Black Hole Transients and MAXI Nova Alert System

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Abstract

MAXI, Monitor of All-sky X-ray Image is one order of magnitude more sensitive than previous instruments, so that MAXI is the most advanced X-ray monitor to discover X-ray transient objects such as X-ray novae. MAXI's capability to discover black hole X-ray novae and scientific objectives are discussed through a historical and statistical analysis of newly compiled list of 45 black hole candidates. Finally, MAXI's nova finding and alert system is discussed.

Key words: X-ray transients: X-ray novae, black holes — MAXI, all sky monitor

1. Introduction

In the X-ray sky, new stars often appear and disappear. Such X-ray stars are referred to as X-ray transients. X-ray transients of which emission lasts relatively long, on timescales of days or months, are called *X-ray* novae (XNe), distinguishing them from flares, bursts, and flashes. X-ray novae are binary systems consisting of a main sequence star and a black hole (candidate) or a neutron star. Most black hole candidates, BHCs, are such X-ray novae (McClintock & Remilard 2007, hereafter MR07, and references therein). Inversely, X-ray novae sometimes stands for BH transients. Especially, so-called soft X-ray transients, SXTs, often indicate BH transients (Tanaka & Shibazaki 1996, TS96).

MAXI, Monitor of All-sky X-ray Image (Matsuoka et al. 1997), is undeniablely the best X-ray monitor to date to discover such X-ray transients. MAXI has the largest effective area to date, thereby providing a sensitivity that is one order of magnitude higher than that of previous instruments. Furthermore, by making the best use of the International Space Station, ISS, network, MAXI can send alert information to the world in as fast as ∼10 s!

In §2, the importance of the discovery of BH transients to the BH study is emphasized. In §3 and §4, a rate for the discovery of new BH transients with MAXI is estimated, and MAXI's scientific objectives are discussed. Finally, transient source finding/alert system of the MAXI ground software system, currently under development, is described.

2. Black Hole Study and Black Hole Transients

A number of efforts to find evidence for the existence of black holes has been made, and indications have been found (e.g., Narayan et al. 1997). However, so far we have only observed conditions *necessary* for the presence of black holes, and are still lacking any solid direct evidence, for instance, for the existence of the event horizon. Thus, the BHCs are still BH "candidates", though in this and other papers the term "black hole" is often used.

The number of BHCs that are persistent-emission sources is very small in our Galaxy. More than 90 % of BHCs are indeed X-ray transients (MR07). Thus, to study BHCs is to study BH transients. The BH transients also have provided us with new insights into the BH studies: powerful jets, various QPOs in addition to various states and the state transitions. Some of these properties are also good candidates for direct evidence for the black hole. In this sense, to discover BH transients is of great importance to the study of black holes.

3. X-ray Novae & MAXI

Currently, 20 mass-estimated BHCs and 25 second-class BHCs which show similar timing or spectral properties to those of the mass-estimated BHCs are known in our Galaxy (LMC X-1 and LMC X-3 are also included according to MR07). Shown in Table 1 & 2 is a newly compiled list of the BHCs, focusing especially on the first detections of the sources. After the publication of the paper by MR07, A 1742-289 was found to be a neutron star burster (Maeda et al. 1996). Casares et al. (2004) and Orosz et al. (2004) have upgraded X1354-64 and XTE J1650-500 to the mass-estimated BHCs, respectively, and 5 second-class BHCs have been added to the list.

3.1. Discovery Rate of Previous X-ray Novae

Figure 1 illustrates the history of the discoveries of the last 20 years, when *Ginga*/ASM and *RXTE*/ASM had

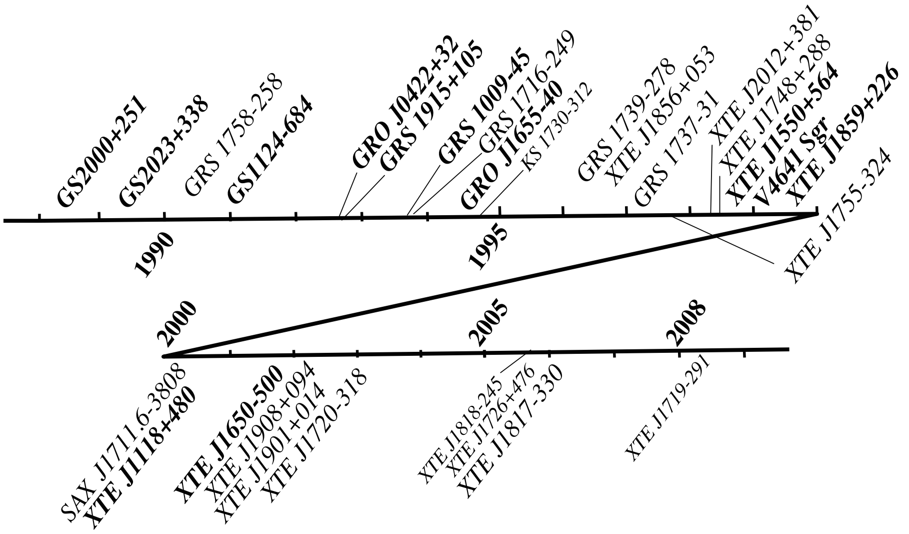

Fig. 1. XNe discovery history of the last 20 years. The sources written in bold font are mass-determined BHCs. The font size shows the grade of BHCs (see table 1–2).

and have been in use. Recurrent outbursts are omitted. In the last 20 years, 29 black hole transients have been found. The discovery rate is about 1.5 per year. Of course, each source was found with various instruments in various energy bands and with various detection limits. In fact, about 2/3 XNe were found with *Ginga*/ASM (GA) and *RXTE*/ASM (RA), and some others were found by pointing observations to the Galactic center region with *RXTE*/PCA (RP) and *Granat*/SIGMA (GS). Interestingly, however, the discovery rate is roughly constant.

This might be due to the large X-ray flux during the outburst. For instance, the flux at the first detection with *RXTE*/ASM, mainly reported to the IAUC and The Astronomer's Telegram, were 20 $\sim$ 200 mCrab above the detection limit of $\sim$ 20 mCrab.

3.2. Distribution of the BHCs on the Galactic Plane

Many BHCs are, however, located relatively close to the solar system. Figure 2 shows the geometric distribution of the 38 BHCs of which distances have been estimated on the Galactic plane. The distances to the sources in the direction of the Galactic center are unknown. Energy spectra of these sources are often heavily absorbed so that the sources are assumed to be near the Galactic center. Here, the sources less than 10 degrees apart from the center are adequately plotted near the center except for H 1705–250 and GRS 1716–249. V4641 is also likely to be such a Galactic center source though the source is plotted behind the center region.

It can be seen from the Fig. 2 that many BHCs are located near the Galactic center ($\sim$ 15 BHCs) and near the solar system ($\sim$ 11 BHCs within 4 kpc, and $\sim$ 15 within 6 kpc). Relatively long distance sources more than 6 kpc apart, except for the Galactic center ones and GRS 1915+105 and XTE J1859+226, are all bright, and/or persistent-emission sources found before 1987, the *Ginga* launch. About half of the Galactic center sources have been found by pointing observations, i.e., deeper observations. This implies that most XNe (BH transients) recently discovered are outbursts near the solar system and near the Galactic center, and that the discovery rate is limited mainly by the detection limit of the previous detectors.

3.3. Expected Discovery Rate of X-ray Novae with MAXI

MAXI with a much higher sensitivity will be able to observe a more extended region of our Galaxy and a deeper area near the Galactic center, compared with the previous all-sky monitors. The increase of sensitivity by one order of magnitude translates to a 3 times larger observable distance and to an about 10 times more extened scannable region (not volume). (Note that most BHCs are in the Galactic plane.)

If the observable distance has been limited to 3–5 kpc previously, then MAXI will be able to observe a 9–15 kpc distance, which corresponds to more than half the area of our Galaxy. MAXI/GSC having sensitivity up-to 30 keV will most certainly be helpful when looking for heavily absorbed, embedded sources near the Galactic center and in far distant region as *Granat*/SIGMA and *CGRO*/BASTE. Current simulation results also support this (Tomida, private comm.).

Taking into account the extension of observable region and the star distribution in our Galaxies, and also frequent scanning of the Galactic center region, an expected discovery rate of XNe with MAXI is optimistically 5–10 times higher than before: 1.5 BHCs/yr × 5–10 $\sim$ 7.5–15

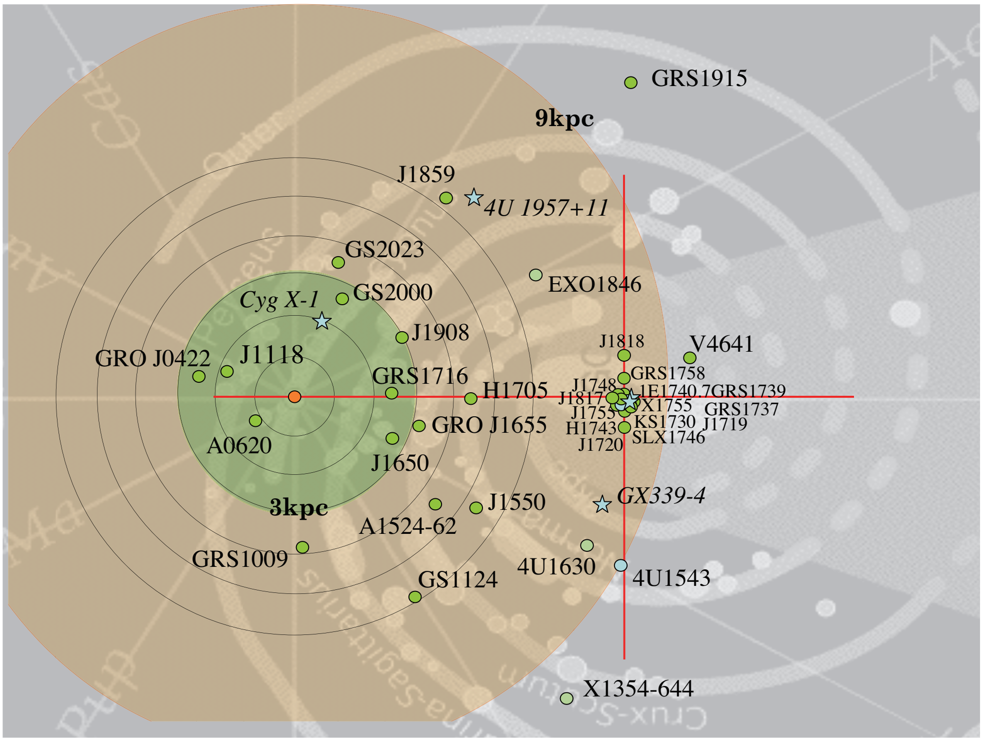

Fig. 2. The Galactic plane map of BHCs, of which distances have been measured. The background image is from wikipedia.org. The distances used are basically the latest estimates as shown in table 1–2. The sources near the Galactic center are projected onto the plane at the distance to the center. Source names starting with "J" should be read as "XTE J". The persistent emission sources are marked with (cyan) star symbols. The distance to the Galactic center is assumed to be 8 kpc.

BHCs/yr. This means that if MAXI works as expected, we could discover as many as one new BHC per month! Of course, recurrent outbursts of the known BHCs and other X-ray novae of neutron binaries are also expected to be observed frequently with MAXI.

4. MAXI Objectives

BHCs exhibit various timing and energy spectral features classified into several states: ultrasoft/slim-disk, very high, high/soft, intermediate, low/hard and quiescence/off states. MAXI has two different kinds of instruments, the GSC with the wide energy band sensitive at 2–30 keV and the SSC with good energy resolution, so that one can see detailed spectral evolution during an outburst just like that of GS 1124-684 observed with *Ginga* /ASM (Kitamoto et al. 1992) and LAC (Ebisawa et al. 1994). Of course, followup observations with other satellites or observatories like for instance *Suzaku* are essential for further detailed study.

Oda et al. (2007, also see Matsumoto in this volume) have found from their MHD simulations a new solution of the accretion disk model, a magnetically supported, optically thin cool disk, which is expected to appear during the transition between the hard and soft states. Observationally, it may be referred to the "high-to-low transition" state (Miyamoto et al. 1993) or the "intermediate" state (Mendez & van der Klis 1997). For such a study, MAXI will also be very helpful.

It has been difficult for pointing observatories to catch powerful, relativistic jets. Fender et al. (2004) have shown that the powerful jets tend to appear just before the transition to the soft state. From the continuous observations with MAXI it will be possible to predict the appearance of jets. It will therefore become easier than before to observe a jet source simultaneously in X-rays (MAXI) and other wavelengths, for instance with FOFAR (see Fender in this volume). The origin of these mysterious jets might be understood from upcoming MAXI and other wavelength data.

It is difficult for MAXI to detect high frequency QPOs, but their appearance is expected from that of low frequency QPOs detectable with MAXI (e.g., Remillard et al. 2002). Followup observations with *RXTE*, *Suzaku* and *ASTROSAT* are highly encouraged.

Finally, the beginning of an outburst, which has rarely been observed, is of great interest because we might finally be able to determine whether the event horizon really exists or not (c.f., Narayan et al. 1997).

Table 1. List of the Black Hole Candidates

Source Name[a]	Date[b]	Satellite[c]	Flux[d] [mCrab]	Recurrence[e]	Distance[f] [kpc]	References & Notes[g]
GRO J0422+32, v518 per	1992/08/05	CB	200		2.6 ± 0.7 $2.49 \pm 0.30^{\mathrm{Hy}}$	1
LMC X-3[1]	*p*	–	–	–	50 ± 2.3	
LMC X-1[1]	*p*	–	–	–	50 ± 2.3	
A0620-00, Mon X-1, V616 Mon	1975/08	AV		(1917)	1.16 ± 0.11	2, RJ
GRS 1009-45, MM Vel	1993/09/12	GW CB	600 ± 100@8-20keV 500 ± 100		5.0 ± 1.3, $5 \pm 1.5^{\mathrm{Ha}}$ $3.82 \pm 0.27^{\mathrm{Hy}}$	3
XTE J1118+480, KV Uma	2000/03/29	RA	39 ± 8		1.8 ± 0.5	4
GS1124-684, GRS1121-68, GU Mus	1991/01/08	GW GA	~ 2000 800		5 ± 1.3, $5.5 \pm 1.0^{\mathrm{Ha}}$ $5.89 \pm 0.26^{\mathrm{Hy}}$	5
X1354-64(4)[2], GS1354-645, BW Cir	1966/10?			71?,72?,87/02[GA300], 97/10-11[CB200,RA16]	$10?^{\mathrm{Ch}}$ ($> 27?^{\mathrm{ref.10}}$)	6–10
A1524-62[A], TrA X-1, KY TrA	1974/11	AV		90/08[GS]	4.4^{Ch}	11,12
4U1543-47, IL Lupi	1971/08	Uhuru		83/08[Tenma],92/04[CB1080], 02/06[RA54]	7.5 ± 0.5, 4^{Ch}, $9.1 \pm 1^{\mathrm{Ha}}$	13–15
XTE J1550-564, V381 Nor	1998/09/07	RA	70	99/01[CB(300)],00/04[RA(60)], 01/01[RP],02/01[RP60], 03/03[II150]	5.3 ± 2.3	16–21, HFQPO, RJ
4U1630-472[A], Nor X-1, GX 337+00, A1630-742	1971/02	Uhuru		~ 1.8 yr interval	$8?^{\mathrm{Ch}}$	22, HFQPO
XTE J1650-500[3]	2001/09/05	RA	140 ± 20		$2.6^{\mathrm{ref.24}}$	23,24, HFQPO
GRO J1655-40, V1033 Sco	1994/07/27	CB		95/01[CB150],95/02[CB,MIR1700], 95/07[CB],96/04[RA71]	3.2 ± 0.2	25–30, HFQPO, RJ
GX339-4, V821Ara	*p*(1972 ∼?)	–	–	–	4, 6-$15^{\mathrm{ref.31}}$	31
H1705-250, A1705-250, V2107 Oph	1977/08	AV/H1			8 ± 2, 4.3^{Ch}	32,33
SAX J1711.6-3808[B]	2001/02/08	BW	$30 \sim 80$@2-9keV			34
GRS 1716-249[B], GRO 1719-24, Oph	1993/09/24 (09.25)	CB GS	70 ± 14@20-100keV 342 ± 45@35-75keV	94/09[GS,MIR]	$(2.4 \pm 0.4)^{\mathrm{Hy}}$	35,36
XTE J1719-291, SWIFT J171916.9-290410	2008/03/21	RP	5		(GC)	37
XTE J1720-318[C], Sco 2003	2003/01/09	RA	130 ± 20		3–$10^{\mathrm{ref.37}}$(GC)	38,39
XTE J1726-476, IGR J17269-4737	2005/10/04 (05/10/6-7)	RA II	32 ± 4 11@20-40keV			40 41
KS 1730-312[C], GRS1730-312	1994/09/23 (09.22–23)	MIR GS	70 ± 10@2-30keV 130@40-150keV		(GC)	42
GRS 1737-31[B]	1997/03/14	GS	90 ± 16@35-75keV 130 ± 20@75-150keV		(GC)	43

[a] Sources written in bold font are mass-determined BHCs (MR07 and recent papers cited). Upper scripts (^{A,B,C}) are BHC grades by MR07. Constellation names at the end are used, for instance "Nova Mus 1991".

[b] Date (or month) of the first discovery. *p* in this column indicates a "persistent" emission source, but a nova.

[c] AV="Ariel V", BW="BSAX/WFC", CB="CGRO/BASTE", GA="Ginga/ASM", GP="Granat/ART-P", GS="Granat/SIGMA", GW="Granat/WATCH", H1="HEAO1" II="INTEGRAL/IBIS(/ISGRI)", IJ="INTEGRAL/JEM-X", MIR="MIR-KVANT-TMM/SIGMA", RA="RXTE/ASM (2-12 keV)", RP="RXTE/PCA (typically 2–10 keV)", SX="Swift/XRT"

[d] Flux in the first detection in mCrab unit.

[e] Recurrence Dates, YY/MM, and [detected satellite[c] and flux[d]] are shown from MR07, TS96 and IAUC and ATel. Years or monthes in parenthesis are from optical plates.

[f] No mark: HR07, and references therein, Ch: Chen et al. 1997, Ha: Hameury et al. 2003, Hy: Hynes 2005. "(GC)" means that the source is assumed/likely to be near the Galactic center.

[g] References for the columns 2-4 (first detections), 5 (recurrences), and 6 (distance). HFQPO="high frequency QPO", RJ="relativistic jet", FXT="fast X-ray transient"

[1] LMCs are not Galactic sources; [2] $M > 7.8 M_\odot$, see Casares et al. 2004; [3] $M \sim 4 M_\odot$, see Orosz et al. 2004

Table 2. *continued.*

Source Name^a	Date^b	Satellite^c	Flux^d [mCrab]	Recurrence^e	Distance^f [kpc]	References & Notes^g
GRS 1739-278^A	1996/02/28 (96/03/18?)	MIR GS	200 ± 50@2-27keV 80 ± 28@40-75keV		(GC)	44 45
1E 1740.7-2942^A	*p*	–	–	–	(GC)	46
H1743-322^A, IGR J1746-3213, XTE J17464-3213	1977/08	H1		77,03/05[II60,RP50], 04/07[RP16],05/08[RA21], 07/12[RA200],08/09[IJ10]	(GC)	47–52, HFQPO
SLX 1746-331^C	1985/07-08	Spacelab-2		90,03/04[RP40], 07/10[RP8]	(GC)	53 54
XTE J1748-288^A	1998/06/04	RA	90/300/470 @1.5-3/3-5/5-12keV		(GC)	55
XTE J1755-324^B	1997/07/25	RA			(GC)	56
X1755-338^B, V4134 Sgr, 4U1755-33?	*p*	–	–	(GC)		57
GRS 1758-258^A	*p*(90/03∼?)	GA (GS)	40 ± 8@10-20keV 90 ± 20@20-40keV		(GC)	58,44
XTE J1817-330	2006/01/26	RA	930 ± 30		(GC)	59
XTE J1818-245,	2005/08/12	RA	55 ± 5		(GC)	60
V4641 Sgr, SAXJ1819.3-2525, XTE J1819-254	1999/02/20 (99/02/18)	BW RA	20	02/05[RP4.5], 03/08[RP20], 04/07[RP8.2],05/06[RP],07/07[SX]	7.4–12.3 (GC)	61–67, RJ, FXT
EXO 1846-031^C	1985/04	EXOSAT	200	94/09	7?$^{\mathrm{Ch}}$	68
XTE J1856+053	1996/09/10	RP/RA[1]	66/35	07/02[RA23]		69,70
XTE J1859+226, V406 Vul	1999/10/09	RA	160 ± 15		11, $6.3 \pm 1.7^{\mathrm{Ha}}$ $(8 \pm 3)^{\mathrm{Hy}}$	71, HFQPO, RJ?
XTE J1901+014 (GRB020406)	2002/04/06	RA	900			72, FXT?
XTE J1908+094^B	2002/02/17	RP			$> 3^{\mathrm{ref.74,75}}$	73-75
GRS1915+105, V1487 Aql	1992/08/15	GW	~ 300		11–12	76, HFQPO, RJ
Cyg X-1	*p*	–	–	–	2.0 ± 0.1	RJ
4U1957+11^{C,77}, 3U1956+11, V1408 Aql	*p*	–	–	–	7	77
GS2000+25(1), QZ Vul	1988/04/23	GA	$\sim 2,000 - 3,000$		2.7 ± 0.7	78
XTE J2012+381^B	1998/05/24	RA	23			79
GS2023+338, V404 Cyg	1989/05/22	GA	$100 \sim 1,200$	(38/10,56/08)	2.2-3.7, $3.5 \pm 1^{\mathrm{Ha}}$	80

[1] First detected with PCA on Sep. 17–18, and ASM data were retrospectively analyzed.

REFERENCES (#:IAU Circular, @: ATel.): 1. Paciesas et al. 1996 #5580; 2. Elvis et al. 1975 #2184; 3. Lapshov et al., Harmon et al. 1993 #5864; 4. Remillard et al. 2000 #7389; 5. Lund et al. (GW), Makino et al. (GA) 1991 #5161; 6. see Kitamoto et al. 1990; 7. Makino 1987 #4342; 8. Harmon & Robinson 1997 #6774; 9. Remilard et al. 1997 #6772; 10. Casares et al. 2004; 11. Kaluzienski 1975 STIN., 7528978; 12. Barret et al. 2002; 13. Tanaka et al. 1983 #3854; 14. Harmon et al.1992 #5504; 15. Miller et al. 2002 #7920; 16. Smith et al. 1998 #7008; 17. Harmon et al. 1999 #7098; 18. Smith et al. 2000 #7399; 19. Tomsick et al. 2001 #7575; 20. Swank et al. 2002 #7792; 21. Dubath et al. 2003 #8100; 22. e.g., Kalemci et al. 2008 ATel,. 1348; 23. Remillard 2001 #7707; 24. Homan et al. 2006; 25. Zhang et al. 1994 #6046; 26. Harmon et al. 1995 #6128; 27. Alexandorovich et al. 1995 #6143; 28. Harmon et al. 1995 #6147; 29. Harmon et al. 1995 #6196; 30. Remillard et al. 1996 #6393; 31. Hynes et al. 2004; 32. Kaluzienski & Holt 1977 #3104; 33. Griffiths et al. 1977 #3110; 34. in 't Zand et al. 2002 #7582; 35. Ballet et al. (CB), Harmon et al. (GS) 1993 #5781; 36. Churazov et al. (GS), Borozdin & Alexandrovich (MIR) 1994 # 6083; 37. Markwardt 2008 @1442; 38. Chaty & Bessolaz 2006; 39. Remillard et al. 2003 #8050, ATel113; 40. Levine et al. 2005 @623; 41. Turler et al. 2005 @624; 42. Borozdin et al. (MIR), Churazov et al. (GS) 1994 #6083; 43. Sunyaev et al. 1997 #6599; 44. Borozdin et al. 1996 #6350; 45. Paul et al. 1996 #6348; 46. Main et al. 1999; 47. Revnivtsev et al. 2003 @132; 48. Markwardt & Swank 2003 @133; 49. Swank et al. 2004 @301; 50. Swank et al. 2005 @576; 51. Kalemci et al. 2008 @1348; 52. Kuulkers et al. 2008 @1739; 53. Markwardt 2003 @143; 54. Markwardt 2007 @1235; 55. Smith et al. 1998 @25, # 6793; 56. Remillard et al. 1997 #6710; 57. (McClintock et al. 1978 #3251); 58. Mandau 1990 #5032; 59. Remillard et al. 2006 @ 714; 60. Levine et al. 2005 @578; 61. In'tZand 1999 #7119; 62. Warkwardt et al. 1999 #7120; 63. Markwardt & Swank 2002 #7906; 64. Bailyn et al. 2003 @171; 65. Swank 2004 @295; 66. Swank et al. 2005 @536; 67. Cackett & Miller 2007 @1135; 68. Parmer & White 1985 #4051; 69. Marshall et al. 1996 #6504; 70. Levine & Remilllard 2007 @1024; 71. Wood et al. 1999 #7274; 72. Remillard & Smith 2002 @88; 73. Wood et al. 2002 #7856; 74. in't Zand et al. 2002; 75. Chaty et al. 2006; 76. Castro-Tirado et al. 1992 #5590; 77. Wijnands R. et al. 2002; 78. Makino et al. 1988 #4587; 79. Remillard et al. 1998 #6920; 80. Makino et al. 1989 #4782;

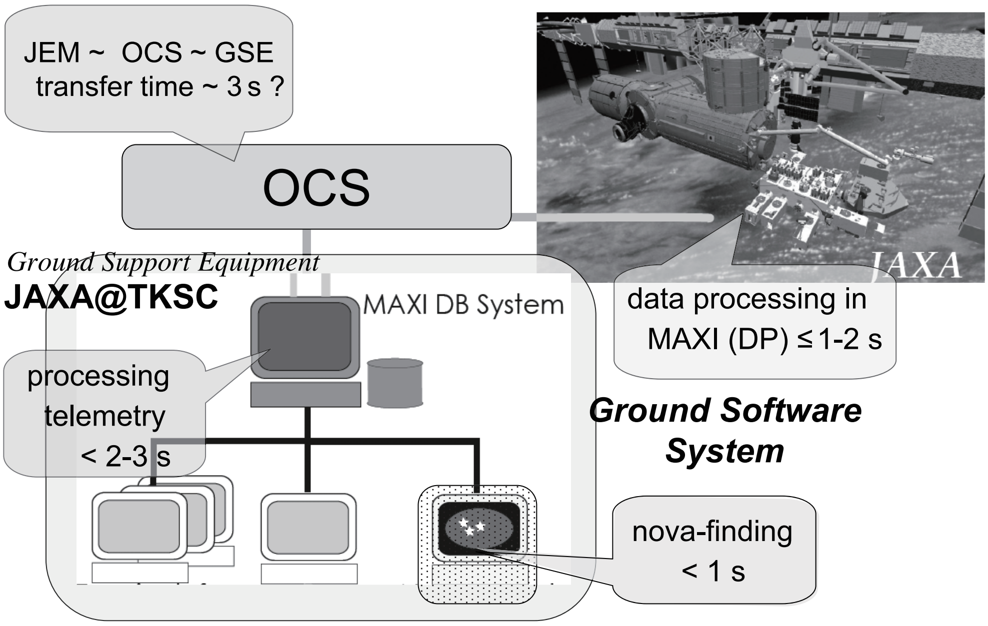

Fig. 3. Data flow and necessary time to generate/transfer data from MAXI onboard to a nova-finding system on the ground.

5. MAXI Nova Alert System

This section describes our nova (transient object) finding and alert system currently under development and how one can obtain information about a nova and other transient object discovered with MAXI.

Figure 3 illustrates the data flow from MAXI onboard the ISS to the ground data processing system. Telemetry data are generated every second and transfered to the ground using the ISS quasi-realtime network. However, the whole transfer takes about 10s to complete, even though our nova-finding system takes only less than 1s to obtain the first alert information (Negoro et al. 2008).

After the detection of a new source, we are planing to send alert information via the GCN (Gamma-ray burst Coordinates Network: http://gcn.gsfc.nasa.gov) circular for short transient events such as gamma-ray bursts on the timescale of seconds. For X-ray novae, which will be detectable on timescale of one scan (∼40 s) or hours, information will be sent via e-mail to the people who have registered at the MAXI web site (http://maxi.riken.jp; see Kohama et al. in this volume).

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References

Barret D. 1992 ApJ., 392, L19
Casares J. 2004 ApJ., 613, L133
Chaty S. & Bessolaz N. 2006 A&A., 455, 639
Chaty S. et al. 2006 MNRAS., 365, 1387
Chen W. et al. 1997 ApJ., 491, 312
Ebisawa K. et al. 1994 ApJ., 46, 375
Esin A. et al. 1997 ApJ., 489, 865
Fender R. et al. 2004 MNRAS., 355, 1105
Hameury, J.-M. 2003 A&A., 339, 631
Homan J. et al. 2006 MNRAS., 366, 235
Hynes, R.I. 2004 ApJ., 609, 317
Hynes, R.I. 2005 ApJ., 623, 1026
in't Zand J.J. et al. 2002 A&A., 394, 553
Kitamoto S. et al. 1990 ApJ., 361, 590
Kitamoto S. et al. 1992 ApJ., 394, 609
Maeda Y. et al. 1996 PASJ., 48, 417
Main D.S. et al. 1999 ApJ., 525, 901
Matsuoka M. et al. 1997 SPIE., 3114, 414
Mendez M. and van der Klis M. 1997 ApJ., 479, 926
McClintock J.E. and Remillard R.A. 2007 (MR07) in *Compact Stellar X-ray Sources*, eds. W.H.G Lewin and M. van der Klis, Cambridge University Press. 39, Chap.4 (astro-ph/0306213v4)
Miyamoto S. et al. 1993 ApJ., 403, L39
Narayan R. et al. 1997 ApJ., 478, 79
Negoro H. et al. 2008 ASPC., 394, 597
Oda H. et al. 2007 PASJ., 59, 457
Orosz J.A. et al. 2004 ApJ., 616, 376
Remillard R.A. et al. 2002 ApJ., 580, 1030
Tanaka Y. and Shibazaki, N 1996 (TS96) ARAA., 34, 607
Wijnands R. et al. 2002 MNRAS., 331, 60