SURVEY OF STELLAR OUTBURSTS OF THE PRETELESCOPIC ERA

Yu. P. Pskovskii

Shternberg Astronomical Institute, Moscow

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A list is presented of 125 objects qualifying as stars that have suffered outbursts. Possible supernovae and recurrent novae are discussed, including V603 Aql, GK Per, the novae of 393 and 1600, the slow novae of 396 and of 1431, and the nova of 1006, at whose site a bright stellar remnant of $9\text{-}10^m$ (IR Nor?) should be located.

1. THE MATERIAL

The information available to us on ancient and medieval outbursts is based on systematic observations conducted in Far Eastern countries and, in individual cases, in European and Near Eastern lands. Past and present investigators have made varying use of this material [1-10]. With the exception of Williams and Brosche, however, none of the authors seems to have been familiar with the catalog of 717 comets and novae compiled by Pingré [11], who, 63 years before Biot, already had at his disposal translations of Ma Tuan-lin's encyclopedia and several manuscripts, some of which were lost soon afterward[1] [3].

Pingré's catalog is exceptionally valuable; it includes phenomena not mentioned by later investigators, and furthermore it reveals a most curious fact: Of 125 outbursts, fully 25 (not just 5-7, as is generally believed) were also observed in Europe and in the Near East. Cases occur where skimpy descriptions of phenomena are supplemented by European accounts, enabling the character of the event to be established more accurately. However, the European data often contain errors in dates and definite anachronisms arising from a lack of system in the chronicles, whereas the dating adopted in the Chinese chronicles has received splendid confirmation from their descriptions of solar-eclipse observations [13].

2. SELECTION OF PHENOMENA

To facilitate the study of ancient outbursts we have compiled a list of objects that were called unusual stars by the authors of chronicles or by subsequent researchers and translators [14]. Despite the detailed classification of these stars in the Chinese chronicles, it is not always easy to distinguish accounts of comets from accounts of outbursts. In some cases a cross-comparison of Chinese and European information is helpful; in other cases, various astronomical criteria can be used.

In their recent catalog, Xi and Po [8] utilize not only obvious criteria (fixed stars were novae, moving and extended objects were comets) but criteria that are not adequately motivated. One criterion is more stringent than necessary (regarding as comets all phenomena in the zone of the ecliptic or not accompanied by some indication of direction; regarding as novae "comets" that were observed for six months, even though no comet has ever been observed with the unaided eye for more than four months). Other criteria that they use are simply wrong. For example, the "sparkling stars" (po-hsing) are considered to have been comets: as specialists in the history of science, rather than astronomers, Ho [7] and Xi and Po [8] are genuinely mistaken in supposing that comets can be seen with the unaided eye for a prolonged time sending out rays from head to tail.

In analyzing the phenomena, estimates for their duration are particularly important. The chronicles give the observed duration or the date of the first

[1] But specialists in comets were well acquainted with Pingré's work [3, 12]; their catalogs actually contain elements of a comet of 1006, the object that was in fact a supernova or nova.

observation. The maximum duration is diminished by inclement weather (in Southeast Asia the wet monsoon prevails from April to September) and by the season of daytime visibility. The first effect is illustrated by Fig. 1, which is a diagram of the monthly number of first observations of phenomena throughout 15 centuries, according to Ho [7]. Following the dry season the number of discoveries drops by one half. When the monsoon is relieved in September there is a small rise in the diagram, corresponding to comets and novae that had appeared during the rainy season but were now being observed for the first time.

Cases where stars were observed in the daytime are usually attributed to Venus. The circumstances of visibility can readily be examined by means of Neugebauer's tables [15]. A nova would have been detected not only at night but at twilight, if observable then, because the only "star" of comparable brightness would have been the original twilight star, Venus. From Neugebauer's tables one can also establish the "culprit" of an "assault" on the moon. Usually the culprit is Venus or Jupiter, or perhaps Spica or Regulus, which might not have been recognized because of the disappearance of faint stars making up the configuration of the familiar constellations to which they belonged. The discovery of comets at the time of an encounter with the moon would have been considerably less probable.

The distinctions between the visibility of novae and supernovae are clearly demonstrated by comparing their mean absolute magnitudes $\overline{M}_V$ and their mean galactic $\bar{z}$ coordinates with estimates for the apparent magnitudes m_V and the galactic latitudes b of the outbursts (a_V represents the absorption):

$$m_v \leqslant \overline{M}_v + a_v + 5\lg\frac{|\bar{z}|}{10\sin|b|}.$$

The mean values $\overline{M}_V$ and $\bar{z}$ and the mean brightness amplitude A_V are given in Table 1, along with

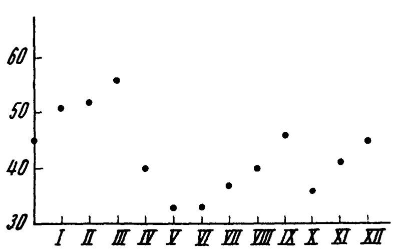

Fig. 1. Monthly number of initial observations of phenomena from A.D. 100 to 1600.

TABLE 1

Object	$\overline{M}_v$	$\bar{z}$, pc	m_v, $b = 90°$	m_v, $b = 10°$	A_v
SN I	-19^m	2000	-7^m	-3^m	20^m
		160	−13	−8	
SN II	−17	100	−12	−7	?
Na	−9	450	−1	3	14
Nc	−7	450	1	5	12

upper and lower estimates for the apparent brightness of each type of object. Evidently supernovae at $|b| > 10°$ would have been freely observable during the daytime. Furthermore, one can calculate from the light curves of novae and supernovae the length of time that an outburst can be observed during the day and at night as a function of the apparent magnitude at maximum (Mayall and Oort [16] investigated the 1054 outburst in this manner). The actual period of visibility would usually have been shorter, not only for the reasons mentioned above, but also because an outburst would not have been discovered until near maximum if its apparent magnitude was brighter than 2^m, whereas after discovery the star would have been followed until it disappeared at 6^m (see Fig. 2). The length of time a nearby supernova was observed is an important criterion, serving to distinguish it from fast novae when analyzing ancient observations.

A valuable auxiliary criterion is the color of the outburst [17, 18]. An inspection of Ho's catalog [7], which contains 102 color estimates, shows the predominance of a white color reported for comets

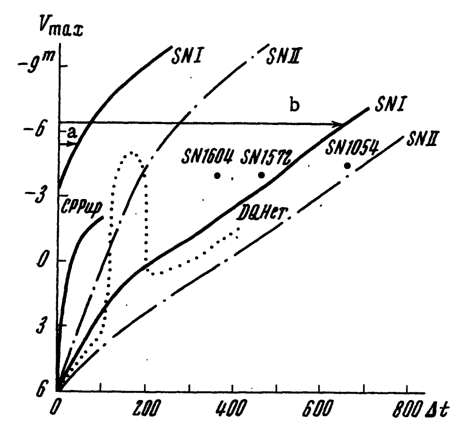

Fig. 2. Duration of observation of nearby galactic novae and supernovae. Ordinate, apparent brightness at maximum; abscissa, length of visibility Δt in days. a) Duration of daytime visibility; b) duration of night visibility.

TABLE 2

No.	Year, month, day	α	δ	Δt	Type	Catalog Nos.	Region	Phenomenon
1	BC 2296	—	—	—	?	P	C	N?
2	BC 2241	—	—	—	S	P	C	SN?
3	BC 1400:	16h+	−30°	57	S	X1 T1—2 H1	C	N
4	BC 532 IV:	21	−10	+	S	X2 T3 H6 P	C	N
5	BC 525 I:	16+	−30	+	P	H7 W2 P	C	N?
6	BC 134 VII 7:	16	−25	+	E	X4 T6 L1 H40 W31 B P	CE	N
7	BC 108/7	7+	+20	?	P	X5 H45 W35 P	C	N?
8	BC 77 XI 1:	11:	+80	—	E	X6 T7 L2 H50 W38 B	C	N
9	BC 76 V 26:	1+	+25	+	C	T8 L3 H51 W39	C	N
10	BC 69 II 14:	18	−20	—	P	T9 H52 W44	C	N
11	BC 4 II 23	20	+10	—	P	X9 H64 W53 P	CKP	N
12	AD 29	17+	+10	—	E	X10 T12 H67	C	N
13	59 VI 24:	3	+50	+	P	H72	K	N?
14	71 I 5:	10:	+10:	48	E	T13 L7 H79 B P	C	N
15	101 XII 30	10	+20	—	E by	T14 L8 H88	C	N
16	107 IX 13	7	−10	+	E	X12 T15 L9 H90 B	C	N
17	125 XII 27:	18+	0	—	E	X13 T16 L10 H94 B	C	Nd
18	185 XII 7	14+	−60	225:	E v	X15 T17 L12 H109 W76 B	C	SN?
19	193 IV	—	—	—	S	P	E	N
20	200 XI 6	4	+20	—	P	X16 H115 W81 P	C	N?
21	213 I 24:	7	+30	—	P	X18 H120 W85 P	C	N?
22	269 X 27:	Tzu-Wei		—	P	X19 H145 P	CK	N?
23	275 I 28:	12	−20	—	P	X20 H146 W107 P	C	N?
24	290 V 21:	Tzu-Wei		+	E	X21 T19 L14 H155 W115	C	N
25	300 IV 20:	S		+	O	T20 L15 H158 W117	C	N
26	304 VII 4:	4+	+15	+	E	X22 T21 L16 H163 W122 B	C	N
27	369 IV 8:	Tzu-Wei		140	E	X24 T24 L17 H174 W132 B	C	N
28	386 IV 30	19	−30	90:	E	X25 T25 L18 H177 W134	C	N
29	393 III 14:	17	−40	200	E	X26 T26 L20 H179 W136 B	C	Nd
30	396 VIII 5	4	+20	+150	H y	X27 T27 H182	C	N
31	398	—	—	—	S	P	E	N?
32	414 VII 20	3+	+20	—	P	X28 H187	C	N?
33	419 II 17	11	+15	—	P	X29 H192 W142 P	CK	N?
34	421 II 3:	11	−15	—	E	X30 T28 H194 P	C	N
35	436 VI 21	16	−25	+	P	X31 T29 H199 P	C	N
36	437 I 26	7:	+20:	—	S y	X32 T30 H200	C	N
37	537 II	Tzu-Wei		—	E	T31 H220	C	N
38	541 II 5:	Tzu-Wei		—	E	X33 H222 P	CE	N
39	561 IX 26	11	−15	—	E	X34 T32 L21 H224 W164 B	C	N
40	575 IV 27	14	+20	+	P	X35 T34 H231 W157 P	C	N
41	588 XI 22	20	−20	—	P	X36 T35 H235 W169 P	C	N
42	617 VII 23	11+	+15	+5	P ry	H241 W174 P	C	N
43	668 V 31	5	+50	+22	H	X37 T38 H252	CK	SN?
44	683 IV 20	5	+50	25	H	X38 T39 L23 H257 W185 P	CK	N?
45	708 VII 28	3	+25	+	P	X39 H 262 W189 P	C	N?
46	709 IX 16	Tzu-Wei		—	P	X40 H263 W190 P	C	N?
47	722 VIII 19	1	+60	+5	E	X41 T41 H266	J	N
48	725 II 11	1+	+70	—	P	X42 T42 H267	J	N
49	745 I 8	1	−10	39?	P	X44 T43 H271 P	JE	N?
50	823 II 19	SW		3	P	T44 H286	J	N?
51	829 XI 15:	8	+10	—	E	T46 L25 H288 W203 B	C	N
52	837 IV 29	7	+10	23	E	X45 L26 H291 W206/8 B	CJE	N
53	837 V 3	12	+10	70	E	X46 L27/8 H291 W207/9 B	C	N
54	837 VI 26	18	−25	+	P	H291 W210	C	N?
55	839 III 12	3+	+40	10	H	T47 W215 P	C	Nd
56	881 I 18	8+	+20	—	E	X48 P	CE	N
57	891 V 11	16+	−20	+	E	X49 T51 H313	J	N?
58	894 VIII 11:	—	—	+	?	H 317	C	N
59	902 II 25:	0	+70	350:	E ry?	X50 T54 H320 B (X-III L31 P)	CE	SN?
60	911 VI 14:	17+	+10	+	E w	X51 T55 L30 H324 B	C	N?
61	930 VI	23	−20	80+	E	T56 H329	JE	N
62	965 V 12	—	—	—	E	H343	K	N?
63	980 V	17+	+10	+100	S	X52	K	N
64	1006 IV 3	15	−45	220	E v	X53 T57 L33/4 H356/7 B P (X-II T45 L24 P)	CKJAE	N
65	1011 II 8	19	−30	—	E	X54 T58 L35 H358 B	C	N
66	1020 I 26	17+	−5	—	E	X55 H363	K	N?
67	1031 X 4	8+	+20	—		X56 P	KE	N?

Table 2 (continued)

No.	Year, month, day	α	δ	Δt	Type	Catalog Nos.	Region	Phenomenon
68	1054 V 20	5+	+20	670	E rw	X57 T60 L36 H375 B	CJ	SN
69	1070 XII 25	3	+5	—	E	T62 L37 H382 B	C	N
70	1073 X 9	0	+10	—	E	X59 H383	K	N
71	1090 III 31	SE+SW		—	SS	H388	K	N?
72	1104	—	—	—	S	P	E	N
73	1113 VIII 15	23	+20	+	P	X60 H394	K	N?
74	1123 VIII 11	12	+60	+	P	X61 H 395	K	N?
75	1139 III 23	14	—10	—	E	X63 T65 L39 H404 B	C	N
76	1175 VIII 10	14	+40	+6	P r?	X64 T66 H413	C	N
77	1181 VIII 6	1	+65	+185	E by	X65 T67 H415 B P	CJE	SN?
78	1203 VII 28	17+	—40	+10	E bw	X66 T68 L40 H419 B	C	N
79	1210 III 12:	Tzu-Wei		—	E r	H420	C	N?
80	1217	16	+30	10	S	P	E	N
81	1220 I 25	0	+50	—	H r	H22	K	N?
82	1221 I 10:	12	+60	—	P	X67 H424	KE	N?
83	1230 XII 15	18+	+20	105	H	X69 T70 L41 H428 B P	CJE	K
84	1234 X 30	—	—	—	E	H430	J	N?
85	1240 VIII 17	17+	—40	+	E	X70 T73 H433	C	N
86	1245 VII 25	21:	—20:	40	S r	X-IV	E	N
87	1349 II 3:	—	—	—	E	H458	J	N?
88	1388 III 29	0	+20	?	S	X72 T77 L43 H482 W348 B	C	N
89	1397 XII 25	—	—	—	E	H485	J	N?
90	1404 XI 14	20	+30	—	S y	T78 H490	C	N
91	1408 VII 14	—	—	—	E	H492	J	N?
92	1414 IV 8	—	—	—	S	H493 P	JE	N?
93	1415 IX 17:	19:	—25	—	H	X73 H494	C	N?
94	1416 VII 29	—	—	—	O	H495 P	JE	N?
95	1421 XII 27	—	—	—	E	H498	J	N?
96	1430 IX 9	7+	+10	26	S b	X74 T79 L44 H500 W349 P B	CJ	N
97	1431 I 4	5	—10	116+	S wy	T80 L45 H502 W351	C	N
98	1437 III 11	17+	—40	14	E	X75 H508	K	N
99	1438 III 16	—	—	—	E	H509	J	N?
100	1452 III 21	4+	+15	—	P	X76 H515 W310 B P	CE	N?
101	1460 III 8	7:	—10:	—	S	X77	V	N
102	1469 II 26:	—	—	—	E	H527	J	N?
103	1471 V 20	—	—	—	E	H529	J	N?
104	1476 II 10:	—	—	—	E	H531	J	N?
105	1482 VI 30:	E		+30	S	H533	J	N
106	1523 VII 27:	Thien—Shih		+	P	X78 H543 W324 B	C	N?
107	1572 XI 8	0	+60	485	E	X79 T82 H565	CKE	SN
108	1584 VII 11	16	—20	3	S	X80 T84 L48 H572 W367 B	C	N
109	1592 XI 28	1	—10	450	E	X81 H577	KC	M
110	1592 XI 30	1	+60	100	E	X82 H577 P	K	SN?
111	1592 XII 4	23	+60	62	E	X83 H577	K	N
112	1600 VIII 24	= P Cyg		—	S	X-VI	E	Nl
113	1600 XII 14	17+	—40	22	E yr	X84 H 581	K	Nd
114	1604 X 9	17+	—20	365	S yr	X85 T85 L49 W368 B	CKE	SN
115	1612	Antinous		—	S	L51	E	N
116	1618 XI 15	—	—	19	S w	L52 W371 B	C	N?
117	1621 V 22	E		—	S r	T87 L53 W372	C	N?
118	1645 III 13:	8+	+20	—	S	X86	K	N
119	1661 XII 27:	21	—10	—	S	X87	K	N
120	1664 XI 3:	17+	—20	230	S	X88	K	N
121	1667 IV 18	= V 529 Ori		—	S	L54	E	Nd
122	1670 VI 20	= CK Vul		—	S	X-VII	E	N
123	1676 II 18	4	—5	—	E w	X89 T88	C	N
124	1688 XI 2	1	+30	—	E w	T89	C	N
125	1690 XI 29	18	—35	2	E y	X90 T90	C	N

and fast novae, but yellow and red for supernovae and slow novae. Supernovae are actually white at the epoch of maximum, but three to four weeks later their color changes to yellow and red. The reports of several colors for southerly outbursts may, incidentally, be ascribed to atmospheric dispersion of the source near the horizon.

3. THE CATALOG

From the indicators described above we have been able to discriminate 125 outbursts with various degrees of confidence. Table 2 presents a catalog of these outbursts, some of which will be discussed further. Successive columns give: 1) a serial number; 2) the year and date of the outburst, with the first 11 dates being B. C., and with a colon designating a date of low accuracy (± 14 days); 3) the celestial coordinates of the phenomenon, to an accuracy of order ± 10° [19], with α given to the nearest half-hour (a half-hour increment is denoted by a plus sign); 4) the duration Δt of the phenomenon in days (here a plus sign indicates that the rainy season might have shortened the duration); 5) the classification of the phenomenon according to the original source, and its color (S, a star; P, a "sparkling star"; O, an "ominous star"; E, a "guest star"; H, a "broom star"; b, blue; y, yellow; r, red; v, variable in color); 6) the number of the phenomenon in various catalogs (X, Xi and Po [8]; T, Hsi [6]; L, Lundmark [5]; H, Ho [7]; W, Williams [3]; B, Biot [2]; P, Pingré [11]; 7) the region from which the phenomenon was observed (A, the Arab East; C, China; E, Europe; J, Japan; K, Korea; P, Palestine; V, Viet Nam); 8) our classification of the phenomenon (SN, a supernova; SN?, a possible supernova; N, a nova; Nd, a recurrent nova; N?, a possible nova; M, a Mira star, in this case Mira itself, o Ceti).

4. SUPERNOVAE

Nonthermal radio emission from expanding gaseous remnants is regarded as evidence for galactic supernovae. Only four of these have been found: the Crab Nebula of 1054, Cassiopeia A (1677?; outburst not recorded), Tycho's supernova of 1572, and Kepler's supernova of 1604. However, outbursts whose optical characteristics resemble supernovae have been observed considerably more often. In such cases either: 1) one type of supernova does not have radio-emitting remnants, or 2) nearby novae have been observed.

In the first interpretation, suspicion falls on type I supernovae, since the resemblance between their light curves and those of the galactic supernovae is not an adequate criterion (similar light curves are also observed for type II supernovae). Instead, the diversity in the properties and shapes of known supernova remnants corresponds more closely to the photometric and spectroscopic diversity of type II supernovae. However, this first interpretation is unpromising, because from formal evidence supernovae can experience outbursts of all kinds.

The second possibility imposes a severe condition on the identification of outbursts: an agreement between the ages of an outburst and the corresponding supernova remnant (the age of the remnant is usually estimated from the characteristics of its expansion or its radio emission [20-22]). Otherwise, one could merely establish an agreement between one or several objects and the neighborhood of the outburst. Many attempts at identification have proved unsuccessful because of this circumstance. In particular, from the outset, correlations of outbursts have been sought with hot stars, planetary nebulae, and thermal radio-emission sources [6, 8, 23]. Identifications with radio nebulae also have not lasted for long, as the nebulae have been found to be far older than the outbursts identified with them [6, 8, 23, 24].

The discovery of a relationship between pulsars and supernovae has likewise stimulated a series of identifications with outbursts [25], but here too nothing has been added. The rate of change $\dot{P}/P$ in the logarithm of the period of a pulsar is proportional to its age [26]. The oldest pulsars have proved to be far longer lived than supernova remnants. Pulsars have been discovered, properly speaking, in only two remnants: the youngest known, in the Crab Nebula; and the next youngest, in Vela X, although the age of the second pulsar, 12,000 yr, is considerably smaller than the age of Vela X [27], which is estimated from the radio emission at 30,000-50,000 yr. Apart from the standard explanation of the disparity we should point out that the ($\dot{P}/P$, P) diagram (the age—period relation for pulsars), which is shown in logarithmic form in Fig. 3 and indicates that the age of a pulsar is proportional to the cube of its pulsation period, exhibits a real scatter, and the true age of a pulsar, as estimated from $\dot{P}/P$, should fall within this dispersion. The scatter exceeds the disparity found between the ages of pulsars and supernova remnants, an effect which may be explained by the low accuracy of the method for estimating the age of a pulsar. The pulsar third in order of age, MP 1449, occurs in the neighborhood of the outburst of A. D. 185, but cannot be associated with it, as the pulsar is older.

Table 3 assembles the outbursts observed for more than 100 days or identified with supernova remnants, or being given optical identifications now; the indisputable supernovae of 1054, 1667?, 1572, and 1604 have been omitted. In addition to the notation introduced in Table 2, H II here represents an ionized-hydrogen region; NT, a nonthermal galactic radio source; SNR, a supernova remnant; ERS, an extragalactic radio source. The customary nomenclature has been adopted for the catalogs.

Six supernova remnants have been identified with outbursts, but reliable estimates of their ages and distances are not yet available (our previous estimates [31] by Harris' method [38] are now obsolete). Some of the remnants may prove older than the outbursts attributed to them, while the outbursts themselves might be nearby novae. Furthermore, according to Ho [7] the outburst of 1230 coincides with a comet of that year.

TABLE 3

Year	Δt	Color	Obsolete identifications with nebulae and sources	Type of nebula	Present identifications with variables and supernova remnants	Type of object
77 BC	—		NGC 3587 [6]	HII		N
48 BC			NGC 6587 [6]	HII		K
107 AD	+		NGC 2452 [6]	HII		N
125	—		—	—	V603 Aql [28]	Nd
185	225:	v	Cen B [24]	NT	PKS 1439-62	SN?
					[25]	
369	140		a) Cas A [29]	SNR	Obsolete	N
			b) Abell — 72 [23]	HII		
386	90		BSS 23=3C 396 [24]	HII		
393	150	y	IC 4637 [6]	HII	= Nd 1600	N
396	200			—	N (DQ Her	Nd
					type)	N
437	—	y	a) IC 443 = CTB-20 [6,	NT	Obsolete	N
			8, 25]			
			b) Sharpl — 34 = CTB-47	NT	"	
			[25]			
561	—		NGC 3242 [6]	HII		N
668	+22		CTB-13 [8]	NT	Doubtful	SN?
683	25		HB-9 = CTB-14 [8]	NT	Obsolete	N
722	+5		Sharpl-188 = CTA-1	NT	"	N
			[23]			N
829	—		Abell-16 [23]	HII		N
837			a) IC 443 = CTB-20 [30]	NT	"	
			b) Sharpl — 275 =	HII		
			= CTB-21 [8]			
839	10			—	GK Per [28]	Nd
902	350:	ry		SNR	a) Sharpl-188	SN?
					= CTA-1 [23,	
					25, 31]	
					b) HB-3 [25]	
1006	220	v	a) Sco A [24]	NT		N
			b) PKS 1459-41 [32]	NT	See text	
1181	+185	by		SNR	HB — 3	SN?
			a) NGC 4637 [6]	HII		
1203	+10	bw	b) Sharpl-51 = CTB-37	ERS	[33]	N
			[8]			
			c) CTB-35 [34]	HII	[37]	
1230	105		3C 386 [31, 35, 36]	SNR	Comet [7, 41]	K
1430	26	b	Abell-16 [23]	HII		N
1431	116+	wy		—	N (DQ Her type)	N
1437	14		CTB-35 [19]	HII	[37]	N
1592	450			—	o Cet	M
1592	100		Cas A [9]	SNR	Doubtful	SN?
1600	22+	yr		—	Nd = N 393	Nd
1664	230			—		N

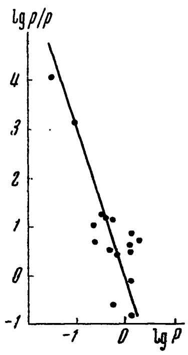

Fig. 3. The relation between age (∝ P/Ṗ) and period for pulsars.

5. NOVAE

It is particularly interesting to investigate recurrent novae. The unaided eye can observe novae within a radius of about 0.5 kpc, so that their distribution over the sky, apart from selection effects, is of trivial character. However, Hsi [6] has found places in the sky where several bright novae have appeared. If they were all different novae, then their spatial relationship was unusual, for no such tendency has otherwise been discerned in the space distribution of novae (but the ancient observations do cover more than 2000 years, and modern observations only about a century). Still, a recurrence of nova outbursts seems more probable. But Xi and Po's attempts [8] to associate the recurrent outbursts of 204 B.C. and A.D. 575 with AB Boötis, the outburst of 4 B.C. with V500 Aquilae, and the outburst of A.D. 1020 with RS Ophiuchi were naive (in our times these novae have exhibited outbursts

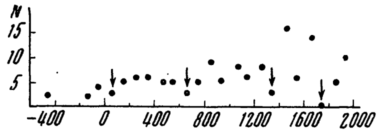

Fig. 4. Diagram of the number of cases per century where novae or supernovae brighter than $2^{m}.5$ at maximum were observed. The arrows designate centuries having a minimum number of such observations.

of low brightness and could not have been responsible for the far brighter flares of the past). Nor have our contemporaries found the "triple" outburst of A. D. 29, 911, and 980.

It is more justifiable to search for former outbursts of novae which have shown bright flares in our day, such as V603 Aquilae, GK Persei, and CP Puppis. Two outbursts have in fact been detected in the neighborhood of V603 Aql and one other in the neighborhood of GK Per [28], although in the vicinity of CP Pup, whose location is inconvenient for systematic observation, and in the neighborhood of novae fainter than these, no outbursts have been found.

The "cross" observations of the event of A.D. 125, which was recorded in China and also in the Roman legend about the death of Antinous, correspond accurately to the site of V603 Aql, and the outburst of 1612 was also associated, less definitely, with Antinous. If in accordance with the latter date we adopt a cycle of about 300 yr between outbursts, and if we regard V603 Aql as a typical nova, then we obtain several statistical inconsistencies: 1) The number of ordinary novae in the Galaxy becomes three times too low; 2) with so short a cycle, recurrent outbursts should be so numerous that repetitions would easily have been recorded; 3) a histogram for the number of observations of novae and supernovae brighter than $2^{m}.5$ at maximum from century to century (Fig. 4) has four minima, separated by an average interval of six centuries, so that the cycle between outbursts of typical novae could not be much shorter than 600 yr, for otherwise the distribution in Fig. 4 should be considerably more uniform. Accordingly the 1612 outburst does not appear to have been associated with V603 Aql.

In Table 4 we summarize the data on the recurrent novae known at the present time, as well as V841 Oph, for which a flare may be expected, judging from the amplitude, sometime during the 20th century. These data have been taken from the variable-star catalog [14], and for V841 Oph and V1017 Sgr, from [39]. The labels for each column are self-evident. The amplitude–cycle relation inferred from Table 4 has the form (Fig. 5)

$$A = 3.0 + 3.23 \lg C,$$

where C represents the cycle in years. Note the small scatter in the amplitudes of the short-cycle (ordinary) recurrent novae. It would be difficult on the basis of these stars to extend the relation to the region of typical novae (long-cycle recurrent outbursts).

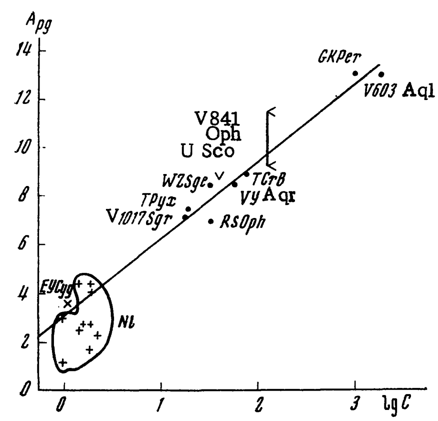

Fig. 5. The amplitude–cycle relation for recurrent novae.

TABLE 4

Nova	m: maximum	m: minimum	Amplitude A	Mean cycle P, yr	Nova	m: maximum	m: minimum	Amplitude A	Mean cycle P, yr
VY Aqr	$8^{m}0$	$16^{m}6$ p	$8^{m}6$	55.0	U Sco	8.8	[17.6 p	[8.8	36.6
T CrB	2.4	11.4 p	9.0	79.7	V 603 Aql	−1.1	10.8 p	12.9	1793
RS Oph	5.3	12.3 p	7.0	30	GK Per	0.2	13.0 p	12.8	1062
T Pyx	7.0	14.5 p	7.5	19.1	AD 393	0	?	?	1207
WZ Sge	7.0	15.5 p	8.5	32.6	V 841 Oph	4.2	13.1 v	8.9	
V 1017 Sgr	7.2	14.4 p	7.2	17.5					

On the whole, the recurrence of outbursts with a negligible mass loss per flare would not conflict with current ideas regarding novae, but recurrent novae having short cycles do exhibit certain spectroscopic peculiarities. These evidently are associated with the small flare amplitude and are not a necessary indication of recurrence. Among the short- and long-cycle novae, both fast and slow novae occur, as well as giants and dwarfs, judging from the luminosity at the minimum phase. The diagram for the relation between fading rate and amplitude (Fig. 6) suggests a probable connection between these parameters: The longer the cycle of the nova, the steeper the relation mentioned. But the material is insufficient to permit quantitative conclusions.

A study of the bright outbursts listed in Table 4 is rich in surprises. Thus, in 1600, at a fairly definite place in Scorpius, the outburst of 393 was evidently repeated (a fact not mentioned by Hsi [6], or Xi and Po [8]). The star was brighter than Antares (that is, $\approx 0^m$), and evidently the flare was a prolonged one (in 393 it was observed for 200 days). Thus the mean fading rate was $\approx 0^m.03$/day, and the cycle was ≈ 1200 yr (hence the amplitude was 13^m); this former nova should therefore be sought among 13^m stars.

In 396 and 1431, novae were observed with deep minima during the transition phase of the light curve and were far brighter than the familiar prototype of such novae, DQ Herculis. A detailed comparison with the light curve of DQ Her suggests that the maximum of the 396 outburst occurred during the rainy season (-2^m), and if we adopt an amplitude of 13^m, we should seek a star of 11^m at its site, perhaps with signs of being an eclipsing variable. We might mention that the region contains, for example, the little-studied variable GR Tauri, $10^m.5$, A9, P = 0.47 day. An analysis of this variable would be very important. A similar discussion can also be made for the 1431 outburst.

Was the outburst of 1006 studied by Goldstein [10] actually a supernova? As a supernova at b = 8°, it should have been brighter than -2^m and have been observable for 10 months. Comparisons of its brightness with the half-moon (-10^m or -8^m) are not realistic, as the phenomenon was not reported to have been visible in the daytime for four to eight months. The maximum brightness of the outburst was described by the following estimates: April 28, bluish white; May 1, like Mars ($-1^m.8$); May 6, like Venus or brighter, with objects casting shadows ($-3^m.5$); and by the end of May, again like Mars. If the maximum brightness was $-3^m.5$, the distance to the supernova would have been 10 kpc and the height above the galactic plane 1.5 kpc. In order to interpret the faintness of the radio source that may possibly be identified with the 1006 supernova, one must resort to conjectures [40]. On the other hand, if the outburst was merely a nova, then an eclipsing variable of $9\text{-}10^m$ should have been left behind. According to Goldstein's position ($15^h40^m \pm 10^m$, $-44°.4 \pm 2°$, 1900), the variable IR Normae is nearby ($15^h41^m58^s$, $-43°47'$, 1900; $9.0\text{-}9^m.5$, A3; HD 141080). An examination of its resemblance to an old nova could prove very interesting, as it would be the closest and brightest object of that type.

Several outbursts in the polar region of the sky are poorly localized because of the uncertainty of directions. But even here there are opportunities for analysis. For example, the 369 outburst was seen for 140 days, but no claim had been made that it was visible in the daytime, nor were there comparisons with the brightness of the planets. Hence it would have been no brighter than 0^m, and according to Table 1 it should have been a fast nova.

One other curious fact is an observation on 1592 November 28, in the constellation Cetus, of the celebrated variable Mira, four cycles before its discovery by Fabricius on 1596 August 13. Its average cycle is 332 ± 30 days, and its computed mean maximum would have occurred in mid-December, 1592, with an uncertainty of about one month. Mira was apparently observed during the dry season on the next cycle also, and its disappearance on the 450th day took place during the minimum phase.

There can be no question but that the discovery of new historical materials could permit further refinements in the classification of outbursts and of comets, and could afford a basis for searches for nova and supernova remnants.

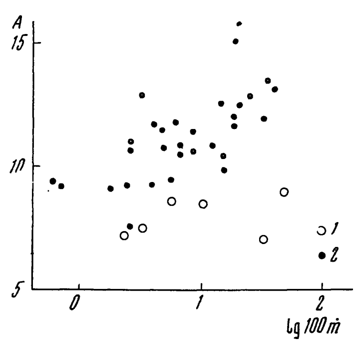

Fig. 6. Relation between amplitude and fading rate ($\alpha\dot{m}$) of a nova. 1) Recurrent-novae; 2) ordinary novae.

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