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Catalog of Non-Stellar Objects

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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CATALOG OF NON-STELLAR OBJECTS

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Group 94

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ABSTRACT

A catalogue of non-stellar astronomical objects brighter than $m_{pg} = 12\overset{m}{.}5$ has been constructed. The Catalog includes galaxies, star clusters, nebulae, and asteroids. The main purpose for creation of the Catalog is the reduction in the probability of false alarm during searches for artificial satellites. A total of 1371 extra-solar system objects and 131 minor planets are included. The principles of construction, the completeness of the Catalog for each component, and the special problems of the asteroids are discussed.

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I. BACKGROUND AND SOURCES

Searching the night sky for new or additional celestial objects has always been a difficult and time consuming task. Charles Messier, a noted comet hunter of his time, repeatedly rediscovered the same "false comets". His solution to this problem was the construction of a catalogue[1,2] of these diffuse nebulosities. The "Messier Catalogue" was the first catalogue of non-stellar objects (109 entries*). As astronomy advanced, more accurate and complete catalogues were needed. William and John Herschel's contribution[3] of "A General Catalogue of Nebulae and Star Clusters" contained 5079 entries. Dreyer[4] improved upon the Herschel's work and created "A New General Catalogue of Nebulae and Clusters" (7840 entries). Dreyer further extended the NGC with the publication[5] of two "Index Catalogues" (5386 additional entries). The next catalogue of this sequence is "The Revised New General Catalogue of Nonstellar Astronomical Objects" published by Sulentic and Tifft[6].

In between Dreyer's efforts (1888) and the release of the Revised NGC (1973) the true nature of the majority of the NGC and IC objects was recognized. This development led to the construction of specialized catalogues, one for each type of object. For galaxies the principal catalogues relevant here are the Shapley-Ames[7] galaxy survey, being "A Survey of the External[+] Galaxies Brighter than the Thirteenth Magnitude" (1249 entries) and the de Vaucouleurs'[8]

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*Messier listed five non-existent objects and M73 is a grouping of only four stars.

+Note that in 1932 it was necessary to emphasize that spiral and elliptical nebulae were not members of the Galaxy.

two "Reference Catalogues of Bright Galaxies" (2599 and 4364 entries). The next most populous class of object among the NGC entries are the galactic clusters for which the "Catalogue of Star Clusters and Associations" by Ruprecht[9] and coworkers is the basic reference. The NGC is complete[10] with regard to globular clusters outside of the zone of avoidance (see Section IIA). Finally, the "Catalogue of Galactic Planetary Nebulae"[11] serves as a fundamental source for data on these objects (1034 entries).

In the case of non-stellar solar system objects only the asteroids concern us here (the moon and the other major planets being special cases). The "Ephemerides of Minor Planets" serves as the source of orbital elements and photometric data[12].

Optical searches for artificial satellites will repeatedly rediscover all of Messier's "false comets" and more. Thus, an especial catalogue of non-stellar objects has been constructed to avoid recurrent false detections. The Catalog consists of two parts: Part I is concerned with extra-solar system objects and Part II is concerned with the minor planets. The principles behind the Catalog's construction are explained below. Also, estimates of completeness to the fixed limiting apparent photographic magnitude of $12^{m}.5$ (integrated for Part I) are given.

II. PART I OF THE CATALOG

The Revised NGC incorporates the information contained in references 1-5,7,9, and 11. Reference 8 was used as a supplement. Since simple confusion during search is the principal complication to be avoided, the Catalog has been kept simple. The principal point of confusion and error is in the magnitudes. The magnitudes used are at least roughly comparable independent of object type, original source of the magnitude, or type of magnitude.

For every object in the Revised NGC or the Second Reference Catalog of Bright Galaxies with an integrated, corrected (see Section IIA), apparent, photographic magnitude $\leq 12^{m}.5$ (rounded to the nearest $0^{m}.5$) the Catalog contains (1) NGC or IC identification; anonymous galaxies have an identification number of zero, (2) 1975.0 right ascension and declination accurate to the nearest $0^{m}.1$ and 1' respectively, (3) a corrected, integrated, apparent, photographic, magnitude rounded to the nearest $0^{m}.5$, and (4) a numerical code indicating the type of object. A legend for this code is given in Table 1. It follows the Revised NGC code except for class 7 objects. In the Revised NGC this means a non-existent object whereas in the Catalog it means one of the 28 IC or anonymous galaxies from the Second Reference Catalogue of Bright Galaxies. The total number of entries is 1371. All of the above information was transcribed to punched cards. Table 1 contains a statistical summary as a function of object type and apparent magnitude. Table 2 contains a breakdown as a function of right ascension and declination.

A. Galaxies

The Revised NGC, and especially the two Reference Catalogues of Bright Galaxies, contain much more information for each entry than the Catalog does.

TABLE 1

PART I OF THE CATALOG: MAGNITUDE - OBJECT DISTRIBUTION

Object	Code	Integrated Apparent Photographic Magnitude																					Totals
		$2^{m}.5$	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	
Galactic Cluster	1	0	0	4	3	6	5	10	9	16	17	16	29	31	39	29	33	16	17	15	16	7	318
Globular Cluster	2	0	0	0	1	1	0	0	0	1	5	9	5	12	9	12	14	11	15	9	12	4	120
Diffuse Nebula	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Planetary Nebula	4	0	0	0	0	0	0	0	0	0	0	1	1	2	3	4	3	2	1	10	12	5	44
Galaxy	5	0	0	0	0	1	0	0	0	0	1	2	1	3	1	6	16	36	52	109	233	362	823
Cluster Nebulosity	6	1	0	0	1	0	3	0	0	1	5	1	0	8	8	2	1	0	0	2	3	1	37
IC Galaxy	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	9	16	28
Totals		1	0	4	5	8	8	10	9	18	28	29	36	56	60	55	67	66	85	146	285	395	1371

TABLE 2

PART I OF THE CATALOG: CELESTIAL DISTRIBUTION

δ \ α	$0-2^h$	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	Totals
+75°	1	0	0	5	3	0	0	0	2	0	0	0	11
60	17	1	4	4	13	8	9	1	5	3	7	5	77
45	9	7	7	2	11	34	19	15	1	3	9	9	126
30	10	14	9	4	8	13	35	4	3	3	8	5	116
15	7	2	5	8	5	24	32	3	2	7	8	5	108
+0	12	5	2	18	6	28	99	17	3	10	3	4	207
-0	20	17	5	20	9	7	37	13	7	17	5	4	161
15	9	24	6	24	15	15	21	4	19	23	3	9	172
30	5	20	6	8	14	13	13	7	29	11	7	23	156
45	1	7	14	1	9	8	12	14	18	7	12	7	110
60	25	3	52	6	2	9	13	1	5	4	5	1	126
-75	0	0	1	0	0	0	0	0	0	0	0	0	1
Totals	116	100	111	100	95	159	290	79	94	88	67	72	1371

It is difficult to see how most of this would be of value during a search for artificial satellites (e.g. HI mass, redshift, radio spectral indices and strengths, galaxian type, etc.). Similarly for all of the other specialized catalogues for the rest of the objects comprising Part I of the Catalog. If needed, additional information will be incorporated.

Positions for the nearest Besselian year are computed following Taff[13,14]. For the 28 IC and anonymous galaxies the only available positions were for 1950.0. These too were updated by the same procedures.

The limiting magnitude of $12^m.5$ was chosen to satisfy both the needs of searches for artificial satellites using intensified EBISCON cameras and CCD imaging arrays as well as offset the exponential increase in the numbers of galaxies with decreasing brightness*. In particular, a severely incomplete catalogue would be self-defeating. While the Shapley-Ames catalogue was thought to be complete† to $m_{pg} = 13^m.0$, de Vaucouleurs[15] estimated its completeness to be 98% at $m_{pg} = 11^m.5$ but only 50% at $m_{pg} = 12^m.5$. On the other hand, Holmberg[16] estimated its completeness to be 100% at $m_{pg} = 12^m.0$. Clearly, an extension of this Catalog beyond $12^m.5$ is premature.

The magnitudes listed in the Revised NGC are corrected Harvard[7] magnitudes. The original Harvard magnitudes were integrated, photographic, apparent magnitudes. Shapley and Ames obtained these by using small-scale plates made with patrol cameras. Corrections are needed for inclination of the galaxy

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*If N(m) is the number of galaxies per square degree brighter than m, then $d\ell og_m[N(m)]/dm \simeq 0.6m$ for $10 \leq m \leq 14$. Thus, increasing the magnitude limit by $0^m.5$ would increase Part I of the Catalog by 62% just due galaxies.

†All but 61 galaxies in the Shapley-Ames catalogue were in the NGC and 48 of these were in the IC.

relative to the plane of the sky, a varying surface brightness, and luminosity gradients. The latter two are a function of galaxian type. The major effect is small and systematic [15,16], the average mean error of the correction being $\approx 0^{m}.25$. While the Harvard magnitudes are the more desirable ones for our purposes, the problem of overall homogeneity and larger corrections for brighter galaxies are somewhat eased by using rounded, corrected magnitudes.

Figure 1, taken from the Shapley-Ames catalogue, shows the distribution On the celestial sphere of the thousand brightest galaxies. Of these, 851 are included in the Catalog (cf. Table 1). Two principal features are noticeable. One is the evident clustering near right ascension $12^{h}.5$ and declination +12°. This is the Virgo Cluster. The other obvious point is the dearth of galaxies near the Galactic Equator. Proctor[17] had already noticed this from the Herschels' General Catalogue and Waters[15] remarked on this in his analysis of the NGC (see also Sanford[19]). We now know that the disc of the Galaxy contains a considerable amount of obscuring matter (Trumpler's[20] analysis of the apparent magnitude-apparent diameter relationship for galactic clusters) which leads to this region or zone of avoidance for extra-galactic objects. This effect is confused in Table 2 because of the concentration of the galactic clusters in precisely this region.

B. Star Clusters

From Holmberg's analysis of the completeness of the Shapley-Ames catalogue and the fact that only 61 new galaxies (i.e., not already in the NGC) were discovered by this survey, it followes that the NGC is >95% complete to $m_{pg} = 12^{m}.0$. Knowing that 48 of these 61 galaxies were in the IC implies that the NGC plus IC are >99% complete at $m_{pg} = 12^{m}.0$. Thus, Arp[10] reasoned that,

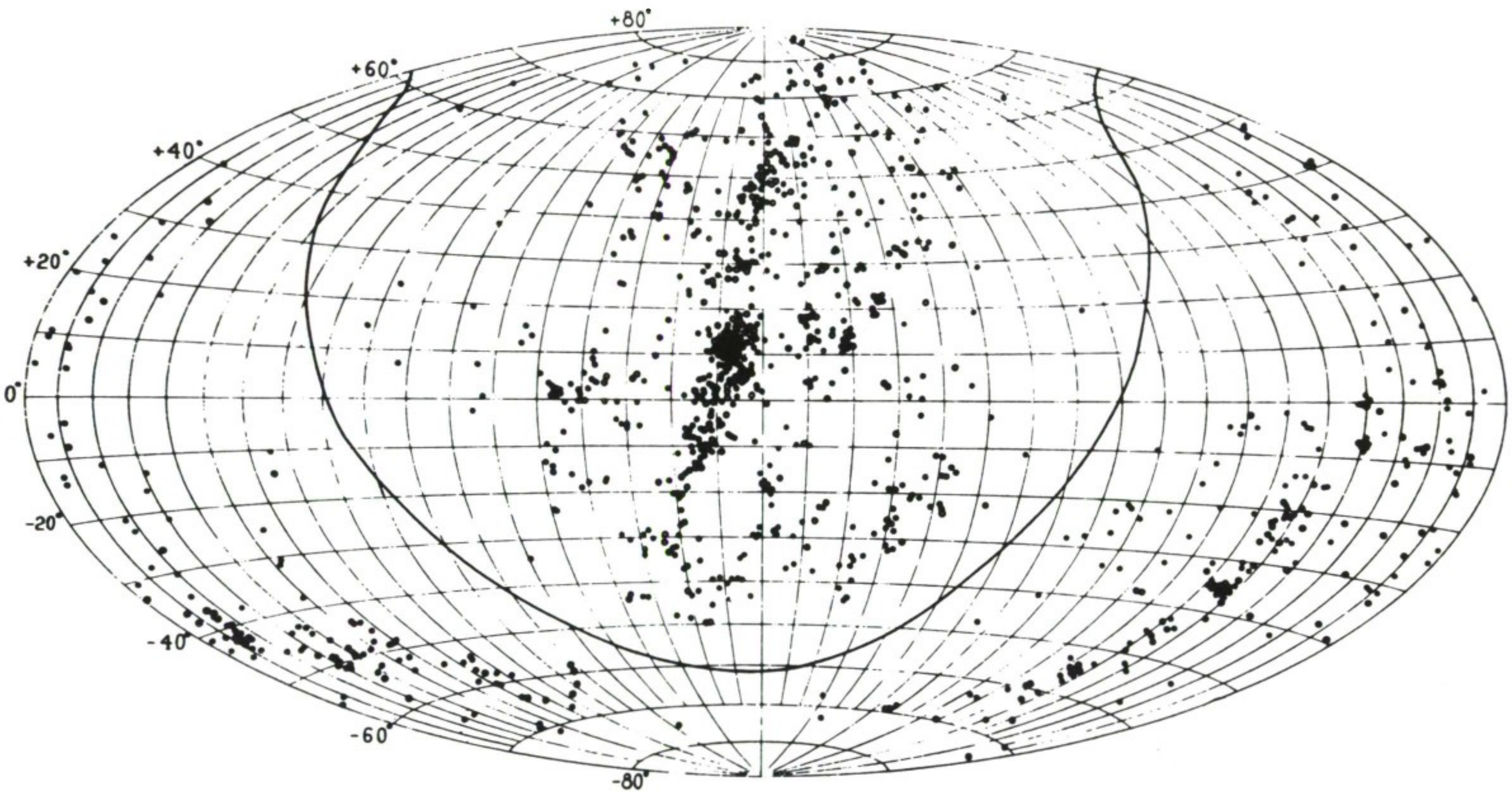

Fig. 1. An equal area projection of the entire sky showing the positions of the thousand brightest galaxies from the Shapley-Ames survey. Declination is indicated on the left. The solid curve is the projection of the equator of the Galaxy. Taken from reference 7.

except for low galactic latitudes on the other side of the galactic center, the globular cluster subset of the NGC plus IC is also >99% complete at $m_{pg} = 12^{m}.0$.

Unlike the globular clusters, whose spatial galactocentric distribution is nearly spherical, the galactic clusters are preferentially found in the disc of the Galaxy. Hence, obscuring interstellar dust and gas plays a major role in hiding them. However, because of their astrophysical importance, galactic clusters are sought after objects. Therefore, we may assume that for at least the rich and medium population clusters the Catalog's completeness is is comparable to that of the galaxies.

C. Nebulae

Nebulosities include such diverse objects as the Ring Nebula (a planetary nebulae), the Horsehead Nebula (a reflection-emission nebulosity), the Crab Nebula (a supernova remnant), the nebulosity around Merope (a reflection nebula), and the North American Nebula (a dark nebula). Selection effects, both observational and those due to theoretical considerations, severely affect the catalogues of these objects.

D. The Magellanic Clouds

The Large and Small Magellanic Clouds dominate the southern sky near right ascension $1^{h}.0$ declination -69° and ($1^{h}.0$, -73°). See Table 2. The additional code numbers of 8 and 9 (29 implies a globular cluster in the SMC while 38 denotes a nebulosity in the LMC) are used for objects in the Clouds.

III. PART II OF THE CATALOG

Unlike the objects in Part I of the Catalog, the members of Part II pose two separate, additional problems; their positions and brightnesses vary on short time scales. Their motion is a combination of their revolution about the Sun as well as the motion of the Earth. Their magnitude variations are due to a combination of rotation, surface inhomogeneities, distance variations, and phase effects. These difficulties are separately dealt with below. Table 4 gives a list of the asteroids included in the Catalog.

A. Position Predictions

The prediction of an asteroid's position is complicated by the perturbations caused by the planets. Jupiter provides the principal perturbing influence. Sufficient accuracy is possible only if this is accounted for. An analytical formulation coupled with numerical integration is used. Moreover, the average mean heliocentric diurnal motion of the asteroids is 761" (= 31".7/hr) so that multiple predictions per night are needed. These are best made by interpolation. As the inclination, the argument of perihelion, and the longitude of perihelion are given with respect to the equator and equinox of 1950.0, the simplest net result is a set of helicocentric rectangular ecliptic coordinates. Let these be $(x''', y''', z''') = \underline{r}'''$. Then heliocentric rectangular equatorial coordinates are obtained by multiplication with the matrix $\underline{S}''$,

$$S'' = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\varepsilon & -\sin\varepsilon \\ 0 & \sin\varepsilon & \cos\varepsilon \end{pmatrix}, \tag{1a}$$

where ε is the 1950.0 obliquity of the ecliptic, viz,

$$\underline{r}'' = S''\underline{r}'''. \tag{1b}$$

If $\underline{R} = (X,Y,Z)$ is the geocentric rectangular equatorial location of the Sun and

$$\underline{r}' = \underline{r}'' + \underline{R}, \tag{2}$$

then $\underline{r}'$ is the geocentric rectangular equatorial location vector of the minor planet. Next, one computes the geocentric rectangular equatorial coordinates for beginning of the nearest year by multiplication with S,

$$\underline{S} = \begin{pmatrix} \cos\zeta_o\cos\theta\cos z - \sin\zeta_o\sin z & \cos\zeta_o\cos\theta\sin z + \sin\zeta_o\cos z & \cos\zeta_o\sin\theta \\ -\sin\zeta_o\cos\theta\cos z - \cos\zeta_o\sin z & -\sin\zeta_o\cos\theta\sin z + \cos\zeta_o\cos z & -\sin\zeta_o\sin\theta \\ -\sin\theta\cos z & -\sin\theta\sin z & \cos\theta \end{pmatrix} \tag{3a}$$

where (for reductions from 1950.0 to 1950.0 + T, T in centuries)

$$\zeta_o = 2304''.9518T + 0''.3022T^2 + 0''.0180T^3, \tag{3b}$$

$$z = \zeta_o + 0''.7930T^2 + 0''.0003T^3, \tag{3c}$$

$$\theta = 2004''.2583T - 0''.4269T^2 - 0''.0418T^3, \tag{3d}$$

viz.

$$\underline{r} = S\underline{r}'. \tag{3e}$$

Finally, geocentric spherical equatorial coordinates are calculated from

$$x = r\cos\delta\cos\alpha, \tag{4a}$$

$$y = r\cos\delta\sin\alpha, \tag{4b}$$

$$z = r\sin\delta. \tag{4c}$$

The values obtained from Eqs. (4) are geometric. To reduce them to topocentric values corrections for annual aberration, diurnal aberration, planetary aberration, diurnal parallax, astronomical refraction and intra-year precession and nutation are necessary.

B. Magnitude Predictions*

The light curves of approximately fifty asteroids had been studied as of 1971. Since that time photometry on these objects has been concentrated on obtaining diameter estimates. Of these fifty the range of periods is from $2^h16^m.4$ for Icarus (1566) to $18^h48^m.8$ for Herculina (532). Their amplitudes range from $<0^m.01$ for Flora (8) to $1^m.2$ for Geographos (1620). In addition, the amplitude depends on the unknown inclination of the minor planet. For example, Hektor's (624) amplitude can be as small as $0^m.1$ or as large as $1^m.1$. The mean amplitude for this group is $0^m.25$. Until real experience with semi-automated or automated searches for artificial satellites indicates that such variations are important they will be ignored. Similarly for brightness variations due to surface mottling.

Changes in apparent magnitude due to phase and distance effects are more easily and accurately computed. Let α† be the phase angle (i.e., the angle Sun-asteroid-observer) and $\phi(\alpha)$ the phase function. The standard normalization is that $\phi(0) = 1$. The apparent magnitude of an asteroid with phase angle α, a distance r A.U. from the Sun, Δ A.U. from the Earth, with geometric albedo p, and effective radius R A.U. is given by

$$m = m_{\odot} - 2.5\ell og p - 2.5\ell og\phi(\alpha) + 5\ell og(r\Delta/R), \qquad (5)$$

where $m_{\odot}$ is the apparent magnitude of the Sun. In terms of the absolute magnitude, g, (m when $r\Delta = 1, \alpha = 0$)

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*All magnitudes are B values. The mean B-V of the brighter asteroids is $+0^m.86$.

†The notation here does not conform to that of Section III A above.

$$m = g + \Delta m(\alpha) + 5\ \ell og(r\Delta), \quad (6)$$

where $\Delta m(\alpha) = -2.5\ \ell og\phi(\alpha)$ is the phase function in magnitudes.

The absolute magnitude is useful for studies of the intrinsic properties of the minor planets but the mean opposition magnitude, m_o, (m when $r = a$, $\Delta = r-1$, $\alpha = 0$) is more useful for studies of observational selection effects and completeness;

$$m = m_o + \Delta m(\alpha) + 5\ell og\left\{r\Delta/[a(a-1)]\right\}. \quad (7)$$

The perihelion opposition magnitude, m_q, [m when $r = a(1-e)=q$, $\Delta = r-1, \alpha = 0$], the aphelion opposition magnitude, m_Q, [m when $r = a(1+e) = Q$, $\Delta = r-1, \alpha = 0$], and the mean quadrature magnitude, $m_{\square}$, (m when $r = a$, $\Delta^2 = a^2 -1$, $\csc\alpha = a$) are also useful in determining completeness and the average brightness variations of the asteroid population as a whole.

The phase function in magnitudes for the brighter asteroids is given by

$$\Delta m(\alpha) = 0^m.023|\alpha|, \quad 10° \le \alpha \le 20°, \quad (8)$$

when the phase angle is measured in degrees*. For smaller phase angles than $\simeq 10°$ the phase function in magnitudes is not a linear function of the phase angle. This is known as the opposition effect and was first noticed by Gehrels[21].

From the 1971 edition of reference 12 (1748 entries) the average value of the semi-major axis is 2.79 A.U. and the average value of the eccentricity is 0.150. Hence, from Eqs. (5-8).

$$m_q \simeq m_o - 0^m.93, \quad (9a)$$

$$m_Q \simeq m_o + 0^m.76, \quad (9b)$$

$$m_{\square} \simeq m_o + 1^m.30. \quad (9c)$$

*At quadrature $\alpha \simeq 21°$ for $a = 2.79$ A.U.

The distribution, in steps of $0^m.5$ steps, of the mean opposition magnitude for all* minor planets with $m_o < 15^m.5$ is given in Table 3.

C. Completeness and the Catalog

The 1977 edition of reference 12 contains 192 more entries than the 1971 edition does. Of these five have mean opposition magnitudes $<15^m.5$†. None of the more than four thousand new asteroids discovered by the Palomar-Leiden Asteroid Survey[22] are this bright‡. Hence, I assume that the 1977 edition of the Ephemerides of Minor Planets is >99% complete to $m_o = 15^m.5$ (apparent photographic magnitude). However, consistency with Part I of the Catalog dictates that only those asteroids with $m_o \leq 12^m.5$ be included. A list of these 131 minor planets is given in Table 4.

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*Asteroids for which q < 1 A.U. were excluded.

†The brightest of these, Cerberus (1865, $m_o = 12^m.2$) has a semi-major axis of 1.0801 A.U. and an eccentricity of 0.4669. Clearly, not a typical case.

‡ The brightest two are No. 4196 ($m_o = 15^m.95$) and No. 4007 ($m_o = 15^m.97$)

TABLE 3

DISTRIBUTION OF MEAN OPPOSITION MAGNITUDES

m_o	$N(m_o)$	m_o	$N(m_o)$
$5^m.75$	0	$10^m.75$	21
6.25	1	11.25	26
6.75	1	11.75	51
7.25	0	12.25	85
7.75	0	12.75	96
8.25	1	13.25	106
8.75	3	13.75	166
9.25	3	14.25	216
9.75	5	14.75	274
10.25	8	15.25	296

Total: 1359

TABLE 4

PART II OF THE CATALOG: MINOR PLANETS

No.	m_o	No.	m_o	No.	m_o	No.	m_o
4	$6^{\mathrm{m}}.7$	22	$11^{\mathrm{m}}.1$	185	$11^{\mathrm{m}}.8$	173	$12^{\mathrm{m}}.3$
		51	11.1			198	12.3
1	7.4	89	11.1	31	11.9	344	12.3
		230	11.1	79	11.9	387	12.3
2	8.5	12	11.2	287	11.9	389	12.3
		30	11.2				
6	9.3	43	11.2	54	12.0	55	12.4
7	9.3	511	11.2	59	12.0	57	12.4
				64	12.0	83	12.4
15	9.4	21	11.3	69	12.0	119	12.4
		324	11.3	85	12.0	308	12.4
8	9.5	532	11.3	111	12.0	326	12.4
				130	12.0	356	12.4
3	9.6	17	11.4	194	12.0	375	12.4
		23	11.4	386	12.0	385	12.4
9	9.8	129	11.4	554	12.0	423	12.4
		433	11.4	925	12.0	432	12.4
20	10.0	471	11.4				
				46	12.1	61	12.5
18	10.1	28	11.5	48	12.1	67	12.5
		42	11.5	93	12.1	72	12.5
29	10.2	216	11.5	116	12.1	146	12.5
		704	11.5	128	12.1	247	12.5
11	10.4			144	12.1	337	12.5
14	10.4	25	11.6	145	12.1	345	12.5
		37	11.6	148	12.1	346	12.5
16	10.5	41	11.6	172	12.1	419	12.5
		52	11.6	270	12.1	584	12.5
10	10.6	80	11.6	674	12.1	712	12.5
40	10.6	88	11.6				
44	10.6	115	11.6	24	12.2		
		409	11.6	70	12.2		
63	10.7			78	12.2		
		32	11.7	92	12.2		
39	10.8	68	11.7	105	12.2		
		196	11.7	113	12.2		
13	10.9			124	12.2		
192	10.9	26	11.8	313	12.2		
		45	11.8	451	12.2		
5	11.0	71	11.8	654	12.2		
19	11.0	97	11.8	679	12.2		
27	11.0	103	11.8				
349	11.0	110	11.8	65	12.3		
354	11.0	135	11.8	101	12.3		

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A catalogue of non-stellar astronomical objects brighter than $m_{pg} = 12\overset{m}{.}5$ has been constructed. The Catalog includes galaxies, star clusters, nebulae, and asteroids. The main purpose for creation of the Catalog is the reduction in the probability of false alarm during searches for artificial satellites. A total of 1371 extra-solar system objects and 131 minor planets are included. The principles of construction, the completeness of the Catalog for each component, and the special problems of the asteroids are discussed.

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