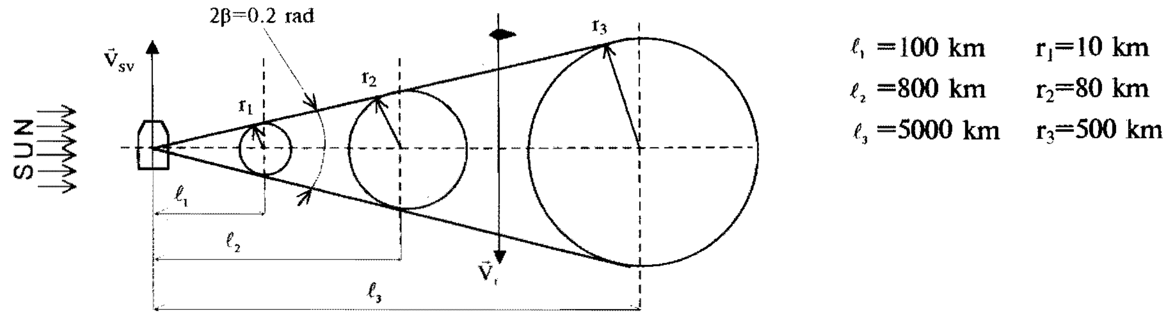


Fig. 2. SSDF observation conditions in EOJ field of view

Electrooptic observation device field of vision is advisable to be as wide as possible and about ~10 ... 15° in altitude.

Assume, that we possess some electrooptic system, comprising a single device with a field of vision of, for instance, 2β=0.2 rad and with parameters, which ensure observation range ℓ_i =100, 800 and 5000 km for SSDF 0f 0.1, 1 and 10 cm in size (Fig. 2).

Fig. 2 shows, that during any SD fragment coplanar movement to SSDF, time t of the fragments presence in the electrooptic device (EOD) field of view is equal to

$$t=\frac{2\beta \cdot \ell_i}{V_{SV}+V_f}\ .$$

V_{sv}, V_f - velocity space vehicles and fragment SD.

Thus, a fraction of 0.1 cm, flying at a distance of 100 km from any observation SV will stay in EOD field of vision during 1.43 s, a fraction of 1 cm - at a distance of 800 km during 11.42 s and a fraction of 10 cm - at a distance of 5000 km - during 71.42 s accordingly.

At other fractions velocity vector they will stay longer in EOD field of vision. Such periods of fragments fly by time are qiute sufficient for their registration.

The fragments have different angular velocity in EOD field of vision (~ 0.2 ... 0.002 rad/s).

By the way, SD fragment may be easily selected against their background (stars, external atmosphere particles (EAP), which get in EOD field of vision.

Stars angular velocity in EOD field of vision is equal to SV angular stabilisation speed and EAP velocity is one or two orders more, than SD small particles.

At expected SD fragments distribution density at altitudes from 10^{-6} 1/km^2 for fragments from about 0.1 cm to 10^{-8} 1/km^2 for fragments about 10 cm we obtain about 50, 330 and 1300 fragments from 0.1 cm, 1 cm and 10 cm, getting into EOD field of vision per one circuit of Earth by SOSV accordingly.

If to use EOD with wider field of vision, one can receive much more information on contamination, in particular, on SD small-sized fragments (from 0.1 to 1 cm). In any case, in order to make accurate estimation of SSDF real distribution density it would be sufficient to have the observation SOSV in any enumerated altitude of solar-synchronous orbit during 2-3 months. Duration of the whole SOSV observation mission is 1.5-2 years.

Much more information on SD fragments dimensions, form and chemical composition may be obtained if to use two observation SV in Solar- synchronous orbit, distancing at about 50-100 km. In this case triangulation method may be used to define SV distance from any SD fragment, and to carry out observations in different spectral sub-ranges 0.2 ... 1.0 mcm in order to define a fragment chemical composition.

Geostationary orbit contamination may be performed using similar SOSV.

At the beginning of 1996 about 565 objects were registered at the altitudes from 35000 to 40000 km with inclination from 0 to 15° in GEO surroundings.

The registered fragments dimensions are more than 1.5 m (in three axes).

About 200-300 fragment of more than 10 cm in size could appear in the result of some objects destruction but they are cannot observed from the Earth.

Space objects distribution density in GEO, including space vehicles, approximates to distribution density in LEO (more than 2.5×10^{-9} object/km^3). SO collision velocity in GEO depends on inclination of the objects and is in the interval from 0.1 to o.8 km/s what is sufficient for SV strong damage, caused by SV collision with SD.

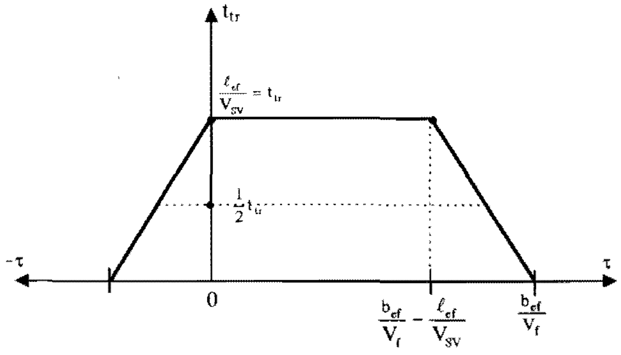
To precise GEO contamination, it's advisable to launch one SV-observer in orbit of 36500 km, inclination - about 7°. It is capable to scan objects around at a distance to 3.5 th km and using its propulsion unit to pass along GEO several times, investigating its most contaminated regions.

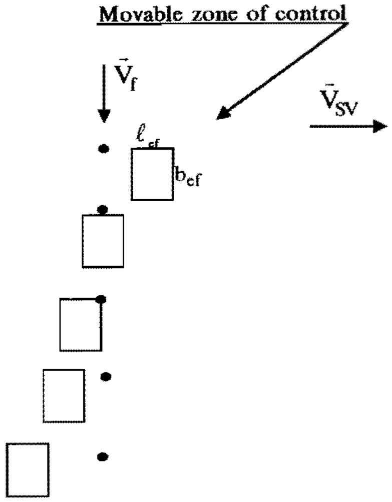
5. Possibilities for SSDF Orbital Parameters Definition

The task of SSDF orbital parameters definition, aimed at their registration, seems rather complicated.

While registering small objects at low altitudes (about 400 km) it's necessary to take into account, that their presence in SSDF at the indicated altitude may be 1-2 orders less, then that of large space objects and EOD range for a small fragment detection shall be about 10^3 km. Necessity in providing such high values of range is caused by rather regular repeat of the registered objects observation sessions. An interval between the two sessions shall not exceed 1-2 days (depending on a fragment altitude and dimensions). We shall estimate its dimensions dependence on longitudinal range of a fragment L detection and on the electrooptic instruments field of vision.

Assume, that EOD is directed along the horizon line. The fragment, being in orbit, which is noncomplanary to SV orbit, occasionally crosses SV orbital plane at some moment. It may be covered by EOD field of vision. Probability of such covering significantly increases together with EOD field of vision and range. The above relates also to the period of any fragment staying inside the EOD field of vision or duration of its imagination track on photoreceiver of EOD t_{tr}. Fig. 3 shows a function of a fragment t_{tr} staying time in a movable controlled zone of space time τ between the moments of its arrival to some point of orbit of the front part of the controlled zone SOSV and of the fragment.





$$t_{tr}(\tau)=\begin{cases} 0 & \text{, at } \tau \le -\frac{\ell_{ef}}{V_{SV}} \\ \tau + \frac{\ell_{ef}}{V_{SV}} & \text{, at } -\frac{\ell_{ef}}{V_{SV}} < \tau \le 0 \\ \frac{\ell_{ef}}{V_{SV}} & \text{, at } 0 < \tau \le \frac{b_{ef}}{V_f} - \frac{\ell_{ef}}{V_{SV}} \\ \frac{\ell_{ef}}{V_{SV}} - \tau & \text{, at } \frac{b_{ef}}{V_f} - \frac{\ell_{ef}}{V_{SV}} < \tau \le \frac{b_{ef}}{V_f} \\ 0 & \text{, at } \frac{b_{ef}}{V_f} < \tau \le T_{SV} - \frac{\ell_{ef}}{V_{SV}} \end{cases}$$

where $\ell_{ef} = \frac{1}{\sqrt{2}} \cdot (L - \frac{H_f - H_{SV}}{2\sin\beta_V})$, $b_{ef} = \sqrt{2} \cdot (L - \frac{H_f - H_{SV}}{2\sin\beta_V}) \cdot \sin\beta_h$ - effective length and width of the controlled zone, approximated by a rectangle;

L - marginal distance of detection of a fragment of some dimension d;

$2\beta_V$ - observation EOD vertical field of vision, a momentary field of vision of an objective;

$2\beta_h$ - horizontal field of vision, total field of vision of an objective.

Fig. 3

Probability $P(\tau)$ of any fragment arrival moment in the interval of meanings of casual values τ is equal to ,

$$P(\tau) = \frac{\tau}{T_{SV}}$$

It presents a probability of any fragment getting in a movable zone of control in orbit of SOSV rotation around the Earth.

Periodicity between consequent sessions of a fragment observation, which crosses SOSV orbital plane which crosses SOSV orbital plane with periodicity of $\frac{T_f}{2}$, is equal to:

$$T = \frac{T_f}{2P(\tau)}$$

Different periodicities may be noticed between successive sessions of fragments observation:

$T(t_{tr})$ - time between successive registration of a track of t_{tr};

$T(\frac{t_{tr}}{2})$ - time between successive registration of a track of $\frac{t_{tr}}{2}$ duration (see dotted line, Fig.3);

$T(t_{tr} \ge 0)$ - time between successive discovering of a fraction with track duration >0.

Value $\frac{T(t_{tr} \ge 0)}{2}$ characterises average time to the first detection of a fracture.

While observing fragments, flying at the altitude equal to SOSV or an orbital station operating orbit, the largest length of registered tracks are realised and shorter periods of time between observation session, as lower edge of a vertical field of vision is directed along the horizon. Data on values t_{tr}, $T(t_{tr})$ dependence on marginal range of fragments L detection and on horizontal field of view are shown in Tables 1, 2 and 3.

Table 1

$2\beta_h=103°$

L, km	1500	1000	750	500
$t_{tr\ max}$, min	2.3	1.5	1.15	0.75
$T(t_{tr})_{max}$, hour	50	75	100	150
$\frac{t_{tr}}{2}$ max, min	1.15	0.75	0.57	0.37
$T\left(\frac{t_{tr}}{2}\right)$max, hour	18	27	36	54
$T(t_{tr} \geq 0)$, hour	11	16.6	22	33

Table 2

$2\beta_h=80°$

L, km	1500	1000	750	500
$t_{tr\ max}$, min	2.3	1.5	1.15	0.75
$T(t_{tr})_{max}$, hour	100	150	200	300
$T\left(\frac{t_{tr}}{2}\right)$max, hour	22	33	44	65
$T(t_{tr} \geq 0)$, hour	12	18	25	37

Table 3

$2\beta_h=60°$

L, km	1500	1000	750	500
$\frac{t_{tr}}{2}$ max	1.15	0.75	0.575	0.375
$T\left(\frac{t_{tr}}{2}\right)$max, hour	28	42	54	84
$T(t_{tr} \geq 0)$, hour	14	21	28	42

At a distance L ≥ 750km a fragment orbit string is possible in one session of observation as t_{tr} max>1 minute.

At a range L=1400 km for initial registration 2-3 observation sessions shall be performed, Periodicity between the tracks registration of duration, exceeding one minute, is more than 30 hours at L=1400km and 42 hours at L=1000km. Condition of a false identification requires, that $T(t_{tr})$ shall not exceed 1-30 days depending on a fracture dimensions and distribution density in the controlled zone, i.e. on H_f altitude.

Thus, at H_f =450 km:

$$T \leq \begin{cases} 1.5 \text{ days at } d_f = 1 \text{ cm}, \\ 3 \text{ days at } d_f \cong 10 \text{ cm} \end{cases},$$

Table 2

and at H_f =400 km:

$$T \leq \begin{cases} 15 \text{ days at } d_f = 1 \text{ cm}, \\ 30 \text{ days at } d_f \cong 10 \text{ cm} \end{cases}$$

Thus, horizontal field of view shall have width more than 60° and detection distance about 1000km.

The equipment shall operate in UV and visible range in order to use brightness amplifier. Amplifying coefficient $\approx 2 \cdot 10^3$ or more is sufficient to enable using low-noise amplifiers on the base of Hane effect.

Vertical field of view, required for fragments monitoring in circular orbits is sufficient in the interval ~ 10°.

EOD installation onboard SOSV requires small volume and mass ($50dm^3$, 20kg) and electric power up to 100W. To cool of CCD-matrix up to 180 K, may be used of power, not exceeding 10W.

6. Observation Instruments Appearance and Characteristics.

Russia possesses the prototypes of the instruments, available for SSDF observation. There are also high qualitative objectives, such as the objective with a field of view 60×20 degrees and matrix photoelectric convertors of high sensitivity computers for initial processing of signal data in real time and other components.

Camera "Fialka" (UV) is used during several years on orbital station "Mir" for observation through the window of the orbital station of technogenic objects near the station and of various natural phenomenas.

Electrooptic system, available in Russia, may be proposed to observe SOSV. The system comprises two measurement chambers, created on the base of structurally similar modules: optic-mechanical, matrix photoreceiver and a specific computer for initial processing of data (table 4).

Table 4

EOD primary characteristics

	Chamber 1	Chamber 2
Wavelength, mcm	0.2 ... 0.6	0.6 ... 1.0
Sensitivity, W/m^2, mcm, sr	10^{-17}	10^{-17}
Operative field of vision, deg	25	25
Brightness amplification coefficient	50 ... $5 \cdot 10^4$	-
Brightness amplification ajustment	50, 500, 5000, 50000	-
Average electric power consumption, W	40 max	
Mass of the system, kg	less than 7	
Dimensions, mm	420×600×400	

Three sets of the system of a total mass of ~20 kg permit to formate a field of vision ~70×25 degrees.

A new development, foreseeing use of an objective 60×20 deg. should require additional expenses for the equipment tests.

7. Small Observation SV Appearance and Characteristics

At the above described mass, dimensions and power consumption of the observation equipment small SV for SSDF observation with characteristics, stated in Table 5 may be created on the base of Russian technologies to 2000 year.

Table 5

SOSV primary characteristics

SOSV and its modules	Dimensions	Characteristics
SOSV on the whole		
SOSV mass	kg	250...300
Orientation and stabilisation accuracy(3σ)		
-on angle	deg	< 0.1
-on angular velocity.	deg/s	0.02
Average day electric power consumption	W	300
Resource	years	3 and more
Propulsion module (PM)		
PM mass with fuel	kg	until 90
PM mass without fuel	kg	until 20
Corrective engine thrust	KGs	until 20
Orientation and stabilisation engines thrust	KGs	until 0.5
Reserve of characteristic speed for SOSV	m/s	until 900
Service module (SM)		
SM mass	kg	until 100
Payload unit (PLU)		
PLU mass with PL equipment	kg	until 60
Electric power consumption	W	until 150

Acceptable observation SV mass and dimensions permit to launch them in required orbits LEO (up to 1500 km) by means of light launchers, created on the base of ballistic missiles, withdrawn from armament, such as launcher "Rokot" or others.

Expenses for small observation SV for SSDF accounting Russian reserves on purpose equipment and service systems, will not exceed $50 million; expenses for creation and launch of two SSV flight patterns will be $30 million and expenses for data obtaining and processing for two years will not exceed $20 million Thus, the total Program cost will be about $100 million. The expenses could be less, if some nations of the World community deliver their instruments and equipment for purpose equipment and SSV service systems completeness.

Realisation of SSDF Program of observation would be an excellent example of international co-operation in the interests of a decision of the global task of space flights safety improvement.

8. Conclusion.

At the present-time all the necessary preconditions for creation of SSDF observation SSV and realisation of the International Program of periodic monitoring and warning a danger of SSDF collision with space objects of different assignment.

High sensitive observation equipment, devices and service systems for a small space vehicle, light launchers, data processing technologies and others are available, whine permitting to realise the Program during a short period of time and with minimum expenses on the base of international co-operation.

9. Literature

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ASTEROID HAZARD WARNING SPACE SYSTEM.

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1. Annotation

Available ground means for asteroids observation are insufficient for a full and true asteroid hazard estimation. In particular, it concerns asteroids of about 50 m in size, in case they drop on the Earth, they may cause damage, comparative with damage caused by Torungues meteorite. Greater space objects investigation is also insufficient.

The article describes scientific-technical aspects of various observation means for small and large asteroids monitoring, warning their collision with the Earth, requirements to observation instruments, and asteroid hazard warning space system appearance. International co-operation program on creation of asteroid hazard observation and warning space system is proposed.

2. Ground and Space Asteroid Observation Capabilities.

According to accumulated observation data and preliminary theoretical calculations a great number of large asteroids create a constant danger of collision with the Earth.

Distribution of asteroids, probability of their collision with the Earth and probable damage from the collisions are shown in Table 1.

Table 1

Asteroid diameter, km	0,01	0,1	0,5	1,0	2,0
A number of asteroids, pieces	$\sim 150 \cdot 10^6$	320000	9200	2100	400
Annual probability of collision with the Earth		10^{-2}			$\sim 10^{-6}$
Expected damage to the Earth	Small	Regional disasters of different gravity, similar to nuclear war			Global catastrophe

Average value of asteroid orbit plane inclination to Earth orbit plane is ~15±13°(1σ) or (-19°...+49°) (2.7σ).

Average value of velocity during approach asteroid to the Earth is ~20 km/s /4/.

Three large telescopes in Palomar (California), Kit Peaks (Arizona) and in Australia permanently monitor large asteroids of more than 1 km. 100 discovered asteroids are registered in Catalogue and that is one percent of the total number of potentially hazard for the Earth large asteroids, capable to cause a Global catastrophe.

A set of six telescopes with a mirror of 2...3m in diameter shall be used as well as large radio telescopes and radars of a rocket attack warning system in order to decide the tasks of large asteroids monitoring according to recommendations of the International Working Group of Near-Earth Asteroids Detection (INEAD).

However, asteroids from 50 m to several hundreds meters cannot be duly detected and monitored and namely those asteroids present the most probable hazard of collision with the Earth and regional disasters arising.

Sensitive of ground radar space control stations (SS) in survey observation mode is insufficient for celestial bodies detection at far distances (≥1.1 a.u), required for early warning of their drop on the Earth.

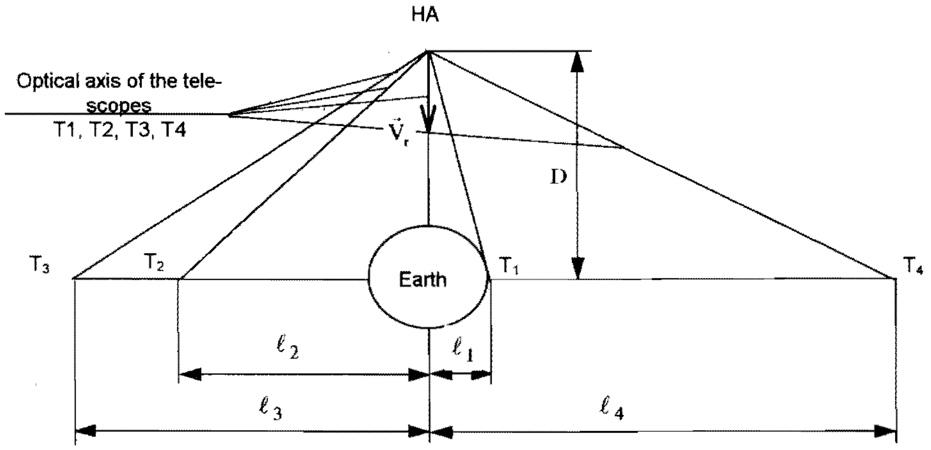
Ground optical space monitoring means due to weather conditions and celestial bodies limited visibility duration during 24 - hours are unable to ensure the required survey observation mode of the whole space .

Therefore, hazard (i.e. moving to the Earth) asteroids (HA) warning means, proposed lately, foresee using electrooptic means, located in artificial Earth satellites (AES) orbits (5,6). Telescopes shall have wide (~40°) fields of view to provide space constant monitoring. CCD-matrices, operating in "looking window" mode, are proposed to be used as an image receiver. In our opinion the above methods have the following shortcomings:

1. The Angle between the optical axis of the telescope and hazard asteroid movement direction in near-Earth orbits is close to zero at indicated significant observation distances from AES orbit and namely hazard asteroids movement parameters (MP) cannot be accurately defined about which the system shall warn the Earth first of all. Precise movement parameters are necessary for drop area definition and people and property evacuation or the active means delivery to HA

Parallax in time of HA image, registered in photo receiver (PhR) of the telescope, may occur only due to constitute relative speed, perpendicular to the optical axis. It is very small at the moment of its discovering at a required far D.A. distance from the Earth, if the telescope is located on the Earth surface or in AES orbit. Therefore rather long period of time $\Delta\tau$ is required for D.A. image drift at least per one PhT resolution element. During the time, less than $\Delta\tau$,asteroid coordinates in the inertial system change due to asteroid movement and the observer doesn't register the changes and that is the reason, explaining low accuracy in HA movement parameters definition.

NECESSARY TIME FOR REGISTRATION OF THE INFORMATION
TRACK OF A REMOTE HAZARDOUS ASTEROIDS (HA)



$\vec{V}_r$ = relative velocity of a hazardous asteroid, 50 km/sec;

ℓ_i = telescope remotness from Earth;

D = asteroid remotness from Earth, 10^7 km;

S_i = displacement of the asteroid image during time τ_i :

$$S_i = \frac{|\vec{V}_r| f' \tau_i}{\left(\frac{S^2}{\ell_i^2}+1\right)\cdot \ell_i};$$

S_{itr} = length of information track, $S_{itr} \approx \frac{\omega f'}{2}$;

2ω = field of view, 10°;

f' = telescope focal length, 3 m.

ℓ_i,[km]	$6\cdot10^3$	$4\cdot10^4$	$1.5\cdot10^6$	$1.5\cdot10^7$
τ_i,[h]	$4\cdot10^3$	$6\cdot10^2$	16.5	5.5
$\Delta\tau_i$,[m]	36	5.4	1.5	0.5

It must have very large time for the information track registration by use of the ground based ($4\cdot10^4$h) and GEO orbit based ($6\cdot10^2$h) telescopes.

Fig.1

Fig.1 illustrates values $\Delta\tau_i$ during the telescope arrangement in different distances l_i from the Earth centre. It was assumed, that HA moves to the Earth centre with relative speed of $|\vec{V}_r|$ = 50 km/sec and an asteroid detection takes place at its distance from the Earth D, equal to 10^7 km. The same figure shows time values $\Delta\tau$, required for information track collection, length of which in a focal plane of the telescope is equal to the forth part of its maximum dimension $\frac{\omega\cdot f'}{2}$, where 2ω~10° - is a field of vision of the telescope observation, f' ~3 m - is a focal length of the telescope objective.

The above estimations show, that the telescopes arrangement on the Earth surface (l_i ~$6\cdot10^3$ km) and in geostationary orbit is not reasonable for definition of hazard used asteroids movement parameters. The telescopes may be used for coordinate measurements of a great number of asteroids, getting in their field of vision and passing near the Earth. However, from the point of view of asteroid hazard warning task decision, those measurements, in our opinion, don't present a lot of interest.

2. Space control means based on constant survey observation of the whole sky sphere is irrational, because its realisation requires a significant number of wide-band telescopes.

3. While observing sky sphere by a telescope, located in AES orbit only one part, external relatively to the circleterrestrial orbit may be controlled. but hazard asteroids may move to the Earth from Solar side.

4. While observing far asteroids "up" they hardly may be distinguished on the back-ground of a number of stars. Registered track of far hazard asteroids and stars, the form of which is defined by observation SV orbital movement, may be similar.

5. While observing space from AES orbit, background noises of "space debris" may cause negative influence. Large scale optical systems /7/ are the most sensitive to such effects.

3. Concept of Asteroid Hazard Warning Space System Creation.

We propose the following principles of a space system creation for early (several days before their drop on the Earth) warning of hazard asteroids, which allow to eliminate the above problems and to ensure its building on the base of the implemented technologies of space facilities and electrooptic instruments manufacture /8/.

- The telescopes monitor only a narrow zone of space, but not the whole space. The zone is a barrier zone of mandatory registration of any HA, moving towards the Earth from a free direction, including direction of the Sun.

- Thickness of the barrier zone provides temporary duration of a registered track (~5 hours), required for HA movement parameters definition. Width of a telescope instant field of vision is selected proceeding only from a condition of indicated duration of the track.

- Observation method shall provide possibility to use CCD - line in a mode of time delay and a charge accumulation what enables to obtain useful signal amplification from a far asteroid in 10^3 times.

- The barrier zone configuration may change depending on minimum dimensions of the hazard asteroids, about drop of which the system shall warn the Earth.

- Hazard asteroids are selected from a great number of non-hazard asteroids and stars, getting in the barrier zone, on the base of their registered tracks form without preliminary calculation of movement parameters of all the registered asteroids. A method of the barrier zone scanning by a field of vision is foreseen for such purposes, which provides hazard asteroids registered images movement in radial direction in rotating focal plane of the telescope objective.

- Besides quaranteed registration of hazard asteroids the space system detects and defines MP of non-dangerous asteroids. Together with ground observation means, a task, of data obtaining is decided on large celestial bodies, much greater than 50 m.

Realization of the above principles in the system design required decision of a series of optimization tasks: selection of the observation SV ballistic structure, definition of means and parameters of a barrier zone scanning by instant field of view, definition of an optimal number of steps for a charge accumulation in columns of CCD-line as well of a type and parameters of the observation instruments (selection of a spectral range, optic scheme of the objective, diameter of an input pupil, focal distance calculations of abberative dissipation and passing as well as photoreceivers (PhR) parameters. The investigations were performed of limitations for a maximum number of charge accumulation steps, proceeding from the condition of asteroids stay within CCD-line columns during accumulation period of time.

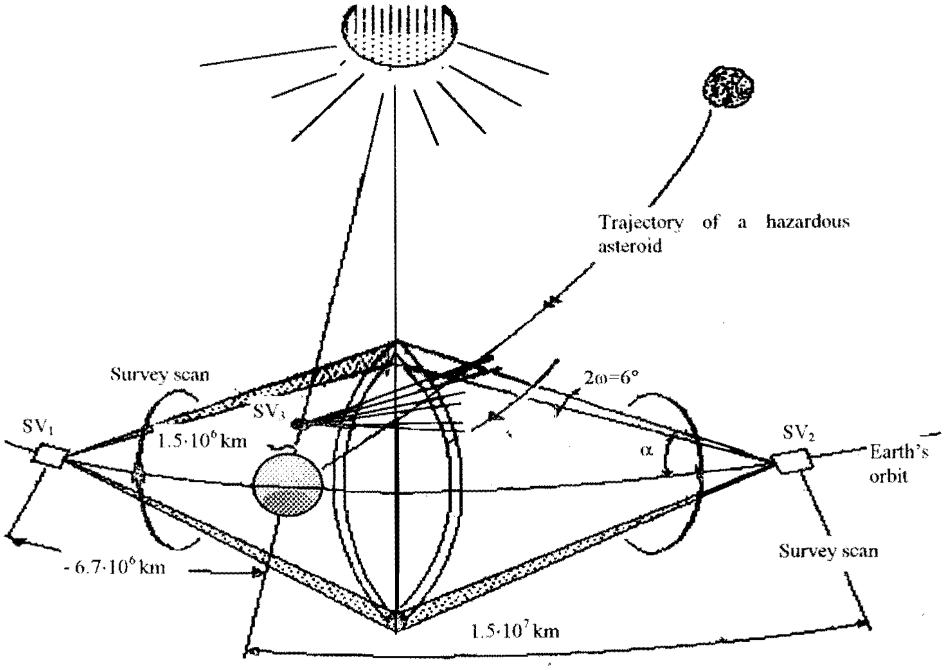
Some results of the indicated optimization tasks decision are described below.

The space system for early warning of any asteroid hazard comprises 2 subsystems.

The first subsystem (Fig.2) decides the task of detection of unknown asteroids of 50 m and more and their movement parameters definition. It contains 2 SV of "detection", located in orbit of the Earth rotation around the Sun in the points in front of the Earth and behind it at different distances ~0.1 a.u. and ~0.7 a.u. accordingly, which provide observation at large angles between optical axis of the telescope and possible HA movement directions to the Earth.

Field of view of the telescope onboard each SV scans a barrier zone of any hazard asteroid mandatory registration with constant angular speed. Scanning is

ORBITAL CONSTRUTION OF THE SPACE SYSTEM OF THE EARLY WARNING
ABOUT ASTEROID HAZARD



SV_1, SV_2 -space vehicles of the asteroids detection and preliminary their ephemerids determination
SV_3 - space vehicle of the precision ephemerids determination

Fig. 2

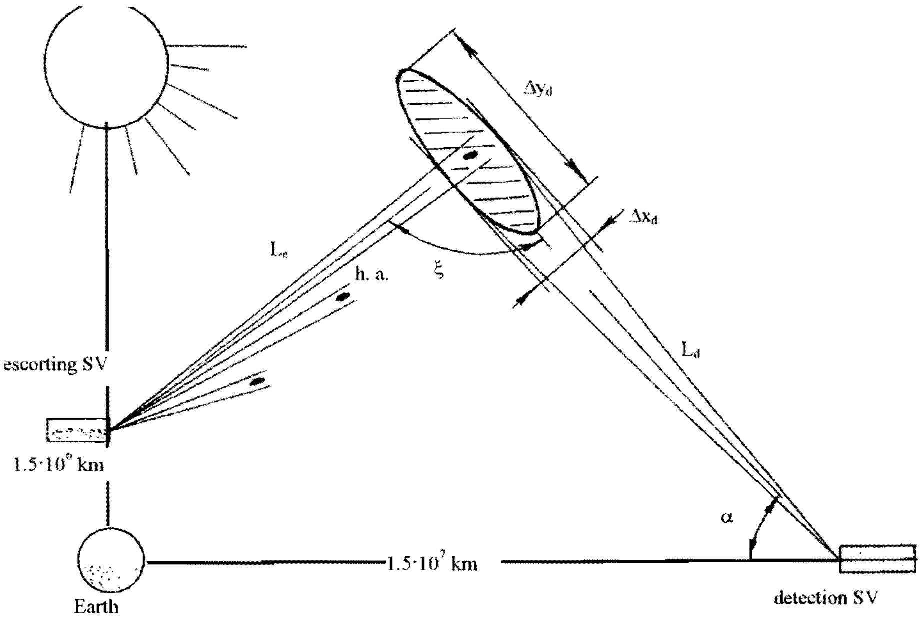
carried out due to SV twist around "SV-Earth" direction.

the optical axis of the telescope constitutes angled with that direction. Narrow field of view of the telescope (~6°) is sufficient for several HA observation sessions. The sessions form in the process of HA capture in the successive cycles of field of vision rotation during asteroid. crossing the barrier zone. Telescopes with such fields of vision have a focal surface. close to a plane one. Its dimension is about 0.3m. A hazard asteroid image in a rotation focal plane moves in a radial direction. Non-hazard asteroids images move in free directions and form tracks. registered in each scan of a rotated field of vision. Stars images in different scans preserve their radial and azimuth co-ordinates. Several images. obtained in different scans. are sufficient for MP HA definition. HA presence time in the barrier zone depends on its distance from the telescope and its relative speed is several hours. However. the first. subsystem has limited accuracy in asteroids MP definition. speed commented of which differs from zero in direction. parallel to optical axis of the telescope. That's why the first subsystem is supplemented by another one.

The second subsystem is designed for high accurate definition of a selected hazard asteroid MP (or considered as hazard). The subsystem comprises one SV (Fig. 2). located in lagrange liberation point between the Earth and the Sun. It provides pointing of narrow (~40 angl.min.) field of view of long-focal telescope at HA, using purpose command from the first subsystem. their capture and further tracking. It's very important. that a long-focal telescope was located in space in such a way. that optic axes of "detecting" and tracking telescopes formed large angles with HA movement direction and between each other. High ratio "signal-noise" is performed due to increase of exposition time during HA directed observation. Therefore CCD-matrix in a looking "window" mode may be used as a photoreceiver. A small error in definition of asteroid angular position relatively axis of the tracking telescope is obtained due to a large focal distance (~20 m). Fig.3 illustrates mutual arrangement of field of visions of detecting and tracking telescopes and corresponding values of errors in definition of asteroid co-ordinates are indicated.

Fig.4 shows ratio "Signal-noise". being realized during asteroid registration by the detecting telescope at different diameters of asteroid Da and the input pupil of the objective Dt. They are calculated at phase angles of observation φ, equal to $2/3\pi$, $\pi/2$ (a part of the barrier zone on the side of the Sun-the upper figure) and $\pi/2$, $\pi/3$ (a part of the barrier zone on the side, opposite to the solar direction - figure below).

INTERACTION BETWEEN THE DIRECTION TELESCOPE AND THE LONG-FOCAL ESCORTING TELESCOPE



ξ - angle between optical axis detection and escorting telescopes at the covering of a hazardous asteroid with both field of view, ξ 25°

α - angle between optical axis of the detection telescope and the direction "detection S. V. - Earth", α=35°

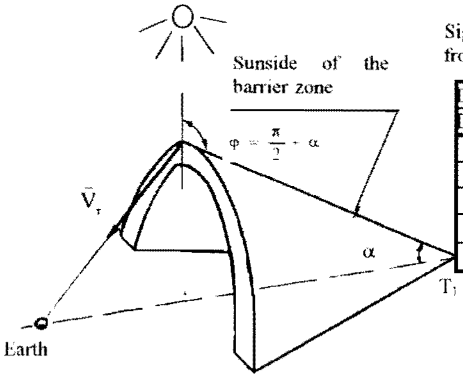
Δy_d, Δx_d errors in the measurements of asteroid positions
Δy_e, Δx_e - by detection and escorting telescopes

$\Delta y_d \sim 2 \cdot 10^4$ km; Δy_e, $\Delta z_e \sim 10$ km; $\frac{\Delta z_e}{L_e} \approx \frac{\Delta y_e}{L_e} \approx 0.2$ang. sec.

Fig.3

DEPENDENCE OF THE RADIATION TO THE TELESCOPE E/E(0) ON THE ANGLE α OF THE CONICAL BARRIER ZONE.

α,[rad]	0	π/6	π/4
E min(φ)/E(0)	0.32	0.11	0.05



Signal-to-noise ratio at the large phase angles φ of π/2 to π/2 +α, if a HA moves to Earth from the sunside of the barrier zone.

Da,[m] DT,[m]	50		100		150	
1.00	0.6-1.7	1.6-4.6	2.3-6.5	6.2-18	5.0-14	14-3
1.50	0.9-2.7	2.6-7.4	3.7-11	10-28	8.2-23	22-5
2.00	1.3-3.8	3.6-10	5.2-15	14-38	11-31	30-7
	$L=10^7$ km	$L=6 \cdot 10^7$km	$L=10^7$ km	$L=6 \cdot 10^7$km	$L=10^7$km	$L=6 \cdot 10^7$ km
$\alpha=\pi/6$, $\pi/2 \le \varphi \le 2\pi/3$, $n_a=800$, N-2.5ph·sec^{-1}·nm^{-1}·m^{-2}·arcsec^{-2}, $\rho_a=0.15$						

Detection probability of acteroid of 100m diameter is equal to 0.95 if the telescope aperture is 1.5m.

Signal-to-noise radio at the large phase angles φ of π/2 -α to π/2, if a h.a. moves tj Earth from the sunside of the barrier zone.

Da,[m] DT,[m]	50		100		150	
1.00	0.6-1.7	1.6-4.6	2.3-6.5	6.2-18	5.0-14	14-3
1.50	0.9-2.7	2.6-7.4	3.7-11	10-28	8.2-23	22-5
2.00	1.3-3.8	3.6-10	5.2-15	14-38	11-31	30-7
	$L=10^7$ km	$L=6 \cdot 10^7$km	$L=10^7$ km	$L=6 \cdot 10^7$km	$L=10^7$km	$L=6 \cdot 10^7$ km
$\alpha=\pi/6$, $\pi/3 \le \varphi \le \pi/2$, $n_a=800$, N-2.5ph·sec^{-1}·nm^{-1}·m^{-2}·arcsec^{-2}, $\rho_a=0.15$						

Detection probability of acteroid of 50m diameter is equal to 0.95

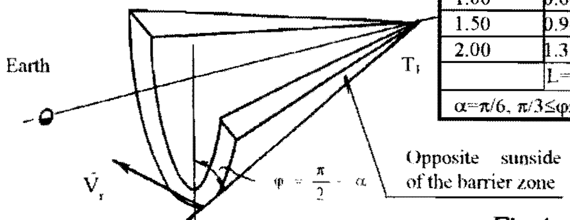


Fig.4

One can see that the detecting telescope with the input pupil of 1.5m in diameter registers asteroids larger than 50m with probability, exceeding 0.95. Asteroid albedo was assumed equal to 0.15.

Fig.5 illustrates a hazard asteroid flight time to the Earth after its crossing the barrier zone of its registration by a front or back detecting telescope

At $|\vec{V}_a|$~20 km/s they are ~3 days and more, depending on the asteroid flight direction to the Earth /8/.

TIME OF THE HAZARDOUS ASTEROID (H.A.) MOTION FROM BARRIER ZONE TO EARTH AGAINST β, THE ANGLE BETWEEN VECTOR OF RELATIV VELOCITY AND ORBIT OF EARTH.

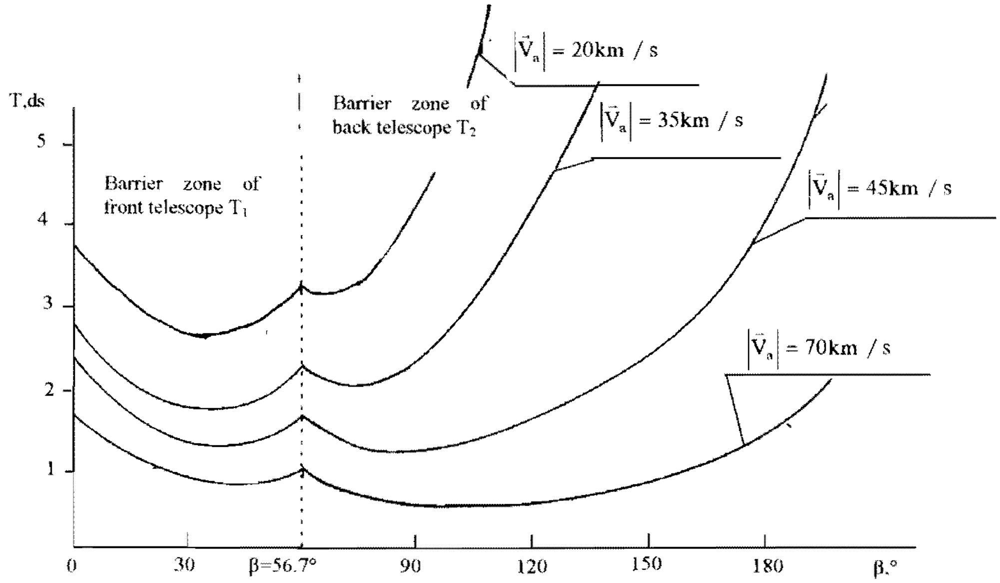


Fig.5

INFORMATION INTERACTION OF THE SPACEBASED AND GROUDBASED SYSTEMS BEING WARNED ABOUT ASTEROID HAZARD

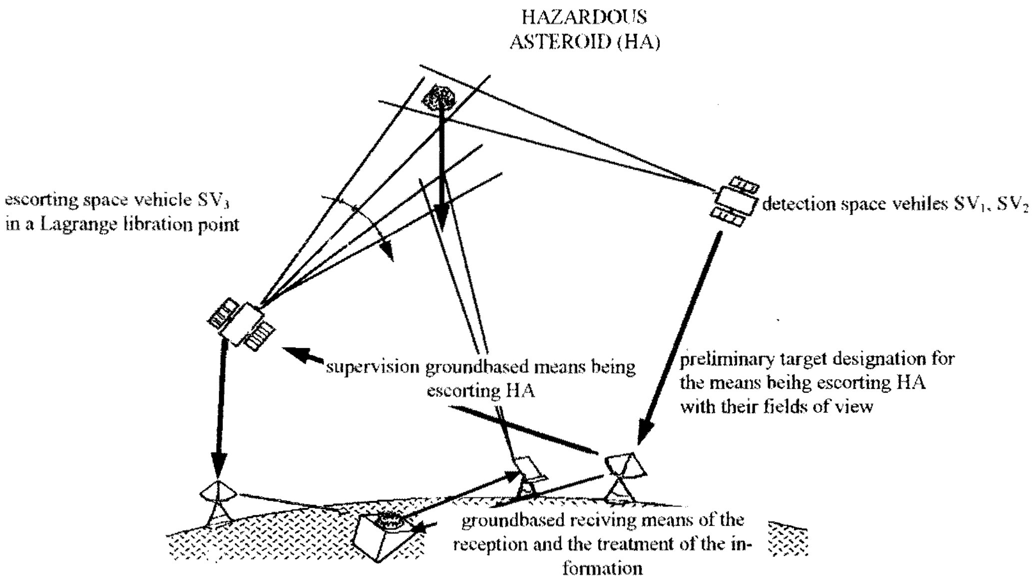


Fig. 6

Fig.6 shows a scheme of the asteroid hazard warning space information means between each other and with the ground means of non-co-ordinated information obtaining on detected hazard asteroids (dimensions, mass, material), as well as with co-ordinate information receiving and processing stations. The information exchange is also foreseen with theground measurement means of co-ordinate information obtaining on hazard asteroid MP of a large size, what allows to contribute a lot to the catalogue of such asteroids, being established on the base of available ground means of co-ordinate information obtaining on large celestial bodies.

4. SV and Hazard Asteroids Observation System Characteristics

Table 2 shows the results of estimation of mass and power consumption of SV primary systems for hazard asteroids detection.

Table 2

№	Subsystem nomination	Power consumption, W.	Mass, kg
1.	Telescope with a blend and a peak	1500	1850
2.	Onboard control complex		
2.1.	Radoitechnical complex	165	216
2.2.	Onboard synchroniser	40	80
2.3.	Controlled computer	190	70
2.4.	SV Control unit	7	10
3.	ORC antenna-fider system	-	70
4.	Attitude control system	500	700
5.	Power supply system	30	900
6.	Power complex unit	160	1000
7.	Thermal control system	400	160
8.	Mechanical system	-	700
9.	Onboard cable network	-	240
		2995	5996

Total fuelled SV mass is about	6000 kg
Its dimensions:	
length	5.8 m(solar panel(SP) flaps are collapsed)
diameter	3.85 m (SP flaps are collapsed)
length	12 m (SP flaps are open)
SP area	120 m^2

Launcher "Proton" with a stock booster and a stock fairing and having 6×3,95m of payload area is capable to launch SV in its working orbit. The above relates also to SV of high accurate definition of asteroids movement parameters and which is equipped with similar detecting instruments and power- mass characteristics.

The following indexes are common general for the whole system of the task decision of unknown hazard asteroids detection and early warning:

Detected asteroid minimum dimension	50 m
HA maximum detection range	$1{,}5\cdot10^{6}$ km
Time of warning before it drops on the Earth	$\geq$3 days ($\lvert\overline{V}_a\rvert \sim$ 20 km/s)
Forecasted drop region	3 days before drop
Probability to detect asteroids, moving to the Earth from a free direction	>0.999

Primary characteristics of the system and its elements

A number of SV in the system	3
SV mass	6000 kg
Aperture of the detecting telescope objective	1,5 - 1,7 m
Focal length	3 m
Field of vision	6^0

(Prototype is an objective "Pikar -11A")

A tracking telescope objective's aperture is 1.5, its focal distance - 17 m, field of view - 49 ang. min. (a prototype - the objective under development according to the scientific program ("Spectre - UV").

The devices with charging communication and with a resolution element of about 20 mcm are used as photo-receiver.

Using new key elements and technologies could allow to reduce SV mass and power consumption in about 1.5 - 2 times and to use lighter vehicle of "Zenit" type for its launch thus significantly lowering the whole Program realization expenses.

Conclusion

The proposed space system of asteroid hazard warning together with ground means of asteroids tracking allows to provide high reliability of warning drop on the Earth surface hazard asteroids of 50 m and more in size thus promoting significant reduction of destructive consequences of similar asteroids drop. As the Program realisation is rather expensive, it would be reasonable to implement it within the frames of the International Co-operation.

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