

# Rockets for Extrasolar X-rays

Jonathan McDowell  
Smithsonian Astrophysical Observatory

February 4, 2013

## Contents

<b>1</b>	<b>Introduction</b>	<b>3</b>
1.1	The rocket era . . . . .	3
1.2	Flight numbers . . . . .	3
1.3	Launch sites . . . . .	5
<b>2</b>	<b>US rocket programs</b>	<b>6</b>
2.1	NRL (1959,1963-1981) . . . . .	6
2.2	AS&E and SAO (1960-1981) . . . . .	8
2.3	Lockheed (1962-1993) . . . . .	10
2.4	Lawrence Radiation Lab (1965-75) . . . . .	12
2.5	Berkeley (1966-1978) . . . . .	15
2.6	MIT (1967-1985) . . . . .	17
2.7	Wisconsin (1967-present) . . . . .	19
2.8	GSFC (1968-present) . . . . .	21
2.9	Columbia (1968-87) . . . . .	23
2.10	Caltech (1969-78) . . . . .	25
2.11	Penn State (1986-1998) . . . . .	27
2.12	Colorado (1991-present) . . . . .	29
2.13	Other US programs . . . . .	31
<b>3</b>	<b>UK groups</b>	<b>33</b>
3.1	Leicester . . . . .	33
3.2	MSSL and Birmingham . . . . .	35
3.3	Bristol . . . . .	37
<b>4</b>	<b>Japan</b>	<b>39</b>
4.1	ISAS and Nagoya . . . . .	39
<b>5</b>	<b>European groups</b>	<b>41</b>
5.1	Bologna . . . . .	41
5.2	Roma . . . . .	43
5.3	LAS and CEA . . . . .	45
5.4	Leiden . . . . .	47
5.5	MPE . . . . .	49

<b>6</b>	<b>Other countries</b>	<b>51</b>
6.1	Australia . . . . .	51
6.2	Canada . . . . .	53
6.3	Argentina . . . . .	55
6.4	India . . . . .	57
6.5	South Korea; KARI program . . . . .	59

# 1 Introduction

## 1.1 The rocket era

In the pioneering days prior to the launch of the first successful X-ray satellite Uhuru in 1970, rockets and balloons were our only tools to study the X-ray sky, and only after the 1978-1981 mission of the Einstein Observatory made satellite observing widely available in the community did the rocket era fade away. Fifty years after the discovery of Sco X-1, suborbital sounding rockets and high-altitude balloons continue playing a useful albeit minor role in X-ray astronomy for the testing of new detector technology. In this paper I attempt a record for posterity of the suborbital X-ray astronomy flights; I will leave the story of balloons to other researchers.

A full history of the early rocket programs would include flights dedicated to solar physics; in particular the NRL and Leicester programs began with solar X-ray studies and were later extended to extrasolar X-ray astronomy. Many of those early flights carried mere film detectors whose level of exposure could be used to deduce X-ray flux; proportional counters came later. It is often difficult to distinguish solar UV, EUV and X-ray instruments with the available documentation and I will leave solar missions for a possible later paper.

Much of the narrative story of this era is given in the book by Hirsh (1983) but there is no existing accounting of individual flights. To remedy this, the main part of this paper consists of chronological tables of rocket launches led by each of the different research groups. Some flights were the result of cooperative work between multiple groups, and assignment of a rocket to a particular nominal lead group should not be taken to imply that the contributions of collaborators were unimportant. Numerous flights were unsuccessful due to either rocket or payload problems; and many of the successful instrument development flights were never mentioned in a journal publication. I have tried to give example citations for those flights which did generate published astronomical results.

The formal records of NASA and other agencies tend to give the official PI for the project, rather than the student who worked on the mission. It would be nice to add data connecting rockets with theses for a future edition of this document - so, Gentle Reader, if you see your 'thesis rocket' in this list, please let me know.

Details of launches were obtained from a large number of different sources, mostly unpublished internal memoranda from launch agencies and rocket manufacturers. Some agencies sent launch data to the World Data Center A (Rockets and Satellites) at NASA-Goddard, and these were summarized in a database known as the 'Rocket File'. (NSSDC 1985, 'WDC'). Unfortunately the file retained only a subset of the original data provided, which was not retained, and contained many incorrect dates and duplications (e.g. an NRL/NASA flight appearing with both NRL and NASA flight numbers exactly 24 hours apart). That dataset has been edited and substantially supplemented with literature and archival searches to create a more extensive list of suborbital launches which has been published online (McDowell 2002,2013) and references for individual launch dates and times may be found there. For NASA sounding rockets, lists issued by NASA's Wallops Island launch site are available (NASA Wallops 1985-2000, 'WISR', in printed form, and 2000-present, 'WISR-WWW', online).

## 1.2 Flight numbers

Each rocket has a flight number (sometimes more than one for cooperative projects) which may be used to distinguish it from other similar rockets; unfortunately these are often omitted in scientific publications about the results. This can be problematic when more than one rocket was launched on the same day.

The most common template for these flight numbers was established for the 1957-58 International Geophysical Year, and is of the form

AA11.222BB

where the first element 'AA' encodes the launching agency and its responsible organizational subelement; the second element '11' encodes the rocket type; the third element '222' is a flight number (in chronological order of project approval rather than launch), and the final 'BB' provides further metadata. For NASA flights this final element gives the sponsor type (D, U, C for Defense, University, Commercial) and the science

discipline (G for Galactic astronomy, S for solar physics, H after 1974 for High Energy Astrophysics). A detailed description of some of these codes is available in NSSDC (1972).

Most launches in the early rocket years used versions of the Aerobee, which had a small solid booster and a liquid-propellant sustainer stage, although the UK used its solid-fuel Skylark rocket. During the 1970s the Aerobee began to be phased out in favor of a Canadian relative of Skylark, the all-solid-propellant Black Brant and its derivatives.

### 1.3 Launch sites

As will be seen from the tables below, the White Sands Missile Range in New Mexico was by far the Northern Hemisphere's nexus of rocket X-ray astronomy, with Woomera in South Australia playing the corresponding role below the equator. I use the same launch site codes as in McDowell (2002-2013), with the relevant ones summarized here for convenience.

---

ANHU	Anhueng, Ch'ungch'ong Namdo, South Korea
CELPA	Centro de Ensayo y Lanzamiento de Proyectiles Autopropulsados, Chamical, La Rioja, Argentina
CERES	Centre d'Essais et de Recherches d'Engins Speciaux, Ile du Levant, France
CLBI	Centro de Lancamento da Barreira do Inferno, Natal, Rio Grande N, Brasil
CSG	Centre Spatial Guyanais, Kourou, French Guiana
EGL	Eglin AFB, Florida
ELAR	El Arenosillo, Huelva, Spain
ESR	ESRANGE, Kiruna, Sweden
FC	Churchill Research Range, Fort Churchill, Manitoba, Canada
HMG	Hammaguir, Algeria
JI	Johnston Island, Pacific Ocean
KASC	Kagoshima Space Center, Uchinoura, Kagoshima, Japan
KAU	Kauai Test Facility, Barking Sands, Kauai, Hawaii
RES	Resolute Bay, Cornwallis I., Nunavut, Canada
SDQ	Salto Di Quirra, Perdas de Fogu, Sardinia
SHAR	Sriharikota Range, Sriharikota, India
SUIST	South Uist Range, Scotland
TERLS	Thumba Equatorial Rocket Launch Station, Trivandrum, Kerala, India
TTR	Tonopah Test Range, Nevada
WI	Wallops Island, Virginia
WOO	Woomera Range, South Australia
WS	White Sands Missile Range, New Mexico

---

## 2 US rocket programs

### 2.1 NRL (1959,1963-1981)

NRL attempted to detect extrasolar X-rays as early as 1959, but the detector was not sensitive enough. After the Giacconi et. al. discovery of Sco X-1, NRL's Herb Friedman directed grad student Stuart Bowyer to build an X-ray detector. The first flight was in Apr 1963, with part of the payload also given over to UV astronomy.

Most of the NRL flight IDs are from WDC, as noted in the table, or from Wallace (1973; W73).

Table 1: NRL extrasolar X-ray astronomy program

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
NRL NN3.23F	1959 Jul 21	NRL		WS	Aerobee Hi	197	Tousey,Purcell		JGR65,370	WDC
NRL NB3.130	1963 Apr 30	NRL		WS	Aerobee 150	197	Bowyer	Sco X-1	Nature201,1307	WDC
NRL NB3.147	1964 Jun 16	NRL		WS	Aerobee 150	127	Bowyer		Sci147,394	WDC
NRL NB3.164	1964 Jul 7	NRL		WS	Aerobee 150	295	Bowyer,Byram	Crab		WDC
NRL NB3.161	1964 Nov 25	NRL		WS	Aerobee 150	200	Bowyer,Byram		Sci147,394	WDC
NRL NB3.176	1965 Apr 27	NRL		WS	Aerobee 150	193	Byram		Sci152,66	WDC
NRL NB3.184	1965 Oct 5	NRL		WS	Aerobee 150	171	Byram,Friedman		WDC	WDC
NRL NB3.194	1966 Dec 14	NRL	? or UV	WS	Aerobee 150	177	Byram			WDC
NRL NB3.177	1967 May 16	NRL		WS	Aerobee 150	148	Byram			WDC
NRL NB3.196	1967 Sep 8	NRL		WS	Aerobee 150	200?	Meekins,Henry	Sco X-1	ApJ153,L199	WDC
NRL NB3.204	1968 Apr 7	NRL	Scan	WS	Aerobee 150	158	Byram	Cen A	Sci169,366	WDC
NRL NB3.210	1969 Mar 14	NRL		WS	Aerobee 150	154	Fritz	Crab PSR	Nature231,107	WDC
NRL NB3.205	1969 Mar 28	NRL		WS	Aerobee 150	161	Chubb,Byram	M87	Nature 229,544	WDC
NRL NB3.237	1970 Mar 1	NRL		WS	Aerobee 150	210	Fritz		ApJ177,629	WDC
NRL NB3.211	1970 May 25	NRL	? or UV	WS	Aerobee 150	200?	Byram			WDC
NRL NB3.245	1971 Mar 27	NRL	? or UV	WS	Aerobee 150	200?	Byram			W73
NRL NB4.244	1971 Nov 11	NRL		WS	Aerobee 170	200?	Fritz			W73
NRL NB3.254	1972 Apr 1	NRL	? or UV	WS	Aerobee 150	200?	Byram			W73
NASA 13.091DG	1973 Apr 10	NRL		WS	Aerobee 170	198	Fritz	Her X-1	ApJ199,L101	WDC
NASA 26.025DG	1974 Sep 7	NRL		WS	Aerobee 200A	250?	Fritz	Cyg	ApJ222,L13	WISR
NRL NB24.275	1974 Dec 28	NRL		WS	Aries	10	?	Crab (fail)	ESA SP-152,189	WDC
NASA 26.047DH	1975 Oct 3	NRL		WS	Aerobee 200A	212	Fritz			WISR
NASA 26.049DH	1976 Apr 21	NRL		WS	Aerobee 200A	202	Fritz		ApJ222,L95	WISR
NRL NB24.276	1977 Jan 26	NRL/MPE	Astro 8-1	WS	Aries	347	Zimmerman		ApJ234,415	ESA SP-135
NASA 26.052DH	1977 Feb 15	NRL		WOO	Aerobee 200A	189	Fritz			WDC
NASA 26.053DH	1977 Feb 23	NRL		WOO	Aerobee 200A	184	Fritz			WDC
NASA 27.035DH	1980 Sep 26	NRL		WS	Black Brant 8C	300	Fritz			WDC
NASA 27.009DH	1981 Nov 17	NRL		WS	Black Brant 8B	253	Fritz			WISR

## 2.2 AS&E and SAO (1960-1981)

American Science and Engineering (AS&E) was a company based in Cambridge, Massachusetts, whose X-ray astronomy group was led by Riccardo Giacconi. Their early work was carried out in collaboration with Bruno Rossi of MIT, and the first flights were done as part of the US Air Force Cambridge Research Laboratories rocket program with the help of AFCRL's John Salisbury, before continuing within the NASA program. After the flight of Uhuru the group left AS&E and formed what is now the High Energy Astrophysics Division of the Smithsonian Astrophysical Observatory (SAO).

Prior to the Sco X-1 discovery flight several failed flights were carried out.

The 1960 Nike Asp flight from Florida's Eglin Air Force Base, a failure, would have looked for lunar X-rays. The Oct 1961 flight was the first search for extrasolar X-rays, but the detector doors failed to open. In 1962 AB3.352 discovered the first extrasolar X-ray source, Sco X-1.

The AFCRL history confirms that the 1960 Sep flight was the first (failed) X-ray flight and suggests that the WDCRF data showing a 1961 Oct 14 flight is a mistake for the 1961 Oct 24/25 mission, which also partially failed.

The SAO flight program in the 1970s included a joint flight with the Frascati group. AFCRL and NASA flight IDs are from WDC.



Table 2: AS&E and SAO astronomy program

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target
AFRL A8.243	1960 Jun 27	AS&E	XR counter	EGL	Nike Asp	0?	Giacconi	Lunar X (fail)
AFRL A8.350	1960 Sep 27	AS&E	XR counter	EGL	Nike Asp	233	Giacconi	
AFRL AB3.351	1961 Oct 25	AS&E	XR counter	WS	Aerobee 150	232	Giacconi	
AFRL AB3.352	1962 Jun 19	AS&E	XR counter	WS	Aerobee 150	224	Giacconi	Sco X-1
AFRL AC3.353	1962 Oct 13	AS&E	XR counter	WS	Aerobee 150	317	Giacconi	PRL9,439
AFRL AC3.354	1963 Jun 11	AS&E	XR counter	WS	Aerobee 150	302	Giacconi	PRL11,530
NASA 4.122GG	1964 Aug 29	AS&E/MIT		WS	Aerobee 150	179	Giacconi,Oda	PRL11,530
NASA 4.123CG	1964 Oct 27	AS&E/MIT		WS	Aerobee 150	192	Giacconi,Oda	Nat204,981
NASA 4.147CG	1965 Sep 22	AS&E		WS	Aerobee 150	199	Giacconi	Nat207,572
NASA 4.148CG	1966 Mar 8	AS&E/MIT	Collimator	WS	Aerobee 150	165	Giacconi,Oda	
NASA 4.149CG	1966 Oct 12	AS&E		WS	Aerobee 150	148	Gursky	ApJ146,310
NASA 4.228GG	1967 Nov 20	AS&E		WS	Aerobee 150	144	Giacconi	ApJ150,L75/L85
NASA 4.261GG	1968 Feb 2	AS&E		WS	Aerobee 150	139	Giacconi	
NASA 4.264CG	1968 Dec 7	AS&E		WS	Aerobee 150	149	Gorenstein	
NASA 4.262CG	1970 Feb 7	AS&E		WS	Aerobee 150	200?	Gursky,Vaiana	
NASA 13.012CG	1970 Jun 27	AS&E	1D XRT	WS	Aerobee 170	175	Gorenstein	Cyg Loop
NASA 13.026CG	1970 Sep 28	AS&E		WS	Aerobee 170	200?	Kellogg	Sci172,369
NASA 13.027CG	1972 Apr 1	AS&E	Focussing Collector	WS	Aerobee 170	193	Gorenstein	Vela
NASA 13.030CG	1972 Aug 5	AS&E	Stellar Telescope	WS	Aerobee 170	200?	Kellogg	Cyg X-1/ Sco-X-1
NASA 17.015UG	1975 Mar 15	SAO	XRT/IPC	WS	Aerobee 350	214	Gorenstein	Virgo
NASA 17.016UH	1975 Dec 6	SAO	XRT/IPC	WS	Aerobee 350	221	Gorenstein	Per
NASA 17.017UH	1976 Jun 17	SAO	XRT/IPC	WS	Aerobee 350	232	Gorenstein	Coma,Eta Boo
NASA 27.008UH	1977 Jun 9	SAO	XRT/IPC	WS	Black Brant 8C	205	Gorenstein	Eta Boo
NASA 27.031UH	1977 Jul 27	SAO	XRT/IPC	WS	Black Brant 8C	203	Gorenstein	Vega
NASA 26.065IH-UH	1977 Oct 2	SAO/FRASC		WS	Aerobee 200A	198	Gorenstein/Spada	
NASA 25.012UH	1978 Jan 10	SAO	XTM/HRI	WS	Astrobee F	196	Murray	
NASA 25.037UH	1978 Jul 20	SAO	XTM/HRI	WS	Astrobee F	190	Murray	Sco X-1
NASA 25.047UH	1980 Mar 22	SAO	Si(Li)	WS	Astrobee F	217	Schnopper	SXB/NPS
NASA 27.058UH	1981 May 4	SAO	Si(Li)	WS	Black Brant 8C	294	Delvaile,Schnopper	SXB/NPS

### **2.3 Lockheed (1962-1993)**

Philip Fisher of the Lockheed Palo Alto Research Laboratories group carried out some of the first X-ray flights. Later on the group under the leadership of Loren Acton concentrated on solar EUV and X-ray studies. NASA flight IDs are from WDC.

Table 3: LPARL extrasolar astronomy rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref
NASA 4.069CG	1962 Sep 30	LPARL		WI	Aerobee 150A	171	Fisher		Nature204,982
NASA 4.070CG	1963 Mar 16	LPARL		WI	Aerobee 150A	201	Fisher		
NASA 4.120CG	1964 Oct 2	LPARL		WS	Aerobee 150	144	Fisher		ApJ143,203
NASA 4.121CG	1965 Oct 1	LPARL	1D XRT	WS	Aerobee 150	148	Fisher		IEEE-NS13-580
NASA 4.168CS	1967 Apr 5	LPARL		WS	Aerobee 150	Weldon,Acton	Solar, other?		
NASA 4.187CG	1967 Aug 26	LPARL		WS	Aerobee 150	125	Fisher		
NASA 17.008CG	1971 Jun 24	LPARL	XRT	WS	Aerobee 350	300?	Acton, Catura	M87	ApJ190,521
NASA 17.012CG	1974 Apr 6	LPARL	XRT	WS	Aerobee 350	238	Catura, Acton	Puppis	ApJ207,L163
NASA 17.013CG	1975 Feb 3	LPARL	XRT	WS	Aerobee 350	253	Catura	ApJ202,L5	
NASA 24.003CH	1980 Sep 20	LPARL	LCXT	WS	Aries	309	Catura		
NASA 24.011CH	1991 May 20	LPARL	SXT/XOGS	WS	Aries	300?	Catura		
NASA 24.017CH	1993 Aug 28	LPARL	SXT/XOGS	WS	Aries	8	Catura		Failed

## 2.4 Lawrence Radiation Lab (1965-75)

G. Chodil and Fred Seward at Lawrence Radiation Laboratory (LRL), after 1971 Lawrence Livermore National Lab (LLNL), began an extensive X-ray astronomy flight program in 1965.

Sandia launched LRL rockets from Kauai and Johnston Island in the Pacific and Tonopah Test Range in Nevada; the Naval Material Command supported Hydra-Iris launches in mid-ocean with the T-AGM-8 USNS Wheeling in the Pacific and the AVM-1 USS Norton Sound in the Atlantic.

A large proportional counter array was launched as a secondary payload on a Thor missile flight from Johnston Island in 1970, but the payload failed to operate correctly.

Launch IDs and launch dates for these flights were obtained from unpublished documents kindly provided by Fred Seward (Seward, 2010).

Table 4: LRL rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref
Sandia 152-80	1965 Jun 12	LRL	BOX-1	KAU	HJ Nike Nike	172	Chodil	Sco X-1	PRL15,605
-	1965 Oct 28	LRL	BOX-2	T-AGM-8	Hydra-Iris	194	Grader	Sco X-1	Sci152,1499
Sandia 152-83	1965 Nov 22	LRL	BOX-3	KAU	Nike Tomahawk	10			(Fail)
Sandia 152-81	1966 May 11	LRL	ROX-1	KAU	HJ Nike Nike	80			(Fail)
-	1966 May 31	LRL	BOX-4	T-AGM-8	Hydra-Iris	188			
Sandia 152-54	1966 Jul 28	LRL	BOX-6	KAU	Nike Tomahawk	173	Chodil		ApJ150,57
Sandia 152-99	1966 Sep 20	LRL	BOX-7	JI	Nike Tomahawk	168	Chodil,Seward	XRB	ApJ150,845
Sandia 152-98	1966 Sep 22	LRL	AXE-1	JI	Nike Tomahawk	160	Seward,Toor		ApJ150,845
-	1966 Oct 30	LRL	BOX-5	T-AGM-8	Hydra-Iris	12			(Fail)
Sandia 152-56	1967 May 18	LRL	BOX-10	KAU	Nike Tomahawk	172	Chodil		ApJ154,645
Sandia 152-97	1967 May 20	LRL	BOX-9	KAU	Nike Tomahawk	22	Chodil		ApJ154,645
Sandia 152-88	1967 Sep 7	LRL	BOX-8a	TTR	Nike Tomahawk	187			
Sandia 152-87	1967 Sep 29	LRL	BOX-12	JI	Nike Tomahawk	168	Chodil		ApJ154,645
Sandia 152-106	1967 Oct 2	LRL	BOX-6	JI	Nike Tomahawk	168			
Sandia 152-110	1967 Dec 6	LRL	BOX-13	TTR	Tomahawk	120			
Sandia 152-114	1968 May 9	LRL	BOX-14	KAU	Nike Tomahawk	178	Harri,Seward		AJS73,184
Sandia 152-111	1968 May 15	LRL	BOX-8b	KAU	Nike Tomahawk	162	Seward,Hill		
Sandia 152-108	1968 May 19	LRL	ACS-1	KAU	Nike Tomahawk	147	Mark		AJS73,184
Sandia 152-?	1968 Aug 23	LRL	AXE-2	TTR	Sandhawk	187			
Sandia 281-10	1968 Oct 29	LRL	ACS-3	JI	Terrier Sandhawk	320			
-	1968 Nov 3	LRL	BOX-15	T-AGM-8	Hydra-Iris	227			
Sandia 281-11	1968 Nov 7	LRL	ACS-2	JI	Terrier Sandhawk	320			
Sandia 152-127	1969 May 17	LRL	BOX-8c	KAU	Nike Tomahawk	159			
Sandia 152-126	1969 May 24	LRL	BOX-16	KAU	Terrier Tomahawk	398	Seward,Hill		
Sandia 152-137	1970 Jan 13	LRL	ROX-3	TTR	Nike Tomahawk	180			
Sandia 152-136	1970 May 5	LRL	ACS-1B	KAU	Nike Tomahawk	144			
Sandia 281-14	1970 May 13	LRL	ACS-4	KAU	Terrier Sandhawk	306	Hill		ApJ171,519
Thor 271	1970 Sep 24	LRL	SXRE	JI	Thor DSV-2J	500	Seward		
Sandia 152-171	1971 May 25	LRL	ACS-1D	KAU	Nike Tomahawk	141			
Sandia 281-19?	1971 May 26	LRL	ACS-4B	KAU	Terrier Sandhawk	300	Seward		
Sandia 281-?	1971 Oct 23	LLNL	ACS-4C	KAU	Terrier Sandhawk	303			
-	1971 Nov 18	LLNL	BOX-17	AVM-1	Hydra Sandhawk	267			
Sandia 281-?	1972 May 20	LLNL	ACS-7A	KAU	Terrier Tomahawk	300			
Sandia 152-185	1972 Jun 2	LLNL	ACS-1C	TTR	Nike Tomahawk	175	Seward		

Sandia 281-29	1972 Oct 20	LLNL	ACS-4D	KAU	Terrier Sandhawk	310
Sandia 152-197	1972 Oct 21	LLNL	ACS-7B	KAU	Terrier Tomahawk	300
-	1973 Apr 26	LLNL	BOX-18	T-AGM-8	Hydra Sandhawk	262
Sandia 281-32	1973 Jun 23	LLNL	ACS-4E/9	KAU	Terrier Sandhawk	297
Sandia 152-202	1974 Jan 26	LLNL	ACS-7C	KAU	Terrier Tomahawk	0
Sandia 428-?	1974 Feb 7	LLNL	ACS-10	KAU	Strypi IIR	5
Sandia 281-?	1974 Jun 30	LLNL	ACS-4F	KAU	Terrier Sandhawk	305
Sandia 428-034	1974 Nov 3	LLNL	ACS-11	KAU	Strypi IIR	255
Sandia 152-?	1975 Sep 3	LLNL	ACS-1D	TTR	Nike Tomahawk	270?
Sandia 152-?	1975 Sep 23	LLNL	ACS-1E	TTR	Nike Tomahawk	270?

(Fail)  
(Fail)

Toor  
Hill, Seward

## **2.5 Berkeley (1966-1978)**

Stu Bowyer moved from NRL to Catholic University and then to the University of California, Berkeley, and flew several X-ray payloads before specializing in EUV astronomy. Two were NASA flights and one used a Kitt Peak rocket. Flight IDs are from WDC.

Table 5: UCB rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref
NASA 4.182UG	1966 Dec 13	Cath. U		CLBI	Aerobee 150	169	Bowyer	XRBB	Nature 217,32
NASA 4.184UG-IG	1969 Jun 14	UCB		CLBI	Aerobee 150	200?	Bowyer	Survey	ApJ174,529
NASA 4.183UG	1969 Jun 22	UCB		CLBI	Aerobee 150	165	Bowyer		
KP3.42	1973 Jan 12	UCB		WS	Aerobee 170	229	Bowyer, Margon	3C273/M87/N4151	ApJ197,25
NASA 21.016UG	1973 Feb 10	UCB		WS	Black Brant 5C	216	Bowyer	M31	ApJ190,285
NASA 21.017UG	1974 Feb 4	UCB		WS	Black Brant 5C	187	Bowyer, Cruddace	Alpha Boo	ApJ202,L9
NASA 21.031UG	1974 Nov 25	UCB		WS	Black Brant 5C	184	Bowyer, Cruddace	Alpha CMi	ApJ202,L9
NASA 27.026UH	1978 Apr 11	UCB		WS	Black Brant 8C	303	Bowyer		



## **2.6 MIT (1967-1985)**

Hale Bradt led the MIT rocket program after three initial experiments by Oda done as part of the AS&E flights. The NASA flight IDS are from WDC and WISR.

Table 6: MIT rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref
NASA 4.190UG	1967 Jul 8	MIT	MIT-4	WS	Aerobee 150	142	Bradt	GC Survey I	
NASA 4.225UG	1968 Jul 27	MIT	MIT-5	WS	Aerobee 150	135	Bradt	GC Survey II	
NASA 4.278UG	1969 Apr 27	MIT	MIT-6	WS	Aerobee 150	158	Bradt		Nature 222,728
NASA 4.279UG	1969 Oct 3	MIT	MIT-7	WS	Aerobee 150M1	158	Bradt	GC Survey III	
NASA 13.006UG	1970 May 8	MIT	MIT-8	WS	Aerobee 170	146	Bradt		
NASA 13.036UG	1971 May 1	MIT	MIT-9	WS	Aerobee 170	200?	Bradt		
NASA 13.037UG	1972 May 19	MIT	BCP 1	WS	Aerobee 170	200?	Bradt	ApJ178,L115	Cyg-Nor
NASA 13.038UG	1972 Aug 10	MIT	LATP 1	WS	Aerobee 170	200?	Bradt	Her X-1	(fail)
NASA 13.039UG	1972 Sep 16	MIT	LATP 2	WS	Aerobee 170	200?	Bradt	Her X-1	ApJ182,L25
NASA 13.040UG	1973 Mar 30	MIT	BCP 2 (Baez Con.)	WS	Aerobee 170	184	Bradt	Cyg	ApJ186,L115
NASA 13.104UG	1973 Nov 6	MIT	BCP 3	WOO	Aerobee 170	167	Bradt	LMC	ApJ 196,L15
NASA 13.105UG	1973 Nov 9	MIT	LATP 3	WOO	Aerobee 170	175	Bradt	Vela	ApJ 190,L113
NASA 13.034UG	1974 Nov 16	MIT	UBP 1	WS	Aerobee 170A	166	Rappaport	XRBB	ApJ205,226
NASA 13.050UH	1975 Aug 16	MIT	UBP 2	WS	Aerobee 170	172	Bradt	Soft XRBB	(fail)
NASA 13.108UH	1975 Oct 18	MIT	UBP 3	WS	Aerobee 170	184	Bradt	Soft XRBB	ApJ211,215
NASA 25.021UH	1977 Jul 27	MIT/LUX	WIXT 1 (Wolter Tel)	WS	Astrobeer F	190	Rappaport	Cyg Loop	ApJ227,285
NASA 25.023UH	1978 Mar 8	MIT/LUX	WIXT 2	WS	Astrobeer F	190	Rappaport	Pup A	ApJ228,L99
NASA 25.040UH	1981 Oct 17	MIT/LUX	WFSXC 1	WS	Astrobeer F	200?	Rappaport	(fail)	
NASA 21.069UH	1982 Nov 1	MIT/LUX	WFSXC 2	WS	Black Brant VC	210	Rappaport	(fail)	
NASA 21.070UH	1985 Mar 18	MIT/LUX	WFSXC 3	WS	Black Brant VC	213	Rappaport	(data not useful)	

## 2.7 Wisconsin (1967-present)

A small X-ray package was carried on Art Code's stellar UV payload in 1967, but the main Wisconsin X-ray program began in 1969 under Kraushaar. The program focussed on soft X-ray measurements of the interstellar medium.

In 1995 a series of joint NASA-Goddard/Wisconsin flights began to test the X-ray Quantum Calorimeter, developed for flights on the Astro-E/H series of Japanese X-ray satellites.

The Aerobee IV payload last flown in 1980 was reflown with modifications in 2012 by M. Galeazzi of the University of Miami.

Table 7: Wisconsin rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref
NASA 4.172UG	1967 Aug 4	UWI		WS	Aerobee 150	130	Code,Bless		
NASA 18.025UG	1969 Jan 28	UWI	Soft XR	WS	Nike Tomahawk	224	Kraushaar		(Pressure failed)
NASA 18.032UG	1969 Jul 16	UWI		WS	Nike Tomahawk	209	Kraushaar		
NASA 4.175UG	1969 Dec 4	UWI		WS	Aerobee 150	200?	Bunner		
NASA 4.301UG	1970 May 29	UWI		WOO	Aerobee 150	200?	Kraushaar		
NASA 4.302UG	1970 Jun 2	UWI		WOO	Aerobee 150	200?	Kraushaar		
NASA 13.021UG	1971 Mar 20	UWI		WS	Aerobee 170	200?	Kraushaar		
NASA 13.082UG	1972 Feb 19	UWI		WS	Aerobee 170	200	Kraushaar		
NASA 13.083UG	1972 Dec 8	UWI	Aerobee III	WS	Aerobee 170	200?	Kraushaar	SX Survey	ApJ269.107
NASA 13.103UG	1973 Nov 1	UWI	Aerobee IV	WS	Aerobee 170	185	Kraushaar	SX Survey	ApJ269.107
NASA 13.102UG	1973 Nov 12	UWI	Aerobee III	WS	Aerobee 170	172	Kraushaar	SX Survey	ApJ269.107
NASA 13.084UG	1974 Jul 20	UWI	Aerobee IV	WS	Aerobee 170	195	Kraushaar	SX Survey	ApJ269.107
NASA 26.032UG	1975 Mar 8	UWI		WS	Aerobee 200A	250?	Kraushaar		
NASA 13.049UH	1975 Nov 8	UWI	Aerobee IV	WS	Aerobee 170	177	Kraushaar	SX Survey	ApJ269.107
NASA 13.122UH	1977 Jan 15	UWI	Aerobee IV	WS	Aerobee 170A	196	Kraushaar	SX Survey	ApJ269.107
NASA 26.061UH	1977 May 24	UWI	Aerobee IV	WS	Aerobee 200A	192	Kraushaar	SX Survey	ApJ269.107
NASA 26.063UH	1978 Feb 4	UWI	Aerobee IV?	WS	Aerobee 200A	29	Kraushaar	SX Survey	Fail
NASA 13.137UH	1978 May 6	UWI	Aerobee IV	WS	Aerobee 170A	200	Kraushaar	SX Survey	ApJ269.107
NASA 25.045UH	1979 Mar 15	UWI	Aerobee IV	WS	Astrobee F	216	Kraushaar	SX Survey	ApJ269.107
NASA 25.051UH	1980 Jan 21	UWI	Aerobee IV	WS	Astrobee F	213	Kraushaar	SX Survey	ApJ269.107
NASA 27.041UH	1980 Jun 24	UWI		WS	Black Brant 8C	300?	Kraushaar		
NASA 17.020UH	1984 May 9	UWI		WS	Aerobee 350	300?	Kraushaar		
NASA 27.103UH	1986 Feb 1	UWI		WS	Black Brant 8C	228	McCammon		
NASA 27.121UH	1988 Dec 7	UWI		WS	Black Brant 8C	340?	McCammon		
NASA 27.132UH	1995 Dec 4	GSFC/UWI	XQC F1	WS	Black Brant 8C	220	McCammon		
NASA 27.140UH	1996 Jun 4	GSFC/UWI	XQC F2	WS	Black Brant 8C	220	McCammon		
NASA 27.141UH	1999 Mar 28	GSFC/UWI	XQC F3	WS	Black Brant 8C	220	McCammon		
NASA 36.223UH	2008 May 1	GSFC/UWI	XQC F4	WS	Black Brant 9	300?	McCammon		
NASA 36.364UH	2011 Nov 6	GSFC/UWI	XQC F5	WS	Black Brant 9	250?	McCammon		
NASA 36.283UH	2012 Dec 13	Miami	DXL (Aerobee IV)	WS	Black Brant 9	257?	Galeazzi		

## 2.8 GSFC (1968-present)

The Goddard Space Flight Center X-ray astronomy flight program began in 1968 under Elihu Boldt, in collaboration with Steve Holt. An additional flight in 1988 tested the mirrors developed by Peter Serlemitsos; GSFC is was a partner with Wisconsin in the ongoing XQC series of flights.

The engineering document for NASA 17.005GT-GG the Aerobee 350 test flight, says that it also carried an X-ray payload 'to investigate solar and stellar X-ray phenomnea'.

Table 8: GSFC rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
NASA 4.198GE	1968 Mar 16	GSFC		WS	Aerobee 150	153	Boldt	Crab, XRB	ApJ156,427	WDC
NASA 4.199GE	1969 Mar 3	GSFC		WS	Aerobee 150M1	163	Holt, Boldt	XR Background	ApJ158,L55	WDC
NASA 17.05GT-GG	1970 Apr 14	GSFC		WS	Aerobee 350	88	?		(fail)	WDC
NASA 13.007GG	1970 Sep 22	GSFC		WS	Aerobee 170A	146	Holt		Nat.PS233,110	WDC
NASA 13.008GG	1971 Aug 10	GSFC		WS	Aerobee 170A	200?	Holt		ApJ174,L101	WDC
NASA 13.009GG	1972 May 19	GSFC		WS	Aerobee 170A	200?	Holt		ApJ184,L1	WDC
NASA 13.010GG	1973 Oct 4	GSFC	XRPC	WS	Aerobee 170A	152	Holt	Cas A, Tycho	ApJ190,L109	WDC
NASA 26.037GG	1974 Oct 3	GSFC		WS	Aerobee 200A	250?	Boldt	Her X-1, Cyg X-1	ApJ201,L9	WDC
NASA 26.038GH	1976 May 11	GSFC/CIT	HEAO A-2 proto	WS	Aerobee 200A	175	Boldt, Garmire	Cyg X-1	WDC	WDC
NASA 36.022GH	1988 Feb 16	GSFC	SXS	WOO	Black Brant 9	300?	Serlemitsos	ApJ233,350		WISR

## **2.9 Columbia (1968-87)**

The Columbia Astrophysics Laboratory (CAL) at Columbia University in New York flew a series of rockets from 1968 to 1987; the PI for most flights was Bob Novick. The flights were launched by NASA, except for two missions flown as part of the independent and little-known Kitt Peak rocket program.

Table 9: Columbia rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
NASA 4.196UG	1968 May 3	CAL		WS	Aerobee 150	3	Novick			WDC
NASA 4.236UG	1968 Jul 27	CAL		WS	Aerobee 150	142	Novick			WDC
NASA 4.286UG	1969 Mar 7	CAL		WS	Aerobee 150	160	Novick			WDC
NASA 13.001UG	1970 Feb 14	CAL		WS	Aerobee 150	231	Novick			WDC
KP3.30	1970 Apr 24	CAL/KPNO		WS	Aerobee 150?	274	Novick			WDC
NASA 17.009UG	1971 Feb 22	CAL	XR Polarim.	WS	Aerobee 350	196	Novick			WDC
KP3.38	1972 Mar 21	CAL/KPNO		WS	Aerobee 150	200?	Novick			WDC
NASA 13.087UG	1973 Jul 2	CAL		WS	Aerobee 170	176	Weisskopf			WDC
NASA 26.021UG	1974 Feb 9	CAL		WS	Aerobee 200A	186	Wolff,Novick	WDC		
NASA 13.107UG	1974 Nov 3	CAL		KAU	Aerobee 170	169	Novick		ApJ202,L15	WDC
NASA 26.030UG	1974 Dec 28	CAL		WS	Aerobee 200A	197	Novick		ApJ202,L21	WDC
NASA 26.054UH	1977 Feb 15	CAL		WOO	Aerobee 200A	176	Novick			WDC
NASA 27.057UH	1981 Nov 17	CAL		WS	Black Brant 8B	253	Ku			WISR
NASA 27.067UH	1983 May 14	CAL		WS	Black Brant 8C	246	Ku			WISR
NASA 36.024UH	1987 Dec 4	CAL		WOO	Black Brant 8	300?	Novick			WISR



## 2.10 Caltech (1969-78)

Gordon Garmire began a rocket program at Caltech; in the 1980s he transferred to Pennsylvania State University.

The Wolter telescope flown on 1978 Dec 11 was reflown on 1981 Mar 24 but this time with a detector whose upper energy was 0.07 keV so I am categorizing it as an EUV mission and omit it here.

Table 10: Caltech rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref
NASA 18.071UG	1969 Oct 4	CIT		WI	Nike Tomahawk	235	Garmire		WDC
NASA 14.413UG	1970 Jun 27	CIT		WS	Nike Apache	200?	Garmire		WDC
NASA 14.414UG	1970 Aug 28	CIT		WS	Nike Apache	200?	Garmire		WDC
NASA 13.011UG	1970 Dec 19	CIT		WS	Aerobee 170	160?	Garmire	AAp21,131	WDC
NASA 13.063UG	1971 Oct 23	CIT		WS	Aerobee 170A	181	Garmire	ApJ183,61	WDC
NASA 14.415UG	1972 Jun 10	CIT		WS	Nike Apache	164	Garmire	ICRC1973,1,56	WDC
NASA 13.064UG	1973 Mar 24	CIT		WS	Aerobee 170A	200	Garmire,Long	ApJ212,427	WDC
NASA 13.065UG	1973 Nov 1	CIT		WS	Aerobee 170A	165	Garmire,Long	ApJ212,427	WDC
NASA 13.106UG	1973 Nov 9	CIT		WS	Aerobee 170A	169	Garmire,Long	ApJ212,427	WDC
NASA 26.038GH	1976 May 11	GSFC/CIT	HEAO A-2 proto	WS	Aerobee 200A	175	Boldt,Garmire	ApJ233,350	WDC
NASA 25.001UH	1978 Dec 11	CIT		WS	Astrobee F	164	Garmire		WDC

## **2.11 Penn State (1986-1998)**

Garmire's Penn State program positioned PSU for its role in Chandra's ACIS camera.

Table 11: Penn State rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref
NASA 24.009UH	1986 Aug 24	PSU/CAL	XR Tel	WS	Aries	23	Garmire,Novick	(Fail)	WISR
NASA 36.030UH	1987 Nov 14	PSU		WOO	Black Brant 9	300?	Garmire		WISR
NASA 36.032UH	1988 Feb 28	PSU		WOO	Black Brant 9	300?	Garmire	ApJ347.1114	WISR
NASA 36.034UH	1990 Mar 17	PSU		WS	Black Brant 9	300?	Garmire		WISR
NASA 36.092UH	1995 May 22	PSU		WS	Black Brant 9	300?	Garmire		WISR
NASA 36.106UH	1995 Oct 25	PSU		WOO	Black Brant 9	300?	Garmire	Mendenhall PhD	WISR
NASA 36.093UH	1997 May 2	PSU		WS	Black Brant 9	300?	Garmire		WISR
NASA 36.176UH	1998 Aug 15	PSU	EUV CCD	WS	Black Brant 9	300?	Garmire		WISR

## **2.12 Colorado (1991-present)**

Webster Cash at the University of Colorado flew soft X-ray telescopes starting in the 1990s.

Table 12: Colorado rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
NASA 36.077UH	1991 Mar 18	UCO	SXT	WS	Black Brant 9	300?	Cash	Sco X-1	ApJ439,976	WISR
NASA 36.096UH	1992 Jan 31	UCO	SXT	WS	Black Brant 9	300?	Cash			WISR
NASA 36.095UH	1993 Apr 17	UCO	SXT	WS	Black Brant 9	254	Cash			WISR
NASA 36.224UH	2006 Nov 21	UCO	CyXESS	WS	Black Brant 9	300?	Cash	Cyg Loop	ApJ680,328	WISR-WWW
NASA 36.252UH	2009 Nov 14	UCO	EXOS/CyXESS	WS	Black Brant 9	300?	Cash	Cyg Loop	SPIE 7732, 77321R	WISR-WWW
NASA 36.274UH	2011 Dec 10	UCO	CODEX	WS	Black Brant 9	250?	Cash			WISR-WWW

### 2.13 Other US programs

According to NASA records, Tackett and Hemenway at the Dudley Observatory flew an X-ray astronomy payload in 1969. L. Gratton was also at Dudley at the time and this was actually a Roma/Frascati payload with Dudley assistance.

Two and possibly three flights by Singer and Blake at the Los Alamos Scientific Laboratory (LASL) are not well documented. The first flight, SHIRX, carried a solid state spectrometer to obtain a spectrum of Sco X-1; its Sandia flight ID is unknown. A flight in 1976 (Joel Powell, personal communication) may have been a reflight of the same payload.

A flight by Art Walker from Stanford in 1983 was recorded in NASA lists as an X-ray astronomy flight; I have no details. Walker was mainly known as a solar physicist and carried out the MSSTA series of multilayer optics flights in 1991-2002.

Table 13: Other US rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
Sandia 281-?	1971 May 22	LASL	SHIRX	KAU	Terrier Sandhawk	300?	Singer		IEEE-NS19,1,628	
Sandia 281-?	1976 Jun 6	LASL	?	KAU	Terrier Sandhawk	300?	Singer?			Powell (2000)
NASA 27.068AH	1982 Jun 22	LASL		WS	Black Brant 8C	245	Blake		WISR	
NASA 27.027UH	1983 Jun 29	STAN		WS	Black Brant 8C	289	Walker			WISR



## **3 UK groups**

### **3.1 Leicester**

Ken Pounds began solar X-ray film flights from Woomera as part of the UCL group in 1959 and continued the program when he moved to Leicester in 1960; extrasolar X-ray studies began with flights in 1964. The program positioned Leicester for its work on the Ariel V satellite.

Table 14: Leicester University X-ray Group extrasolar flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref
SL47	1964 Oct 27	LUX	PC	WOO	Skylark	146	Pounds	S. Survey	
SL118	1967 Apr 10	LUX	PC	WOO	Skylark	167	Pounds	S. Survey	ApJ150,L189
SL119	1967 Apr 12	LUX	PC	WOO	Skylark	160	Pounds	S. Survey	
SL723	1968 Jun 12	LUX	PC	WOO	Skylark	184	Pounds	M87	Nat222,757
SL403	1968 Jul 8	LUX		WOO	Skylark	180	Pounds	M87	Nat222,757
SL724	1969 Apr 1	LUX		WOO	Skylark	192	Cooke	Sco X-1	NatPS229,144
SL901	1970 Mar 18	LUX		WOO	Skylark 3AC	208	Cooke	S Survey	NatPS229,175
SL802	1970 Mar 24	LUX		WOO	Skylark 3AC	179	Cooke	S Survey/MC	(fail)
SL972	1970 Oct 8	LUX		WOO	Skylark 6	232	Adams,Janes	S Survey	
SL904	1970 Nov 19	LUX		WOO	Skylark 3AC	209	Janes	XRB/M87	NatPS230,188
ESRO S55	1971 Mar 11	LUX/TUB/MPE	BCS	SDQ	Skylark 3AC	159	Griffiths		NatPS236,104
SL812	1971 May 10	LUX		WOO	Skylark 6AC	219	Adams	S Survey?	(Fail)
SL1002	1971 Sep 27	LUX		WOO	Skylark 6AC	224	Janes	GX3+1	
SL1202	1972 Dec 7	LUX		WOO	Skylark 3AC	248	Hoffman	GX5-1	
SL1010	1973 Feb 28	LUX	LE Parab.	WOO	Skylark 6AC	199	Griffiths		
SL1011	1973 Apr 17	LUX		WOO	Skylark 6AC	214	Adams,Whitford	Survey, MC?	
SL1304	1974 Oct 7	LUX/MPE/AIT	Astro 9	ELAR	Skylark 6AC	190	Hoffman, Giles	Crab Occ.	
SL1105	1975 Jun 24	LUX	Soft 1D Tel	WOO	Skylark 6AC	180	Pounds	Vela	
SL1112	1975 Nov 24	LUX/CEA	Tel.	WOO	Skylark 7AC	251	Pounds	Crab,ISM	
SL1306	1976 Nov 4	LUX	LAPC	WOO	Skylark 6AC	191	Pounds, Giles	Cyg X-1	

### **3.2 MSSL and Birmingham**

The Mullard Space Science Laboratory is an outstation of University College, London; UCL was the core of the early UK space science program under H. Massey.

The Birmingham flights were mostly carried out in collaboration with MSSL, after Willmore left MSSL in the mid 1970s to take over the Birmingham group, and so are tabulated here.

Table 15: MSSL (and Birmingham) extrasolar X-ray rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
SL821	1969 Oct 22	MSSL		WOO	Skylark 3	216	Boyd, Willmore			WDC, MR86
SL602	1969 Nov 18	MSSL		WOO	Skylark 3 AC	208	Willmore			WDC, MR86
SL921	1970 Mar 11	MSSL		WOO	Skylark 3	247	Cruise, Willmore			WDC, MR86
SL727	1970 Jul 10	UAT/MSSL		WOO	Skylark	203	McCracken		NaturePS234,149	MR86
SL971	1970 Jul 14	MSSL		WOO	Skylark 6	223	Willmore	Vela	MN170,165	WDC,MR86
SL1021	1970 Oct 14	MSSL		WOO	Skylark 3	270	Willmore	Sgr-Sco	MN170,165	WDC,MR86
SL905	1970 Nov 11	MSSL		WOO	Skylark 3 AC	183	Sanford,Newton	Vela	NaturePS244,121	WDC,MR86
SL1001	1971 Jan 29	MSSL		WOO	Skylark 3 AC	203	Cruise,Fabian	XRB	NatPS231,52	WDC,MR86
SL973	1971 Oct 7	MSSL		WOO	Skylark 6	233	Willmore,Cruise	Sgr-Sco	MN170,165	WDC,MR86
SL974	1971 Oct 24	MSSL		WOO	Skylark 6	245	Willmore,Turner			WDC,MR86
ESRO S91	1972 Jun 25	MSSL		SDQ	Skylark 3 AC	213				WDC,MR86
SL402	1972 Oct 23	MSSL		WOO	Skylark 6 AC	210	Culhane			WDC,MR86
SL1205	1973 Jan 30	MSSL		WOO	Skylark 3 AC	234	Culhane,Cruise		WDC,MR86	WDC,MR86
SL1203	1974 Feb 4	MSSL/UCB		WOO	Skylark 6 AC	197	Boyd,Bowyer		SpaRes16,839	WDC,MR86
SL1104	1974 Jun 18	MSSL		WOO	Skylark 6 AC	234	Culhane,Cruise			WDC,MR86
SL1012	1974 Oct 4	MSSL		WOO	Skylark 6 AC	196	Culhane			WDC,MR86
SL1115	1976 May 12	BIR/MSSL/MSFC		WOO	Skylark 7AC	231	Willmore		MN178,57P	WDC,MR86
SL1212	1976 Jun 10	MSSL		WOO	Skylark 7 AC	280	Boyd,Zarnecki		(fail)	WDC,MR86
SL1501	1976 Jun 17	BIR		WOO	Skylark 7AC	256	Skinner,Willmore	Sgr	MN185,745	WDC,MR86
SL1402 (DLR H-GR-77)	1976 Jul 17	MSSL/MPE		ELAR	Skylark 7 AC	256	Staubert			WDC,MR86
SL1115A	1977 Apr 28	BIR/MSSL		WOO	Skylark 7 AC	244	Willmore			WDC,MR86

### **3.3 Bristol**

Gamma ray astronomer R. Hillier flew scintillation detectors to study the X-ray background on Petrel rockets from South Uist in Scotland in 1973 (Massey and Robins 1986). Results are unknown.

Table 16: Bristol University extrasolar X-ray flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
P56H	1973 May 19	BRIS	XRB Scint	SUIST	Petrel	137	Hillier			WDC, MR86
P45H	1973 Jul 23	BRIS	XRB Scint	SUIST	Petrel	143	Hillier			WDC, MR86

## 4 Japan

The Japanese rocket program was led by the Institute of Space and Aeronautical Science (originally Tokyo; later in the suburb of Sagami-hara). University groups participated in the X-ray payloads, especially Minoru Oda's ISAS group and the group at Nagoya university under Hayakawa which also had some independent projects, including the LEINAX series done with Leiden.

The Japanese flights typically carried a mixed payload with experiments from different disciplines and different experimenters; the data below applies only to the X-ray experiments on each rocket.

A set of flights were also carried out in 1968-69 in collaboration with India and NASA; these are noted in the ISRO section.

### 4.1 ISAS and Nagoya

Table 17: ISAS-launched X-ray rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
L-3-3	1965 Mar 18	NAG		KASC	Lambda 3	1085	Hayakawa		SpRes.8,68	Itokawa (1967)
K-9M-12	1965 Jul 26	ISAS		KASC	Kappa 9M	350	Matsuroka		SpaceSciRev5,109	Itokawa (1967)
L-3H-1	1966 Mar 5	ISAS		KASC	Lambda 3H	1829			Itokawa (1967)	
K-9M-15	1966 Mar 20	ISAS/NAG	?	KASC	Kappa 9M	300				Itokawa (1967)
L-3H-3	1967 Feb 6	ISAS/NAG		KASC	Lambda 3H	2150	Matsuoka		ApSpSci4,44	Itokawa (1967)
K-10-4	1969 Jan 14	NAG		KASC	Kappa 10	229	Hayakawa		PASJ25,375	Tamaki (1969)
S-210-1	1969 Aug 7	ISAS		KASC	S-210	101				Tamaki (1969)
K-9M-27	1969 Aug 7	Kyoto		KASC	Kappa 9M	340	Oya		ApSpSci12,378	Tamaki (1969)
S-210-2	1969 Aug 8	ISAS		KASC	S-210	108				Tamaki (1969)
S-210-3	1970 Jan 17	ISAS		KASC	S-210	119				Tamaki (1971)
L-3H-5	1970 Sep 19	NAG		KASC	Lambda 3H	2017	Hayakawa			Tamaki (1971)
K-9M-34	1971 Jan 24	ISAS		KASC	Kappa 9M	328		Sco X-1		Tamaki (1971)
K-9M-31	1971 Aug 18	ISAS/Osaka		KASC	Kappa 9M	330	Miyamoto,Oda	Sco X-1	AAp65,329	Tamaki (1973)
L-3H-7	1971 Sep 3	ISAS/NAG		KASC	Lambda 3H	1718	Hayakawa			Tamaki (1973)
K-10-8	1972 Sep 12	ISAS		KASC	Kappa 10	259				Tamaki (1973)
K-9M-44	1973 Aug 27	NAG		KASC	Kappa 9M	341	Hayakawa		ApSpSci42,169	Mori and Nomura (1975)
K-10-10	1973 Sep 22	ISAS		KASC	Kappa 10	242				Mori and Nomura (1975)
L-3H-8	1974 Jan 22	ISAS		KASC	Lambda 3H	1571			ApSpSci32,L1	Mori and Nomura (1975)
K-9M-50	1975 Jan 25	NAG		KASC	Kappa 9M	353	Iwanami		ApSpSci161.217	Mori and Nomura (1975)
K-9M-52	1975 Sep 23	ISAS	Soft X	KASC	Kappa 9M	336				NCSR (1976)
K-10-11	1975 Sep 24	ISAS		KASC	Kappa 10	196				NCSR (1976)
K-10-14	1980 Aug 26	ISAS	GXX	KASC	Kappa 10	219				NCSR (1981)
K-9M-74	1982 Feb 18	ISAS		KASC	Kappa 9M	315				NCSR (1982)



## 5 European groups

### 5.1 Bologna

Bologna flew two flights on a joint flight with a Royal Observatory Edinburgh UV camera, and four flights with a payload developed in collaboration with ESTEC.

Table 18: Bologna program

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
ESRO S11/1	1966 Nov 26	BOL	Hard X NaI Scin	SDQ	Skylark 3	3	Brini	(fail)		Guerin (1973a)
ESRO S11/2	1967 May 22	BOL	Hard X NaI Scin	SDQ	Skylark 3	230	Brini			Guerin (1973b)
ESRO C35/1	1968 Oct 8	BOL/ESTEC	Hard X NaI Scin	ESR	Centaur 2B	140	Brini,Page			WDC
ESRO C35/2	1969 Jun 5	BOL/ESTEC	Hard X NaI Scin	ESR	Centaur 2B	130	Brini,Page			ESRO (1969)
ESRO S68/1	1969 Oct 24	BOL/ESTEC		SDQ	Skylark	184	Brini	XRB	ApSpSci27,1	ESRO (1969)
ESRO S68/2	1970 Jun 22	BOL/ESTEC		SDQ	Skylark	3	Brini	(fail)		WDC

## 5.2 Roma

L. Gratton of the University of Roma La Sapienza flew an experiment on an ESRO rocket in 1971. An earlier experiment, with Spada of Frascati and Tackett of Dudley Obs., was flown under NASA auspices.

Table 19: Roma-La Sapienza program

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
NASA 14.353UG	1969 Dec 5	ROSAP	FRASC/DUD	WS	Nike Apache	200?	Gratton, Spada			WDC
ESRO S81	1971 Oct 12	ROSAP	-	WOO	Skylark 3	210?	Gratton			BAE (1990)

### 5.3 LAS and CEA

Two French groups, the Laboratoire d'Astronomie Spatiale at Marseille (LAS) and the Commissariat d'énergie atomique's Centre de Saclay (CEA), flew X-ray rocket experiments.

CEA also participated in Leicester flight SL1112.

Included in the list below is ESRO S94 - it is not known which European groups participated in this flight, which is thought to have included an X-ray astronomy payload according to the WDC-A database.

Table 20: CEA and LAS programs

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	Ref ID
CNES VA84	1967 Jan 11	LAS/CEA	CNES FU-161	HMG	Veronique 61	158	Courtes			CNES (1997)
CNES VA88	1967 Apr 4	LAS/CEA	CNES FU-178	HMG	Veronique 61M	196	Courtes		SpRes8,430	SpRes12,1603
CNES T002	1967 Nov 23	CEA	CNES FU-169	CERES	Tacite	0	Labeyrie		(fail)	CNES (1997)
CNES VA89	1968 Jul 25	LAS/CEA	CNES FU-185	CSG	Veronique 61M	185	Morin,Rocchia			CNES (1997)
CNES VA90	1968 Dec 22	LAS/CEA	CNES FU-159	CSG	Veronique 61M	188	Courtes,Ducros	Crab	AAp7,162	CNES (1997)
ESRO S95	1972 Nov 2	CEA/UTR	ESRO S95	WOO	Skylark 6AC	211				ESRO (1972)
ESRO S94	1972 Nov 20	?	ESRO S94	SDQ	Skylark 3	210?	Unknown			ESRO (1972)

## 5.4 Leiden

The Universiteit Leiden carried out a series of X-ray flights in collaboration with the Nagoya group. These Leiden-Nagoya-X-Ray (LEINAX) missions used rockets provided by the US defense contractor Sandia Corporation.

Utrecht also had an X-ray group, which participated in the ESRO S95 flight with CEA Saclay as well as flying solar X-ray and auroral payloads. ESA's ESTEC in Noordwijk prepared European sounding rockets and participated in the Bologna experiments (below).

Table 21: LEINAX program

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
Sandia 281-?	1971 May 26	LEID/NAG	LEINAX I	KAU	Nike Tomahawk	209	Bleeker/Hayakawa		ApJ178,377	
Sandia 281-?	1972 May 22	LEID/NAG	LEINAX II	KAU	Nike Tomahawk	270?	Bleeker/Hayakawa		AAp48,235	
Sandia 281-3	1974 Nov 10	LEID/NAG	LEINAX III	KAU	Sandhawk	180	Bleeker/Hayakawa	Tau to Eri		NCSR (1975)
Sandia 281-?	1976 May 29	LEID/NAG	LEINAX IV	KAU	Terrier Sandhawk	271	Bleeker/Hayakawa		AAp69,145	



## 5.5 MPE

The Max Planck Institut für Extraterrestrische Physik in Garching bei München (MPE) flew rockets prior to the ROSAT era, in collaboration with UK and US groups. In the 1980s, under Joachim Trümper, it led development of the ROSAT satellite.

Table 22: MPE X-ray program

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
DLR H-GR-58	1974 Jan 12	MPE	HRC 1	ELAR	Syklark 4AC	246	Haser		DLR (2000)	
DLR H-GR-59 (SL1304)	1974 Oct 7	LUX/TUB/MPE	Astro 9	ELAR	Syklark 6AC	190	Hoffman		ApJ201,L15	DLR (2000)
DLR H-GR-77	1976 Jul 17	MSSL/MPE	XRCS	ELAR	Syklark 7AC	256	Staubert			DLR(2000)
NRL NB24.276	1977 Jan 26	NRL/MPE	Astro 8-1	WS	Aries	347	Zimmerman		ApJ234,415	ApJ234,415
-	1978 Jun 12	MPE	Astro 8-2	WS	Aries	355	Trummer			Pawloski (1979)

## **6 Other countries**

### **6.1 Australia**

The University of Adelaide flew a series of missions in 1967-1970 in collaboration with the University of Tasmania.

Table 23: Adelaide X-ray rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	IDRef
SL426	1967 Apr 4	ADEL	UAT-1	WOO	Skylark 3	220	Harries	Cen X-2	Nature215,38	
SL425	1967 Apr 20	ADEL	UAT-2	WOO	Skylark 3	218	Harries	Cen X-2	Nature215,38	
SL422A	1967 Dec 1	ADEL	UAT-3	WOO	Skylark	181	Francey	Cetus	PASAU1,236	WDC
SL781	1969 Jan 21	ADEL	UAT-4	WOO	Skylark 6	0	McCracken	(fail)	PASAU1,240	WDC
SL728	1970 Apr 16	ADEL	UAT-5	WOO	Skylark 3	210	Harries	Nor-Lup	ICRC5,3039	WDC
SL727	1970 Jul 10	ADEL	UAT-6	WOO	Skylark	203	McCracken	LMC	NaturePS234,149	WDC

## 6.2 Canada

Wilson at the University of Calgary carried out an X-ray astronomy program using Canadian Black Brant rockets launched from Resolute Bay. His affiliation was later changed from the University of Calgary to the National Research Council.

It's not clear whether the AKF-4A-19 flight carried an X-ray payload.

Table 24: Calgary X-ray rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	IDRef
AKF-3-26	1967 Oct 20	CALG		RES	Black Brant 3	120?	Baxter, Wilson		WDC	
AKF-3-27	1967 Oct 22	CALG		RES	Black Brant 3	156	Baxter, Wilson		Sp.Res9,222	WDC
AKF-3-40	1968 Oct 8	CALG		RES	Black Brant 3	153	Baxter, Wilson	XRB	ApJ155,1145	WDC
AKF-3B-50	1969 Oct 25	CALG		RES	Black Brant 3B	192	Wilson	SX survey	ApJ164,265	WDC
AKF-3B-51	1969 Oct 26	CALG		RES	Black Brant 3B	197	Wilson	SX survey	ApJ164,265	WDC
AKF-4A-19	1970 Dec 7	CALG		CLBI	Black Brant 4A	770	Harrison	Airglow?		WDC
APF-4B-26	1972 May 17	NRCC		FC	Black Brant IVB	660	Wilson	SX survey		NRCC (1985)
APF-4B-30	1973 Jun 21	CALG		KAU	Black Brant 4A	686	Wilson		WDC	
APD-VB-42	1976 Nov 9	NRCC		WOO	Black Brant 5B	215	Wilson		WDC	

### 6.3 Argentina

The database of the World Data Center for Rockets and Satellites encoded the suggestion that two 1967 flights of Orion-2 sounding rockets from Argentina's CELPA launch base carried X-ray astronomy experiments, but I have not been able to find confirmation. I suspect that the payloads were actually to measure the atmospheric gamma ray background (Bosch, SR6,1077) rather than extrasolar X-rays. I welcome information from Argentine colleagues who can provide more details.

The sponsor organization was IIAE (Instituto de Investigaciones Aeronuticas y Espaciae) and the science group was at Instituto de Astronomia y Fisica del Espacio in Buenos Aires.

Table 25: IIAE rocket flights, possibly with X-ray detectors

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID	Ref
Rad 1/67	1967 Dec 14	CNIE/IAFE		CELPA	Orion-2	35	Ghielmetti				WDC
Rad 2/67	1967 Dec 16	CNIE/IAFE		CELPA	Orion-2	70	Ghielmetti				WDC
Orion 2-31	1969 Aug 30	CNIE/IAFE		CELPA	Orion-2	90?	Ghielmetti?				Serra (1995)



## 6.4 India

The Indian Space Research Organization (ISRO) launched X-ray missions, some in collaboration with NASA. Early flights carried payloads from the Physical Research Lab (PRL) in Ahmedabad; later flights involved the Tata Institute for Fundamental Research (TIFR) in Mumbai.

Launches were transferred from the TERLS range in Thumba, Kerala, to the new Sriharikota range (now Satish Dhawan Space Center) in the late 1970s.

Table 26: Indian X-ray rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref	ID Ref
ISRO 40.01 (NASA 14.241IG)	1968 Apr 22	PRL/ISAS		TERLS	Nike Apache	159	Rao, Oda			WDC
ISRO 40.02 (NASA 14.260IG)	1968 Apr 24	PRL/ISAS		TERLS	Nike Apache	159	Rao, Oda			WDC
ISRO 35.01	1968 Nov 3	PRL		TERLS	Centaura 1	159	Rao, Chitnis	Seco X-1	ApJ157,L127	WDC
ISRO 40.03 (NASA 14.261IG)	1968 Nov 7	PRL		TERLS	Nike Apache	150	Chitnis		ApJ157,L127	WDC
ISRO 40.04 (NASA 14.403IG)	1969 Apr 26	PRL/ISAS		TERLS	Nike Apache	144	Oda, Chitnis		ApSpSci12,378	WDC
ISRO 40.05 (NASA 14.404IG)	1969 Apr 28	PRL/ISAS		TERLS	Nike Apache	148	Oda, Chitnis		ApSpSci12,378	WDC
ISRO 45.03	1969 Dec 7	PRL		TERLS	Centaura 2A	123	Rao, Chitnis		Nature229,248	WDC
ISRO 5.15	1973 Jan 21	TIFR		TERLS	Centaura 2A	165	Naranan		ApSpSci32,431	WDC
ISRO 5.36	1976 Oct 27	TIFR		TERLS	Centaura 2B	148	Singh		InJRSF10,16	InJRSF10,16
RH-560-12A?	1979 Jun 24	TIFR		SHAR	RH-560	332	Singh		AAp117,319	InJRSF9,201

## **6.5 South Korea; KARI program**

South Korea's KSR-II sounding rocket carried an X-ray payload, apparently a proportional counter, as a development test for future science missions.

Table 27: KARI rocket flights

Flight	Date	Lab	Notes	Site	LV	Apo	PI	Target	Ref
KSR-II-1	1997 Jul 9	KARI	XDR	ANHU	KSR-II	150	Nam,Choi		Nam and Choi 1998
KSR-II-2	1998 Jun 11	KARI	XDR	ANHU	KSR-II	137	Nam,Choi		Nam and Choi 1998

## References

- BAE (British Aerospace), 1990. Record of Skylark Launches, 1957-1990 Aug.
- CNES, 1997. List of sounding rocket launches - undated. Obtained from CNES-Toulouse archives in 1997.
- DLR, 2000, *Chronology of Ballon and Sounding Rocket Launches Since 1967 Involving MORABA*, <http://dlr.de>, accessed 2000; no longer online.
- ESRO, 1969, Annual Report, European Space Research Organization.
- ESRO, 1972, Annual Report, European Space Research Organization.
- Guerin (1973a), Development, Launch and In Flight Performance of ESRO Sounding Rocket Payloads, Vol. II, ESRO SP-77.
- Guerin (1973b), Development, Launch and In Flight Performance of ESRO Sounding Rocket Payloads, Vol. III, ESRO SP-78.
- Hirsh, R.F., *Glimpsing an Invisible Universe*, CUP, 1983.
- Itokawa, H., 1967, Japanese Sounding Rocket Program 1965-1967, ISTS 7, 3.
- Massey, H, and Robins, M., 1986, *History of British Space Science* (Cambridge University Press). (MR86)
- McDowell, J.C., 2002-2013, *Launch Vehicle Database*, <http://planet4589.org/space/lvdb> (first published 2002 with irregular updates).
- Mori, D and Nomura, T, 1975, Japanese Observation Balloon, Sounding Rocket and Scientific Satellite Program, ISTS 11, 13.
- Nam, U-W and Choi, C-S, 1998, *J. Astron Space Sci.* 15(2),373.
- NASA Wallops Flight Facility, 1985-2000, Sounding Rocket annual launch lists (WISR).
- NASA Wallops Flight Facility, 2000-2012, Sounding Rocket online launch lists. (WISR-WWW).
- NCSR (National Committee on Space Research), 1975, *National Report on Space Research*, Report of Ionosphere and Space Research in Japan, Vol 29, p 1.
- NCSR (1976), *Space Research in Japan 1976*.
- NCSR (1981), *Space Research in Japan 1981*.
- NCSR (National Committee on Space Research), 1982, *Space Research in Japan, 1982*.
- National Research Council, Canada, 1985: *Record of Launchings Conducted in Canada*.
- NSSDC (National Space Science Data Center), Greenbelt, MD., 1972. 'NSSDC Index of International Scientific Rocket Launches Ordered by Sponsoring Country/Agency',
- Powell, J, 2000, personal communication.
- Pawlowski, P.H., 1979, *Heat Pipe Zero Gravity Payload on ASTRO 8/II*, AIAA 14th Thermophysics Conference; AIAA Paper 79-1064.
- Serra, J-J, 1995, personal communication.
- Seward, F.D., 2010, personal archive of program documents.
- Tamaki, F., 1969, Japanese Sounding Rocket Program 1967-1969, ISTS 8, 51.
- Tamaki, F., 1971, Japanese Sounding Rocket and Scientific Satellite Program, ISTS 9, 7.
- Tamaki, F., 1973, Japanese Observation Balloon, Sounding Rocket and Scientific Satellite Program, ISTS 10, 13.
- Wallace, L, 1973, file on KPNO rocket program. (unpublished documents). (W73). Hardcopy in author's collection.
- World Data Center A For Rockets and Satellites, NASA GSFC, 1985: 'Rocket File', Database accessed in 1985. (WDC). Hardcopy in author's collection.

## Appendix

Some comments from Paul Gorenstein: (rocket flight IDs added by the author)

*On the AS&E March 1966 rocket flight (NASA 4.148CG) a non-focusing instrument provided a position for Sco X-1 that was precise enough for an optical identification. It was the modulation collimator invented by Minoru Oda and given more positioning power by Herb Gursky's modification which consisted of using two modulation collimators with slightly different periods to create a finer positioning vernier effect. I took that payload into the field at the WSMR, Herb Gursky came for the final three days. That flight demonstrated the importance of obtaining a precise position and an optical identification.*

*To resolve the question of whether the X-ray source in the Crab Nebula was point-like or extended an NRL rocket flight (NRL NB3.164, Bowyer et al, 1964) observed a rare lunar occultation of the Crab Nebula. It was found to be extended. It had not yet occurred to anyone that it did not have to be one or the other. It could be extended and also contain a point source.*

*In my opinion the Oct. 1966 AS&E rocket flight (NASA 4.149CG), a collimated proportional counter survey of the galactic plane and the Cygnus region was the first survey to provide multiple reliable positions, although not good enough for unambiguous optical identifications. Cygnus X-2 and Cygnus X-3 were discovered.*

*A rocket flight I led in 1970 (NASA 13.012CG) to observe the Cygnus Loop was the first use of imaging X-ray optics, a 1D Kirpatrick-Baez telescope in that case. The first use of 2D imaging optics, as far, as I know was my 1975 rocket flight (NASA 17.015UG) that observed the Virgo Cluster and detected X-ray emission from the guide stars. That flight and two others with the same telescope that followed in 1976 (NASA 17.016UH, Perseus Cluster and guide stars) and 1977 (NASA 17.017UH, Coma Cluster and star(s)) provided the data for the Ph.D. theses of Dan Fabricant and Ken Topka. I think that those flights and successful use of X-ray optics by others facilitated the approval of an X-ray telescope for HEAO-2, which became the Einstein Observatory.*

*A 1967 rocket flight in Australia led by Ken McCracken detected a source in the southern hemisphere as intense or even more intense than Sco X-1. A few weeks later, a second rocket flight in Australia, led either by McCracken or Leicester observed that the source's intensity had diminished significantly and it disappeared eventually. It was the first transient X-ray source and the first indication at least to me how variable X-ray sources could be.*

*It usually took NASA six months to re-launch a rocket payload. That is much longer than it took to refurbish a payload that was recovered successfully without significant damage. Other rocket programs with a different Goddard support group were waiting in line. In June 1976 (NASA 27.008UH) following the failure of the rocket's attitude control system to point our telescope at the main target I was pleasantly surprised when the Goddard manager for our rocket who accompanied us into the field offered to re-launch the payload as soon as possible. Indeed the following month the payload was relaunched and the attitude control system functioned perfectly. I later learned that the reason the Goddard manager was so kind to us was that he had a girlfriend locally that he was eager to get back to.*