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THE *HUBBLE SPACE TELESCOPE*[1] SNAPSHOT SURVEY. III. FURTHER OBSERVATIONS IN SEARCH OF GRAVITATIONALLY LENSED QUASARS

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ABSTRACT

We present new *HST* Snapshot Survey observations of 163 high-luminosity $z > 1$ quasars, bringing the total number observed to date in the survey to 347 quasars. Each exposure was searched for evidence of gravitational lensing. Among the newly observed quasars, six have additional point sources at separations of $2''$–$6''$, but in all six cases ground-based data indicate that gravitational lensing is not involved. No point sources were found at smaller separations. Counting the one new lens candidate the survey has uncovered (1208+1011, described in previous papers) and the known lenses excluded from the sample, the observed frequency of lensing of quasars by galaxies is 5/351. This frequency is in the range predicted by models with a vanishing cosmological constant, but an order of magnitude lower than expected in models strongly dominated by a cosmological constant. The *HST* pointing accuracy under gyroscope control has improved and is now $14'' \pm 9''$ (mean and rms).

Subject headings: gravitational lensing — quasars: general

1. INTRODUCTION

The Snapshot Survey is a search for cases of gravitational lensing among intrinsically luminous, high-redshift quasars using the *Hubble Space Telescope* (*HST*) Planetary Camera (PC). Despite the spherical aberration of *HST*'s primary mirror, the sharp core of the point-spread function affords the high spatial resolution needed to discover the small-separation lenses predicted to exist by theoretical models. Bahcall et al. (1992a; hereafter Paper I) described in detail the objectives of the survey, its mode of operation, and the sample definition. Maoz et al. (1992b; hereafter Paper II) reported results for the first 184 quasars observed and compared the observed lensing frequency to theoretical predictions. The discovery of a possible sub-arcsecond lens system, 1208+1011, is reported in Maoz et al. (1992a), and the results of multicolor imaging of this system with *HST* is described in Bahcall et al. (1992b). Finding charts and astrometric positions for all objects in the survey are given in Schneider et al. (1992).

In the present paper, we report further results of the Snapshot Survey following successful observations of nearly all of the original quasar sample submitted to the Space Telescope Science Institute (STScI). Section 2 describes the observations. Results for some notable objects are presented in § 3. Section 4 summarizes the lensing statistics as currently derived from the Snapshot Survey and compares them with theoretical predictions.

2. OBSERVATIONS

This paper describes the Snapshot Survey observations carried out between 1991 September 27 and 1992 March 9 under *HST* programs 3156 to 3159 and program 4017. Together with the observations in Papers I and II, almost all of the original sample of 354 quasars has been observed. Observations of a supplementary sample of 163 quasars began in 1992 March and will be described in a future paper.

As in Paper II, each quasar was observed for 260 s with the F555W filter, usually with only gyroscope guiding in order to save the time required to acquire guide stars. At STScI's discretion some of the exposures were carried out using Fine Guidance Sensor "coarse track" guiding, rather than the usual gyroscope guiding. In addition, as part of the use of the Snapshot Survey for engineering tests and monitoring of the *HST* systems, STScI used "fine lock" guiding for a series of Snapshot exposures carried out on the first week of 1991 October. The fine-lock guided exposures were done in an experiment to increase the limiting guide-star magnitude during fine-lock guiding from ~13 mag to ~14 mag. In some of these attempts, the Fine Guidance Sensors lost and regained guide stars several times during the exposure. As a result, every point source in the resulting images appears as several unequal trails.

In Paper II, the *HST* pointing accuracy when under gyro controls was measured to be $20'' \pm 13''$. Because the entire PC field of view is only $70'' \times 70''$, some of the targeted quasars (15) in Paper II were outside the field. These 15 objects and two more such "missed" quasars from among the objects described here were returned to the pool of quasars from which STScI selects Snapshot observations. Thirteen of the "missed" quasars were reobserved, 12 successfully. They are identified as *HST* program 4017. The exposure time for objects from program 4017 was 230 s, rather than the usual 260 s.

The observations described in this paper are summarized in Table 1, which has the same format as Table 1 in Paper II. The first column gives the quasar name, excluding any prefixes to the 1950 coordinates. The second column gives another name for the object in cases where Veron-Cetty & Veron (1987) list the object under that name. The third column gives the UT date the object was observed by *HST* (day/month/year), and the fourth column gives the *HST* program number. The fifth column gives the PC CCD chip (5–8) on which the quasar actually appears and the quasar's central pixel coordinates,

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TABLE 1

SUMMARY OF OBSERVATIONS

Quasar	Other Name[1]	Observation Date	Program Number	PC position[2] of Quasar	Offset[3]	Trail[4] Rate	V^5_{obs}	V^6_{tab}	Z	$-Mv^7$	Comments
0007 − 353		13/11/91	3158	6(264,311)	2.1	0.8	18.7	18.04	2.03	25.6	
0021 − 1832	UM663	18/11/91	3158	7(222,142)	14.9	1.5	18.1	17.9	2.	25.7	
0027 + 0059	UM249	12/10/91	3158	7(510,385)	27.4	1.2	18.2	17.	1.46	26.	
0027 + 0149	UM247	12/10/91	3158	7(390,178)	17.3	1.2	17.7	17.	2.35	27.	D
0029 + 0722		23/10/91	3158	6(106,146)	8.4	1.2	17.9	18.4	3.27	26.2	
0033 + 0951	4C09.01	23/10/91	3158	6(304,308)	2.6	1.2	17.7	17.5	1.92	26.1	D
0034 − 3308		01/12/91	3158	6(95,580)	15.4	2.7	17.8	17.8	2.18	26.	
0038 − 3936		02/12/91	3158	6(176,110)	7.6	2.7	18.3	18.	2.37	26.	
0039 − 265		23/11/91	3158	6(359,437)	8.5	4.2	17.6	17.5	1.8	25.9	
0041 − 4023		24/11/91	3158	5(419,186)	27.	1.5	19.9	18.4	2.5	25.7	D
0043 + 0048	UM275	11/11/91	3158	6(62,27)	13.3	0.8	17.9	17.	2.15	26.8	D,K
0045 − 0119	UM278	22/11/91	3158	5(236,236)	18.9	1.5	18.4	18.	2.53	26.1	
0045 − 0341	UM667	01/12/91	3158	8(378,369)	35.1	2.3	18.9	18.6	3.14	25.9	
0046 − 315		18/11/91	3158	5(195,56)	19.3	1.9	18.4	17.7	2.72	26.5	D
0048 − 0119	UM281	22/11/91	3158	6(244,415)	6.6	0.8	17.5	16.	1.87	27.5	
0048 − 261		18/11/91	3158	8(429,55)	29.4	1.5	19.3	18.1	2.25	25.8	
0049 − 2820	CS73	18/11/91	3158	7(111,161)	17.	1.5	18.	18.1	2.27	25.8	D
0049 − 393		15/12/91	3158	6(412,218)	6.7	1.2	17.6	17.9	2.85	26.4	F
0052 − 410		16/12/91	3158	6(171,240)	4.1	0.8	17.8	18.1	2.06	25.6	
0055 + 0025	UM294	15/11/91	3158	7(56,552)	33.7	1.2	17.1	16.	1.92	27.6	F
0055 − 3844		15/12/91	3158	6(119,203)	6.7	1.5	18.3	18.4	2.35	25.6	
0056 − 3924		09/12/91	3158	6(372,248)	4.7	1.2	17.4	17.3	1.41	25.6	
0058 + 0155	PHL938	16/11/91	3158	7(190,552)	32.6	1.2	17.2	17.16	1.93	26.4	
0059 − 4110		09/12/91	3158	6(303,157)	4.9	1.2	17.7	18.	1.96	25.6	
0100 − 270		18/11/91	3158	8(186,149)	22.6	1.9	18.2	17.5	1.6	25.7	D,F
0100 − 3955		15/12/91	3158	6(342,281)	3.5	1.2	19.2	18.4	2.5	25.7	
0102 − 1902	UM669	06/12/91	3158	5(61,256)	11.4	1.9	18.4	18.3	3.03	26.1	F
0103 − 29		06/12/91	3158	7(44,393)	27.3	2.3	18.6	18.6	2.8	25.7	
0105 − 391		24/12/91	3158	6(198,45)	9.8	0.4	18.2	18.1	2.31	25.8	
0109 − 353		27/12/91	3158	6(64,285)	8.6	2.7	16.9	17.4	2.41	26.6	
0112 − 329		29/12/91	3158	6(139,228)	5.5	0	17.6	17.5	1.59	25.7	D
0115 − 0108	UM314	13/11/91	3158	8(283,180)	26.6	0.8	19.7	17.	2.19	26.8	D
0119 − 358		29/12/91	3158	6(72,242)	8.3	0	17.5	17.8	1.8	25.6	
0121 − 329		28/12/91	3158	6(202,235)	2.9	1.2	17.7	17.9	2.33	26.	
0122 − 00		13/11/91	3158	8(628,73)	37.7	0.8	16.8	16.7	1.07	25.7	
0122 − 380		28/12/91	3158	7(114,248)	20.4	1.9	17.	17.5	2.19	27.3	
0123 − 365		05/01/92	3158	6(221,342)	3.8	1.5	18.7	18.5	2.46	25.5	
0125 − 0029	UM327	13/11/91	3158	7(181,333)	23.3	2.3	18.	18.	2.07	25.7	
0125 − 400		04/01/92	3158	5(338,643)	28.4	1.9	17.5	17.1	1.39	25.8	D
0126 + 0301	UM104	17/11/91	3158	8(505,292)	37.1	1.5	17.9	17.	1.62	26.2	
0130 − 403		03/01/92	3158	7(229,141)	14.9	2.7	17.3	17.02	3.02	27.4	
0131 + 0058	UM338	03/01/92	3158	7(94,299)	22.8	2.7	18.	17.	1.37	25.9	
0135 − 0015	UM349	31/12/91	3158	6(108,218)	6.9	2.3	18.7	18.	2.15	25.8	D
0137 − 0153	UM356	31/12/91	3158	6(66,232)	8.6	1.9	18.	18.	2.24	25.9	
0138 − 381		31/12/91	3158	6(47,319)	9.6	1.2	17.9	17.6	2.87	26.7	
0140 − 306		02/01/92	3158	7(289,188)	16.9	1.5	17.8	18.5	3.13	26.	
0143 − 0101	UM368	12/01/92	3158	7(232,72)	11.9	1.2	19.3	18.5	3.16	26.	
0143 − 0135	UM366	30/12/91	3158	6(150,289)	5.	1.9	17.7	18.	3.14	26.5	
0145 + 0416	UM139	09/01/92	3158	6(50,130)	10.8	1.5	18.4	18.	2.03	25.7	
0146 + 0142	UM141	06/01/92	3158	missed	> 24						
0147 + 0146	UM142	06/01/92	3158	6(50,102)	11.	1.5	18.1	17.	1.39	25.9	
0148 − 0946	UM674	06/01/92	3158	7(282,342)	23.4	0.8	18.5	18.6	2.84	25.7	D
0148 − 516		07/03/92	4017	6(114,217)	6.7	1.5	17.9	18.2	2.53	25.9	D,II
0149 − 397		06/01/92	3158	7(582,187)	21.7	0.8	17.9	17.9	2.06	25.8	F
0150 − 0144	UM375	06/01/92	3158	6(547,78)	14.6	1.2	18.2	18.	2.02	25.7	
0150 − 2015	UM675	06/01/92	3158	7(216,401)	26.1	1.2	17.5	17.1	2.15	26.7	
0151 + 0448	PHL1222	06/01/92	3158	6(152,219)	5.1	1.5	17.9	17.63	1.91	25.9	A
0153 + 0430	UM148	13/11/91	3158	7(57,734)	41.3	2.7	17.7	17.	2.99	27.4	
0205 − 379		21/01/92	3159	7(138,209)	18.5	1.5	17.4	17.4	2.42	26.6	A

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TABLE 1—*Continued*

Quasar	Other Name[1]	Observation Date	Program Number	PC position[2] of Quasar	Offset[3]	Trail[4] Rate	V$_{obs}$[5]	V$_{tab}$[6]	Z	−Mv[7]	Comments
0206 + 0008	UM400	29/09/91	3159	6(253,269)	0.5	0.8g	17.3	17.	1.89	26.5	J
0207 + 0041	UM403	29/09/91	3159	6(285,256)	1.	1.2g	18.7	18.	2.19	25.8	J,D
0207 − 398		28/09/91	3159	6(241,253)	1.	g	17.2	17.15	2.81	27.1	
0213 + 0123	UM415	09/10/91	3159	6(250,242)	1.1	g	17.6	17.	1.44	26.	
0215 + 165		02/02/92	3159	6(251,344)	3.5	0	17.4	18.	1.9	25.3	
0216 + 0803		02/11/91	3159	6(247,244)	1.1	g	18.	18.1	2.99	26.3	L
0220 − 142		12/10/91	3159	6(239,223)	2.	g	18.7	18.5	2.43	25.5	
0222 − 415		02/02/92	3159	6(270,369)	4.6	1.2	17.6	17.7	2.	25.9	
0226 − 038		08/10/91	3159	6(242,259)	0.9	g	17.3	16.96	2.06	26.7	
0229 + 13		29/09/91	3159	6(258,258)	0.3	1.5g	17.9	17.71	2.07	26.	J
0232 − 04		01/10/91	3159	6(246,225)	1.8	g	16.4	16.46	1.43	26.5	
0239 − 1527	UM677	01/10/91	3159	6(233,263)	1.3	g	18.1	18.6	2.79	25.7	
0242 − 410		12/10/91	3159	6(239,250)	1.2	g	17.8	18.1	2.21	25.7	
0244 − 128		11/11/91	3159	6(232,260)	1.3	g	18.	17.1	2.2	26.7	
0249 + 1826	UM679	29/01/92	3159	6(185,96)	7.9	1.2	18.6	18.6	3.21	26.	D
0249 − 2212	UM678	27/09/91	3159	6(254,213)	2.2	g	17.7	18.4	3.2	26.1	
0254 − 404		02/02/92	3159	6(509,147)	11.7	0.4	17.2	17.4	2.29	26.5	
0301 − 0035		07/03/92	4017	7(105,45)	12.6	1.5	17.8	18.53	3.2	26.	II
0302 − 223		26/01/92	3159	6(167,150)	6.4	0.8	16.9	16.4	1.41	26.5	
0304 − 392		01/10/91	3159	6(255,231)	1.4	g	17.4	17.6	1.97	26.	
0308 − 1920	UM682	07/11/91	3159	6(248,220)	2.	g	17.9	18.3	2.76	26.	
0321 − 337		02/02/92	3159	8(344,123)	27.4	2.7	17.8	17.81	1.98	25.8	D
0324 − 407		26/01/92	3159	6(265,274)	0.5	0.8	17.7	17.6	3.06	26.9	D
0329 − 255		15/10/91	3159	6(250,214)	2.2	g	18.	17.51	2.69	26.7	
0329 − 385		02/02/92	3159	6(237,249)	1.3	0.4	17.4	16.92	2.42	27.1	
0338 − 394		02/02/92	3159	6(474,196)	9.5	1.2	17.6	18.4	2.59	25.7	D
0347 − 383		15/10/91	3159	6(248,209)	2.4	g	17.9	17.3	3.23	27.3	
0351 − 3749		15/10/91	3159	6(258,235)	1.2	g	18.5	17.8	3.01	26.6	
0352 − 2732	UM684	14/10/91	3159	6(247,250)	0.9	g	18.	18.	2.82	26.3	
0353 − 383		26/01/92	3159	7(167,50)	11.6	1.2	17.6	17.5	1.96	26.1	
0402 − 362		07/10/91	3159	6(220,241)	2.1	1.5g	17.	17.17	1.42	25.8	J
0420 − 388		01/10/91	3159	6(226,263)	1.6	g	17.	16.92	3.12	27.6	J
0447 − 395		01/10/91	3159	6(233,239)	1.7	g	17.3	18.1	1.98	25.5	
0448 − 392		30/09/91	3159	6(227,237)	1.9	g	16.7	16.46	1.29	26.3	
−−"−−		27/02/92	3159	6(69,347)	9.1	1.5	16.8	16.46	1.29	26.3	F
0759 + 341		20/01/92	3159	6(66,344)	9.2	1.5	18.5	18.5	2.44	25.5	
0808 + 28		04/10/91	3159	6(252,264)	0.5	0.4g	18.2	18.	1.91	25.5	J
0812 + 33*A*		14/10/91	3159	6(271,226)	1.6	g	19.1	18.	2.42	26.	
0827 + 24		14/10/91	3159	6(256,226)	1.6	g	17.6	17.7	2.06	26.	
0831 + 1248		03/11/91	3159	6(235,253)	1.3	g	18.1	17.8	2.75	26.5	
0836 + 1932	4C19.31	08/11/91	3159	8(633,180)	39.5	0.8	17.7	17.73	1.69	25.6	D,F
0837 + 4701	US1443	19/10/91	3159	6(244,253)	0.9	g	17.3	17.5	1.56	25.6	
0843 + 1339	4C13.39	25/01/92	3159	6(47,276)	9.3	1.2	17.6	17.8	1.88	25.7	
0846 + 1540		03/11/91	3159	6(247,255)	0.8	g	17.9	18.3	2.92	26.1	
0846 + 51*W*1		28/01/92	3159	6(56,629)	18.1	1.5	19.7	15.72	1.86	27.8	A
0847.6 + 156*A*		25/01/92	3159	6(237,314)	2.5	0.8	18.8	18.	2.66	26.2	
0848 + 1533	LB8755	02/11/91	3159	6(265,237)	1.1	g	17.8	17.93	2.01	25.7	
0848 + 1623	LB8775	29/10/91	3159	6(250,227)	1.6	g	17.7	17.9	1.93	25.7	
0851 + 1942	LB8863	25/01/92	3159	6(93,289)	7.4	1.2	17.9	18.07	2.21	25.8	
0854 + 1632		23/01/92	3159	8(223,75)	21.9	0.8	19.1	18.5	2.54	25.6	
0854 + 1907	LB8956	06/11/91	3159	6(240,251)	1.1	g	18.	17.7	1.89	25.8	
0859 − 14		21/01/92	3159	6(529,518)	15.8	5.4	17.0	16.6	1.33	26.2	
0903 + 1534		08/11/91	3159	6(258,247)	0.7	g	18.2	18.	2.66	26.2	
0903 + 175		08/11/91	3159	6(255,198)	1.7	g	18.2	17.3	2.77	27.	A
0907 + 381		02/11/91	3159	6(248,271)	0.7	g	17.7	18.	2.16	25.8	
0913 + 0715		24/10/91	3159	6(244,229)	1.7	g	18.2	17.1	2.77	27.2	
0932 + 367		01/11/91	3159	6(281,176)	3.8	g	18.3	18.5	2.84	25.8	
0932 + 501		08/11/91	3159	6(310,242)	2.2	g	17.	17.24	1.88	26.3	
0941 + 26		26/10/91	3159	6(561,170)	14.3	2.3		18.	2.91	26.4	A
0945 + 4337	US987	29/01/92	3159	6(138,87)	9.3	1.2	18.1	17.99	1.89	25.5	
0946 + 301		27/01/92	3159	6(297,288)	1.8	1.2	16.4	16.38	1.22	26.3	
0953 + 549		07/10/91	3159	6(253,222)	1.8	g	17.4	17.5	2.58	26.6	
0955 + 4717		11/10/91	3159	6(242,259)	0.9	g	17.4	17.8	2.48	26.3	
0955 + 4739	OK492	14/10/91	3159	6(255,252)	0.6	g	18.5	18.	1.87	25.5	
0956 + 1217		27/10/91	3159	6(250,254)	0.7	g	17.4	18.2	3.29	26.4	

TABLE 1—*Continued*

Quasar	Other Name[1]	Observation Date	Program Number	PC position[2] of Quasar	Offset[3]	Trail[4] Rate	V_{obs}[5]	V_{tab}[6]	Z	−Mv[7]	Comments
0957 + 557		06/02/92	3159	6(209,274)	2.4	1.9	17.7	17.5	2.1	26.2	
0958 + 5509	MARK132	03/11/91	3159	6(198,256)	2.8	g	16.4	16.	1.75	27.4	
1008 + 133		03/02/92	3159	6(217,353)	4.3	0.8	16.4	16.29	1.29	26.5	
1011 + 091		03/11/91	3159	6(249,223)	1.8	g	17.7	17.8	2.26	26.1	
1017 + 1055		09/03/92	4017	missed	> 24	0.8					II
1055 + 584		09/11/91	3156	8(200,177)	23.8	1.5	18.2	18.	2.24	25.9	D
1127 − 14		22/12/91	3156	7(270,95)	12.8	0.4	17.3	16.9	1.19	25.7	
1136 + 1214		27/11/91	3156	6(233,266)	1.3	g	18.1	17.6	2.89	26.8	A,II
−−"−−		07/03/92	4017	6(284,280)	1.2	0.8	17.6	17.6	2.89	26.8	II
1139 + 2833	US2828	07/03/92	4017	6(470,667)	19.5	1.5	17.2	17.2	1.61	26.	D,II
1150 − 1740	POX5B	22/12/91	3156	6(410,210)	6.7	0.8	18.	17.	2.21	26.8	
1203 − 1603	POX61	29/12/91	3156	7(46,55)	14.5	1.2	18.9	17.8	2.46	26.2	A
1208 + 1011		23/12/91	3156	6(249,237)	1.3	g	18.0	17.5	3.80	27.4	A,II
1209.1 + 10.7		06/03/92	4017	7(410,61)	13.	1.5	17.9	17.76	2.19	26.1	D,II
1211 + 33		08/03/92	3156	6(247,243)	1.1	g	17.7	17.	1.6	26.2	
1228.0 + 07.8		06/03/92	4017	6(47,300)	9.4	1.5	17.6	17.47	1.81	26.	II
1228.5 + 07.6		06/03/92	4017	6(524,327)	11.6	1.2	18.3	17.5	1.88	26.	D,II
1248 + 401		07/03/92	4017	6(513,361)	11.5	1.2	16.2	16.28	1.03	26.	II
1254 + 047		26/12/91	3156	5(77,309)	12.2	1.9	16.5	16.14	1.02	26.2	
1256 − 17		06/03/92	4017	7(246,30)	10.	1.5	17.0	17.8	2.06	25.9	C,II
1300 − 243		05/01/92	3156	6(575,122)	14.7	1.5	18.0	17.85	2.26	26.	D
1301 + 3042	W33211	08/11/91	3156	6(444,46)	12.2	0.8	18.	17.56	1.71	25.8	D
1309 + 3402	BSO8	08/03/92	4017	7(289,92)	12.7	0.8	17.3	17.43	1.75	25.9	II
1318 − 113		06/12/91	3156	6(373,184)	5.8	1.9	17.9	17.68	2.31	26.2	
1323 − 1042	POX188	31/01/92	3156	6(254,632)	15.9	1.5	17.9	17.	2.36	27.	
1337 + 1121		03/12/91	3156	7(664,45)	20.3	0.8	19.	18.2	2.92	26.2	
1346 − 036		14/12/91	3156	8(308,108)	25.7	0.4	17.3	17.27	2.35	26.7	
1356 + 5806	4C58.29	28/12/91	3156	6(266,344)	3.5	1.9	17.2	17.37	1.37	25.5	
1400 + 1126		04/12/91	3156	6(355,185)	5.2	g	18.5	18.9	3.17	25.6	F
1413 + 373		07/03/92	4017	6(401,532)	13.	2.3	17.9	18.	2.36	26.	D,II
1414 + 0859		09/12/91	3156	6(434,304)	7.6	0.8	19.1	18.6	2.7	25.6	
1423 + 1007		09/12/91	3156	6(175,371)	5.	1.5	19.8	18.4	2.78	25.9	A
1559 + 140		07/10/91	3156	missed	> 24	2.3					
−−"−−		07/03/92	4017	6(266,180)	3.6	1.5	18.3	18.	2.24	25.9	
1559 + 173		28/12/91	3156	6(113,645)	17.6	1.9	18.2	18.	1.94	25.6	
2116 − 358		19/10/91	3157	7(161,234)	19.3	1.5	17.5	17.35	2.34	26.6	
2144 − 362		24/10/91	3157	5(100,131)	14.2	1.2	18.2	17.8	2.08	25.9	D
2209 − 187*U*		10/10/91	3157	7(171,193)	17.5	0.8	17.6	17.8	2.09	25.9	
2225 − 0534	PHL5200	15/10/91	3157	5(53,433)	13.2	1.5	18.3	17.7	1.98	25.9	
2238 − 1730	UM657	06/11/91	3157	7(534,584)	35.8	1.5	17.5	17.2	1.36	25.7	
2244 − 2218	UM658	13/11/91	3157	5(99,48)	15.9	1.9	18.1	18.1	2.85	26.2	
2251 + 24		06/12/91	3157	7(345,288)	21.4	1.9	18.4	17.8	2.33	26.1	A
2304 − 423		16/12/91	3157	6(347,379)	6.2	0	17.4	17.6	2.61	26.6	
2329 − 0204	UM164	12/10/91	3157	7(232,188)	16.9	1.2	17.8	17.	1.9	26.5	D
2329 − 384		23/11/91	3157	6(285,64)	8.6	1.2	17.4	17.04	1.2	25.6	

[1] Listed for objects for which Veron-Cetty & Veron (1987) give a name that does not include the coordinates.

[2] Planetary Camera (PC) CCD number (5–8) and pixel coordinate with the origin at the PC apex.

[3] From the designated position on PC-6 (263,263), in arcseconds.

[4] In milliarcseconds s^{-1}. "g" designates a coarse-track or fine-lock guided exposure.

[5] V magnitude determined from this *HST* exposure, accurate to $\approx \pm 0.2$ mag.

[6] V magnitude tabulated by Veron-Cetty & Veron (1987).

[7] Assuming $H_0 = 100$ km s^{-1} Mpc^{-1}, $q_0 = 0.5$.

NOTES.—(A) See "Notes on Individual Objects." (C) Quasar image split between PC-6 and PC-7. (D) Quasar not verified to be in the field of view, but likely present based on brightness and/or expected absence of additional objects. (F) Possibly some point-spread function assymmetry at 0.1–0.2″ scales. (G) Identification uncertain. (I) Attempted observation also in Paper I. (II) Attempted observation also in Paper II. (J) Poor fine-lock guiding attempt; multiple/trailed images. (K) Quasar image split between PC-5 and PC-6. (L) Cosmic ray event 0″.3 southeast of the quasar image core.

where the pixel of each CCD that is nearest to the center of the mosaic has coordinates (1, 1). A "missed" entry in this column indicates that the quasar was nowhere in the PC field of view (three such cases). Column (6) gives the offset in arcseconds from the designated position on PC-6. Column (7) gives the drift rate in milli-arcseconds s^{-1} as measured from the length of the trail of the quasar or a star in the field of view. Exposures that were guided in the coarse-track mode or the fine-lock mode (i.e., are untrailed) are marked by a "g" in this column (48 such cases). In cases where the fine-lock experiments described above resulted in multiple trailed images, this column is marked with a "g" next to the trail rate. Column (8) gives the V magnitude measured for each object observed. This was calculated by summing the counts inside a 60 pixel (2″.6) radius, subtracting the median sky value determined in a 80–100 pixel annulus, and assuming one electron corresponds to $V = 31.4$ mag (Griffiths 1990). No attempt was made to remove cosmic-ray events. Columns (9) and (10) give the V magnitude and the redshift tabulated by Veron-Cetty & Veron (1987), while column (11) gives the absolute magnitude, calculated as described in Paper I. Column (12) gives coded comments, which are generally of a technical nature, for some of the objects. Objects for which the comments are of a more scientific nature are coded with an "A" and are further described in § 3, "Notes on Individual Objects."

Of the 131 gyroscope-guided exposures, three missed the target (0146+142, 1017+1055, and 1559+140). The success rate is improved relative to Paper II, where 15 out of 132 gyro-guided exposures definitely missed the target. An improved pointing performance is also suggested by the offsets in Table 1: The mean and rms pointing error of the gyro-guided observations is 14″ ± 9″, compared to 20″ ± 13″ measured in Paper II. The trailing rate under gyro-control is 1.4 ± 0.7 milli-arcseconds s^{-1}, similar to the 1.6 ± 1.0 milli-arcseconds s^{-1} found earlier in Paper II.

Note that the pointing errors that we have reported here and in previous papers are predominantly intrinsic *HST* pointing errors; the astrometric positions of all the Snapshot quasars were measured to better than 1″ accuracy prior to the observations.

Each *HST* exposure was examined in order to identify the field of view by means of at least two objects. In some of the exposures (27), only one object is in the PC field of view, but no objects other than the quasar are expected, and the magnitude of the single object is close to that expected if it were the quasar. These exposures are marked with a "D" in the "Comments" column in Table 1, and we will assume that they are successful observations of the quasar. For three objects (0759+341, 0854+1632, and 1337+1121), ground-based CCD images obtained at the Palomar 1.5 m telescope and at the Apache Point Observatory 1.8 m telescope allowed the identification of faint stars in the *HST* images that were not visible in our finding charts, confirming that the targeted quasar was in the field of view in the *HST* exposure. Each exposure was searched by eye for evidence of gravitational lensing. The reader is referred to Papers I and II for the detection limits of multiple images, which were estimated by simulations designed to reproduce the conditions of the actual exposures.

In the next section we make notes on those objects that merit further comment (marked "A" in Table 1).

3. NOTES ON INDIVIDUAL OBJECTS

0024+22.—In Paper II, we reported that this quasar has a point source 6″.3 to the northeast that is 3 mag fainter than the quasar. It was the only one out of six quasars in Papers I and II having companions with arcsecond separations that lacked ground-based data showing the companion to be a foreground star. We have since learned that Condon et al. (1981) observed this quasar with the VLA at 6 cm and found that the quasar is unresolved, with no additional radio components brighter than ∼0.5 mJy. If the companion were a lensed image of the quasar, it would have a flux ∼15 times fainter than the quasar, or ∼12 mJy. The companion to 0024+22 is therefore also probably a Galactic star.

0151+0448 (*PHL 1222*).—Meylan et al. (1990) discovered that this quasar has a 21.5 mag companion 3″.3 to the northeast having the spectrum of a quasar at a similar (but not identical) redshift. They concluded that this is a physical pair of quasars. The pair is clearly visible in the *HST* image, and no additional sources are seen.

0205−379.—The *HST* exposure shows a point source 2″.3 north of the quasar at p.a. −10°, 2.5 mag fainter than the quasar. S. Djorgovski (private communication) reports, based on CCD imaging with the Las Campanas Observatory 1 m telescope on 1989 November, that the companion is much redder than the quasar and is therefore most probably a foreground star.

0846+51W1.—This highly variable quasar, which during outbursts has a BL Lacertae spectrum, has been the subject of much study (Arp et al. 1979). Stickel, Fried, & Kuhr (1989) found through image decomposition that there is an intervening galaxy almost exactly on the line of sight to the quasar and that the integrated spectrum that is observed could be modeled by assuming a redshift of 0.235 for the galaxy. The detection of a galaxy on the line of sight supported previous suggestions (Ostriker & Vietri 1985; Nottale 1986; Schneider & Weiss 1987) that the large flux variations and spectral changes seen in the quasar were the result of selective amplification of the quasar power-law continuum through gravitational microlensing by the stars in a foreground galaxy. The *HST* image shows that the quasar has $V \approx 19.7$ and is therefore in the faint state where it spends most of the time. Its trailed image is unresolved. In an attempt to measure the surface brightness of the proposed foreground galaxy, we have subtracted at the quasar position a point-spread function determined by scaling the image of a 19 mag star 40″ southwest of the quasar. The quasar-subtracted image shows some residual flux in a 0″.5 region surrounding the quasar position, and possibly offset by 0″.1–0″.2 to the northeast. This residual could be the result of the uncertainties in the subtraction process. However, if real, it corresponds to a V surface brightness of about 18.3 mag arcsec^{-2}. At a redshift of 0.235 this is a surface luminosity of $\approx 400\, L_{\odot}\, \mathrm{pc}^{-2}$.

The critical surface density for gravitational macrolensing is

$$\Sigma_{\rm cr} = \frac{c^2}{4\pi G} \frac{D_{\rm OS}}{D_{\rm OL} D_{\rm LS}} = 1.0 \times 10^4 h_{100} M_{\odot}\, \mathrm{pc}^{-2} ,$$

for $\Omega = 1$, where $D_{\rm OS}$, $D_{\rm OL}$, and $D_{\rm LS}$ are the angular diameter distances from the observer to the source, the observer to the lens, and the lens to the source (e.g., Turner, Ostriker, & Gott 1984). Thus, for a plausible mass-to-light ratio, the surface mass density of the galaxy is subcritical, in accord with the absence of multiple images of the quasar.

0903+175.—Djorgovski & McCarthy (1985) noted that there is a foreground galaxy 4″ east of the quasar with a redshift of 0.127, $V \sim 18$, and strong Hα emission. The *HST* exposure shows the quasar and the galaxy clearly and also suggests the presence of a ∼23 mag point source in the center of the galaxy, 3″.7 from the quasar at p.a. 113°.5. This point source could be the nucleus of the galaxy. However, it is conceivable that it is a lensed image of the quasar, which escaped detection in the galaxy spectrum of Djorgovski & McCarthy because it was swamped by the light from the galaxy. Long-slit spectroscopy in good seeing conditions could answer this question.

0941+26.—There is a point source equally bright as the quasar 4″.3 to the southwest at p.a. 260°. Wills & Wills (1976) find, based on a spectrum, that it is a foreground star. S. Djorgovski (private communication) also finds, based on images taken in 1991 May at the Palomar, 1.5 m telescope, that the companion is redder than the quasar.

1136+1214.—In Paper II, we found, based on ground-based images of the field, that the *HST* exposure had missed the target. The present repeated attempt was successful. The quasar is unresolved.

1203−1603 (*POX 61*).—The *HST* image shows a point source with approximately the same brightness as the quasar 6".1 north at p.a. 10°. Kunth et al. (1981) previously noticed this point source and found it has a featureless spectrum. An additional faint ($V \sim 22$) point source appears between the quasar and the northern object, 2".3 from the quasar at p.a. −20°. Ground-based spectroscopy by Djorgovski et al. (1992) indicates that the northernmost object is an early-type star, and the fainter object in the middle has no emission lines. The central object is therefore also probably a foreground star.

1208+1011.—A gyroscope-guided exposure of this quasar taken in July 1991 showed that this quasar was resolved into two or three components and is an excellent candidate for gravitational lensing (Maoz et al. 1992a, b). A repeated coarse-track guided exposure taken on 1991 December 23 and reported here showed that only two components are present, with a separation of 0".47, while the third component suggested by the trailed image from July is an artifact of the point-spread function. The fainter of the two components is at a position angle of 165° relative to the brighter one, and the brightness ratio is ≈ 4, as found in the first exposure. The December data are described in more detail in Bahcall et al. (1992b), together with further PC images through four broad-band filters. These images confirm that only two point sources are visible. They also show that the brightness ratios of the two components are very similar in all four bands, from the blue to the near-infrared, thus supporting the lensing interpretation.

1423+1007.—There is a $V = 20$ mag point source 6".2 southwest of the quasar at p.a. −135°. S. Djorgovski (private communication) has found from broad-band imaging that the companion is redder than the quasar.

2251+24.—Crampton et al. (1989) obtained high-resolution ground-based images of this quasar and reported, based on image decomposition, that the quasar has a companion 2.8 mag fainter 0".8 to the south at p.a. 165°. The *HST* image of this quasar shows no evidence for such a component, which would have been well within our detection limits. Recently, Crampton, McClure, & Fletcher (1992) have also concluded, based on additional ground-based images, that a second component does not exist.

4. DISCUSSION AND SUMMARY

The observations described in this paper increase by 163 the number of Snapshot Survey quasars successfully observed and searched for evidence of lensing. Including the quasars from Papers I and II, excluding observations where the target was missed, and counting multiple observations of the same object only once, a total of 347 quasars has been observed. This is nearly all of the 354 objects which satisfied the sample criteria described in Paper I. The remaining seven quasars are either "missed" targets that have not yet been reobserved, or quasars that were omitted for scheduling reasons. Among the newly observed quasars described here, none shows evidence of multiple components at scales less than 2". For six quasars that have point sources at separations of 2"–6", ground-based data already exist indicating that these are foreground Galactic stars or, in one case (0151+0448), a physical quasar pair (see § 3, above). In Papers I and II, one promising lens candidate was found, the redshift $z = 3.8$ quasar 1208+1011. Among the quasars having companions within several arcseconds, all have ground-based data indicating the companions are foreground stars (see § 3). Assuming 1208+1011 is a lensed quasar, only one of the 347 quasars observed is lensed into multiple images within our detection limits. In computing the observed number of lenses one must account for previously known lenses which passed the sample criteria but were eliminated from the sample to avoid duplication of other *HST* imaging programs (see Papers I and II). There were five such lensed quasars in our original sample (0142−100, 0957+561, 1115+080, 1413+117, and 2237+0305).

The lensed quasar 2237 + 0305 constitutes a special case. The Veron catalog, from which our sample was derived, is a heterogeneous collection of quasars discovered by many different selection criteria and compiled from the literature. Use of such a sample for studying lensing statistics is, however, quite acceptable, as long as none of the quasars in the catalog was included in it based on their property of being lensed or unlensed (Kochanek 1991b, e.g., has argued that the catalogs may have some bias *against* the inclusion of moderate image-separation lensed quasars). To our knowledge, this is true of all quasars in our sample, which were discovered based on radio flux, blue excess, or broad emission lines, but one, 2237+0305. This object was discovered as a quasar only *because* it is lensed; it was found serendipitously in a survey of bright nearby spiral galaxies (Huchra et al. 1985). By looking for quasars that are projected very near the cores of known nearby galaxies, one almost guarantees that any quasar discovered will be lensed (although, of course, this is an inefficient way of finding quasars or lenses; Huchra's lens is almost certainly one of a kind). Including this lensed quasar in the sample would introduce a selection effect favoring lensed quasars that we do not account for in our calculation of the predicted lensing frequency, below. The only selection effect that favors lensed quasars which we do model is magnification bias. We therefore exclude 2237+0305 from the sample. Together with 1208+1011, the observed frequency of lensing by galaxies of quasars in our sample is then 5/351.

In Papers I and II we calculated the predicted frequency of lensing in our quasar sample under the approximation that gravitational lensing is being done by an unevolving population of galaxies modeled as singular isothermal spheres (Turner et al. 1984; Fukugita & Turner 1991). We repeat this calculation here for the larger sample formed by including all the observations up to 1992 March. The reader is referred to Papers I and II for the mathematical details. We defer a more sophisticated calculation, involving realistic galactic potentials and the detection limits of the survey (e.g., Kochanek 1991b), to a future paper which will include the additional quasars that are currently being observed.

Table 2 presents the results of the calculations of the predicted lensing frequency. The columns of the table give, for six different combinations of cosmological parameters, the expected number of lensed quasars and the probability of seeing the actually observed number of lensed quasars (last column in Table 2), given the model and assuming Poisson statistics. The parameter $\lambda \equiv \Lambda/(3H_0^2)$ is the dimensionless form of the cosmological constant.

In the first row of entries in Table 2, all the observed sample

TABLE 2

PREDICTED AND OBSERVED NUMBERS OF LENSED QUASARS AND MODEL PROBABILITIES

METHOD OF CALCULATION	$\lambda = 0$		$\lambda + \Omega_0 = 1$				OBSERVED
	$\Omega_0 = 0$	$\Omega_0 = 1$	$\Omega_0 = 0$	$\Omega_0 = 0.1$	$\Omega_0 = 0.15$	$\Omega_0 = 0.2$	
All redshifts .... (351 quasars)	4.4 (45%)	2.4 (10%)	36.3 (1×10^{-10})	14.3 (4×10^{-3})	11.3 (3%)	9.3 (10%)	5
Only $z < 2.5$ .... (241 quasars)	3.3 (36%)	1.8 (54%)	21.7 (1×10^{-7})	10.0 (3×10^{-3})	8.1 (1%)	6.7 (4%)	2

was included in the calculation. The magnitudes of the quasars, necessary for computing the magnification bias (see Paper II), were measured from the *HST* data (V_{obs} in Table 1). These magnitudes are generally more accurate than those tabulated by Veron-Cetty & Veron (1987), which are often only rough estimates based on photographic plates.

As in Paper II, we investigate in the second row of Table 2 the effect of excluding from the calculation and the observations quasars with $z > 2.5$, for which the luminosity function (and hence the magnification bias) is uncertain. Note that the observed number of lensed quasars is now only 2, since two of the four previously known lenses removed from the original sample have $z > 2.5$ (0142 − 100 and 1413 + 117), while the one new lens that we assume to have found, 1208 + 1011, has $z = 3.8$.

The results in Table 2 reinforce the conclusion stated in Papers I and II that the observed lensing frequency is consistent with the predictions for standard cosmologies, but, with our present statistics, an order of magnitude lower than expected in cosmologies strongly dominated by a cosmological constant (see Caroll, Press & Turner 1992, for a review on λ-dominated cosmologies).

To summarize, we have searched a total of 347 quasars for evidence of gravitational lensing, utilizing the high spatial resolution afforded by *HST*. Only one new gravitational lens candidate, the $z = 3.8$ quasar 1208 + 1011, has been found. Together with previously known gravitational lenses satisfying the sample selection criteria, the observed lensing frequency is 5/351, in agreement with the predictions of simple models, assuming standard cosmologies. Our continued monitoring of the *HST* performance under gyroscope control indicates an improvement in pointing accuracy, to 14″ ± 9″, and the stability of the drift rate, currently 1.4 ± 0.7 milliarcsec s^{-1}.

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