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News from Cyg X-1 and Other Galactic Black Holes

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Abstract In the first part of my review, the present status of the possible black hole microlensing events and the evidence for the possible presence of intermediate mass black holes in some globular clusters are briefly discussed. The present understanding of high and low frequency quasi-periodic oscillations in systems containing black hole candidates is also reviewed. In the second part, the news from five individual objects (Cyg X-1, LMC X-1, SS 433, GRS 1915+105 and Sgr A*) are presented. Finally, the updated list of confirmed black holes, containing 21 objects is given.

Key words: stars: X-ray binaries — stars: black holes — stars: individual: Cyg X-1, LMC X-1, SS 433, GRS 1915+105, Sgr A*

1 INTRODUCTION

Our Galaxy contains, probably, some $10^7 \div 10^8$ stellar mass black holes (this number is based on stellar population synthesis calculations). In addition, there are, possibly, few to few tens of intermediate mass black holes in some globular clusters. We know also one supermassive galactic black hole at the center of our Galaxy. Inventory of the identified black hole candidates (BHCs) contains some 53 objects in the first category (50 of them are members of the X-ray binaries and 3 are possible black hole microlensing events) and one object (Sgr A*) in the third category.

Below, some statistical information concerning the 50 known stellar mass BHCs in the X-ray binaries is given.

• **Brief Statistics**

The list of BHCs in the X-ray binaries contains now 50 objects (including 21 confirmed BHs - see Tab. 2). About 45 of them (including 17 confirmed) have low mass companions (and so are members of low mass X-ray binaries), while only about 5 (4 confirmed) are members of high mass X-ray binaries. For the X-ray pulsars (strongly magnetized neutron stars) the distribution is just reversed: out of more than 100 accreting X-ray pulsars, presently known, only about 10 are found in low mass X-ray binaries.

• **Black holes and X-ray Novae**

Galactic binary black holes show clear preference for a specific class of X-ray binaries, namely, for X-ray Novae. This is true also vice versa: great majority of X-ray Novae contain black holes. Out of $\sim$ 54 XNe known so far (the precise number depends on the definition of an X-ray Nova, so perhaps it is better to talk about Soft X-ray Transient (SXTs)), only in $\sim$ 13 the compact object is a neutron star. The remaining systems ($\sim$ 41) contain BHCs. Since typical XNe remain dormant most of the time, the true number of the black holes in the X-ray binaries might be easily by one or two orders of magnitude larger than the $\sim$ 50 objects, mentioned above. Most of these black holes reside in presently dormant XNe. The XNe containing BHCs are now being discovered at a rate of $1-2$ new objects per year.

• **Black holes and microquasars**

Out of 16 known galactic microquasars, two contain neutron stars (Sco X-1 and Cir X-1), in one the nature of the compact object is unclear (Cyg X-3) and in 13 the compact object is a BHC. Among these 13, there are 4 superluminal jet sources. There is some evidence that three of these superluminal sources contain Kerr (rapidly rotating) BHs.

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2 BLACK HOLE CANDIDATES FROM MICROLENSING EVENTS

Among several hundreds of microlensing events observed so far there are about 30 so called "parallax events". These events are long enough to show the magnification fluctuations, reflecting the orbital motion of the Earth around the Sun. This effect permits us to calculate the "microlensing parallax" which is a measure of the relative transverse motion of the lens with respect to the observer. Assuming standard model of the Galactic velocity distribution, one is then able to perform a likelihood analysis, which permits us to estimate the distance and the mass of the lens. With the help of the above analysis, three long events were selected as, possibly, caused by black hole lenses. The candidates are: MACHO-98-BLG-6 (probable mass of the lens $\sim 3 \div 13 M_{\odot}$, Bennett et al. 2002a), MACHO-96-BLG-5 (probable mass of the lens $\sim 3 \div 16 M_{\odot}$, Bennett et al. 2002a) and MACHO-99-BLG-22 = OGLE-1999-BUL-32 (probable mass of the lens $\sim 100 M_{\odot}$, Bennett et al. 2002b). Only the last of them seems to be a robust candidate. I will also add, that Paczyński (2003) promised more BH lenses from OGLE III project in some $2 \div 3$ years. OGLE III detects currently more than 500 events per year and, among them, some $20 \div 30$ parallax events. Based on the present (rather poor) statistics, we might expect that few of them (per year) should be BHCs.

3 INTERMEDIATE MASS BLACK HOLES

The case for the existence of intermediate mass black holes (IMBHs) is still not very strong but slowly it gets stronger. The objects suspected of containing IMBHs are ultraluminous compact X-ray sources (ULXs) and centers of some globular clusters (ULXs are point X-ray sources so bright that, even assuming Eddington luminosities, the masses of the accreting compact objects have to be in the range few hundreds to few thousands solar masses). Since there are no ULXs in the Milky Way, the only places to look for IMBHs are centers of some globular clusters. At present, there are two such candidates in our Galaxy (clusters M15 and NGC 6752) and one in the Andromeda Galaxy (cluster G1). The evidence for M15 comes from the HST kinematical data concerning the stellar motions near the cluster center (Gerssen et al. 2003). The inferred mass of the central black hole is $1.7^{+2.7}_{-1.7} \times 10^3 M_{\odot}$. The analysis for NGC 6752 is based on the kinematics of five milisecond radio pulsars known in this cluster (Ferraro et al. 2003). The inferred mass of the central black hole is, in this case, about few thousand solar masses. The best case (at present) can be made for G1. The analysis based on both stellar kinematics and the surface brightness profiles (Gebhardt et al. 2005) leads to the mass of the central black hole equal $(1.7 \pm 0.3) \times 10^4 M_{\odot}$. We should remember, of course, that G1 is not a galactic cluster. However, the strong evidence for the presence of an IMBH in M31 increases the probability of similar objects being present also in our Galaxy.

As far as ULXs in the nearby galaxies are concerned, it seems that some of them (although probably not all) are binary systems containing IMBHs. Again, their existence supports the case for the presence of IMBHs in our Galaxy (in spite of the fact that Galaxy contains no ULXs).

From theoretical point of view, the existence of IMBHs does not seem to be a major problem. In particular, different mechanisms leading to the formation of IMBHs in globular clusters were considered by Colpi et al. (2005) and Kawakatu & Umemura (2005).

4 HIGH FREQUENCY QPO'S IN BLACK HOLE CANDIDATES

The list of high frequency QPOs observed in X-ray emission from galactic BHCs is given in Table 1 (compiled from Remillard et al. 2002 and McClintock & Remillard, 2004, 2005). The most striking feature of these QPOs is the fact, that in most of the systems the QPO frequencies form sets of precise integral harmonics. The fundamental frequency seems to be unique characteristic of each black hole and, presumably, depends only on its mass and spin. We observe 2:3 harmonics in GRO J1655$-$40 and XTE J1550–564 and 1:2:3 harmonics in GRS 1915+105. This last system shows, additionally, an independent set of 3:5 harmonics (41 and 67 Hz). One can also consider the set of 113 and 168 Hz QPOs (2:3). All theories discussing BHCs QPOs predict that the frequencies should scale with the mass of the compact object like M^{-1}. In addition, they should increase with the increasing spin of the black hole. McClintock & Remillard (2003) found an empirical fit to the observations of three galactic microquasars (GRO J1655$-$40, XTE J1550$-$564 and GRS 1915+105) using higher frequency in the 2:3 twin peak QPOs: $\nu_3 \approx 2.8\ (M_{\odot}/M)$ kHz. Their fit neglected the spin dependence. The analysis of the same three BHCs, taking into account the spin, was performed by Abramowicz et al. (2004) and Török et al. (2005) with the help of the parametric epicyclic resonance theory.

Table 1 High Frequency QPOs Observed in BHC Binary Systems.

Name	$\nu_{\rm QPO}$ [Hz]	$M_{\rm BH}$ [$M_{\odot}$]	comments
GRO J1655−40	300±5	6.3±0.3	
	450±3		
XTE J1550−564	184±5	10.6±1.0	
	272±3		
H 1743−322	166±5		
	242±3		
GRS 1915+105	41±1	14±4	
	67±5		
	113±5		
	168±3		
	328±4		
	495		1.5 σ
4U 1630−472	184±5		
XTE J1859+226	193±4	9±1	
XTE J1650−500	250		

NOTE: 495 Hz QPO in GRS 1915+105 was detected at only 1.5 σ signifi cance level.

The authors of this theory (Abramowicz & Kluźniak 2001, Abramowicz et al. 2004, Kluźniak et al. 2004, Lee et al. 2004, Török et al. 2005) noticed that the General Relativity (unlike the Newtonian gravity) predicts independent frequencies of epicyclical oscillation for each spatial coordinate for a blob of matter on a perturbed orbit around rotating compact object. Modeling done by these authors demonstrates that there are locations at the inner accretion disc where the coordinate epicyclical frequencies (e.g. the radial and the azimuthal ones) form small integral ratios like 3:2, 2:1, 3:1 etc. A non-linear resonance develops at such locations leading to the enhancement of the oscillations and producing the observed QPOs. The theory provides a natural and elegant explanation of the small integral ratios found for the frequencies of BHCs QPOs.

The comparison of the predictions of the theory with the observations of the three microquasars, mentioned above, is shown in Figure 1. The obvious conclusion is that the three considered BHCs must possess substantial spins: their dimensionless angular momenta (spin parameters) have to be in the range 0.7 to 0.99. The fit of McClintock & Remillard, mentioned above implies $\bar{a} \approx 0.97$.

5 LOW FREQUENCY QPO'S IN BLACK HOLE CANDIDATES

Low frequency QPOs in BHCs have, generally, lower frequencies (0.1−15 Hz), than similar QPOs in neutron star systems (5−60 Hz) (see e.g. van der Klis, 2005). These QPOs (in BHCs) are classified into three types: A (frequency $\nu \sim 8$ Hz, intensity independent; coherency $\nu/\Delta\nu \lesssim 3$; amplitude $\lesssim 3\%$ rms), B (frequency $\nu \sim 5 \div 6$ Hz, intensity independent; coherency $\nu/\Delta\nu > 6$; amplitude $\sim 2 \div 4\%$ rms) and C (frequency $\nu \sim 0.1 \div 15$ Hz, increasing with intensity; coherency $\nu/\Delta\nu \sim 7 \div 12$; amplitude $\sim 3 \div 16\%$ rms (anticorrelated with frequency)). Recently, Casella et al. (2005) analyzed low frequency QPOs in three BHCs: XTE J1859+226, XTE J1550–564 and GX 339–4. All three sources show all three types of low frequency QPOs: A, B and C. The authors demonstrate that properties of these QPOs indicate close analogy with the QPOs on flaring branch (FB), normal branch (NB) and horizontal branch (HB) of neutron star Z-type sources. It means, in particular, that the evolutionary sequence C $\rightarrow$ B $\rightarrow$ A for BHCs corresponds to the evolutionary sequence HB $\rightarrow$ NB $\rightarrow$ FB observed for neutron star Z-type sources (in both sequences the accretion rate and the X-ray intensity increase along the evolutionary track).

One should remind that we do not understand the physical mechanism responsible for the low frequency QPOs and, therefore, the analogy described above remains, at present, purely phenomenological.

Table 2 Confirmed Black Holes in X-ray Binaries

Name	$P_{\rm orb}$	Opt. Sp	X−R	C	$M_{\rm BH}/M_\odot$	Ref
Cyg X−1	$5^{\rm d}6$	O9.7 Iab	pers	μQ	20 ± 5	1
LMC X−3	$1^{\rm d}70$	B3 V	pers		6 ÷ 9	
LMC X−1	$4^{\rm d}22$	O7−9 III	pers		4 ÷ 10	
SS 433	$13^{\rm d}1$	∼ A7 Ib	pers	μQ	3 ÷ 9	2
GX 339−4	$1^{\rm d}756$	F8−G2 III	RT		$\gtrsim 6$	3
GRO J0422+32	$5^{\rm h}09$	M2 V	T		4 ± 1	
A 0620−00	$7^{\rm h}75$	K4 V	RT		11 ± 2	
GRS 1009−45	$6^{\rm h}96$	K8 V	T		4.4 ÷ 4.7	
XTE J1118+480	$4^{\rm h}1$	K7−M0 V	T		6.0÷ 7.7	
GS 1124−684	$10^{\rm h}4$	K0−5 V	T		7.0 ± 0.6	
GS 1354−645	$2^{\rm d}54$	G0−5 III	T		> 7.8 ± 0.5	4
4U 1543−475	$1^{\rm d}12$	A2 V	RT		8.4 ÷ 10.4	
XTE J1550−564	$1^{\rm d}55$	G8 IV−K4 III	RT	μQ	9.7 ÷ 11.6	
XTE J1650−500	$7^{\rm h}63$	K4 V	T	μQ	4.0 ÷ 7.3	5
GRO J1655−40	$2^{\rm d}62$	F3−6 IV	RT	μQ	6.3 ± 0.3	
H 1705−250	$12^{\rm h}5$	K5 V	T		5.7 ÷ 7.9	
XTE J1819−254	$2^{\rm d}817$	B9 III	T	μQ	6.8 ÷ 7.4	
XTE J1859+226	$9^{\rm h}16$	∼ G 5	T		8 ÷ 10	
GRS 1915+105	$33^{\rm d}5$	K−M III	RT	μQ	14 ± 4	
GS 2000+251	$8^{\rm h}3$	K5 V	T		7.1 ÷ 7.8	
GS 2023+338	$6^{\rm d}46$	K0 IV	RT		10.0 ÷ 13.4	

NOTES:

$P_{\rm orb}$ − orbital period
Opt. Sp − optical spectrum
X-R − X-ray variability
C − comments
$M_{\rm BH}$ − mass of black hole component
Ref − references
T − transient
RT − recurrent transient
pers − persistent
μQ − microquasar

The errors or ranges for $M_{\rm BH}$ are in most cases quoted after original references. The detailed discussion of these estimates is given in Ziółkowski (2003).

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Most of the references are given in Ziółkowski (2003). Additional references are: (1) Ziółkowski (2005a), (2) this paper, (3) Hynes et al. (2003), (4) Casares et al. (2004), (5) Orosz et al. (2004).

6 NEWS FROM THE INDIVIDUAL OBJECTS

6.1 Cyg X-1

Recent calculations (Ziółkowski 2005a), carried out to model the evolution of HDE 226868 (an optical companion of Cyg X-1), provided robust limits on the present mass of this star. The calculations were carried out under different assumptions about the stellar wind mass loss rate. The resulting evolutionary tracks in the H-R diagram are shown in Figure 2. It was found that the present mass of HDE 226868 has to be 40 ± 5 $M_\odot$ if the distance to the system is in the range 1.95 to 2.35 kpc and the effective temperature of HDE 226868 in the range 30 000 to 31 000 K (the most likely ranges for these two parameters). Extending the possible intervals of those parameters to 1.8 to 2.35 kpc and 28 000 to 32 000 K, resulted in the mass of the star 40 ± 10 $M_\odot$. Including into the analysis observational properties such as the profiles of the emission lines, rotational broadening of the absorption lines and the ellipsoidal light variations, it was possible to estimate also the mass of the compact component. It has to be in the ranges 20 ± 5 $M_\odot$ and 13.5 ÷ 29 $M_\odot$ for the two cases described above. The same analysis (using the evolutionary models and the observational properties listed above) yielded lower limit to the distance to the system of ∼ 2.0 kpc, if the

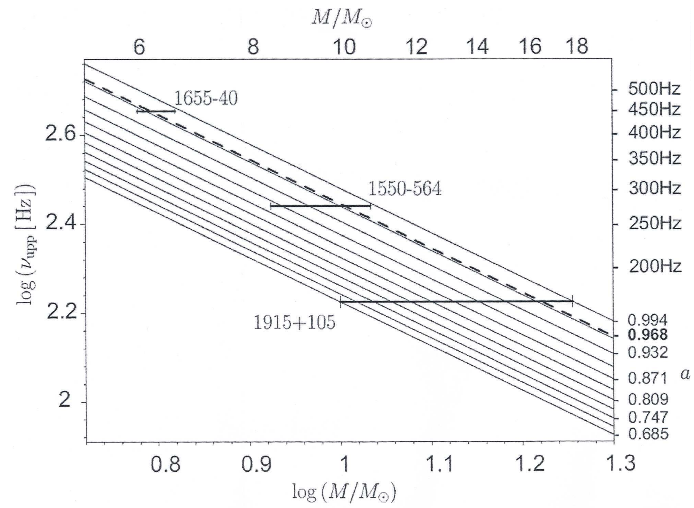

Fig. 1 Fit of the upper frequency ν_3 predicted by the 3:2 parametric resonance model to the frequencies observed in three microquasars with known masses. The lines of the constant values of the spin parameter a are calculated from the model. The deduced black hole spins are rather high: a is in the range 0.7 to 0.99. The dashed line describing the empirical fi t of McClintock & Remillard ($\nu_3 \approx 2.8(M_\odot/M)$ kHz) implies $\bar{a} \approx 0.97$. The fi gure is reproduced after T¨or¨ok et al. (2005).

effective temperature of HDE 226868 is higher than 30 000 K. This limit to the distance does not depend on any photometric or astrometric considerations.

6.2 LMC X-1

Similar evolutionary analysis was carried out (Ziół kowski 2005b) for Star 32 (an optical companion of LMC X-1). Assuming reasonable values of the parameters of this O7 III star (the effective temperature Te in the range 34 000 to 38 000 K and the visual extinction equal $A_V \approx 1.1 \pm 0.25$ as appropriate for the Large Magellanic Cloud), one gets for the present mass of the star the values in the range 24 to 33 $M_\odot$ (see Fig. 3). Assumption that the visual extinction is only $\sim$ 0.6 decreases the lower limit to $\sim$ 22 $M_\odot$. The mass cannot be smaller, because the star is too luminous. However, other observational data (radial velocities of the absorption lines from Star 32 and of the emission lines from the accretion disc, high X-ray luminosity) imply that mass of the Star 32 cannot be larger than $\sim 8 \div 9\ M_\odot$. There are only two possible solutions of this discrepancy: either observations of Star 32 (spectroscopy and/or photometry) are in serious error or Star 32 is essentially a helium star (with only a small remnant of the hydrogen rich envelope). The future observations should solve this problem.

6.3 SS 433

This exceptional object (the first discovered galactic microquasar) was studied very extensively for almost 30 years. In spite of that, the masses of the components of this binary system are still poorly determined. Until recently, it was not even clear, whether the compact component is a black hole. The main reason for the troubles was the fact that the spectrum of the companion of the compact object (the mass donor or the "optical component") was not visible. The reason of this "invisibility" was, in turn, the fact that the optical emission is dominated by the accretion disc. The system is very luminous in the optical band: $L_{\mathrm{opt}} \gtrsim 2 \times 10^{38}$ erg s^{-1}. About 80% of this luminosity comes from the photosphere of geometrically thick accretion disc, which can be treated as a flattened star. The observed He II emission lines originate on the surface of the disc and reflect its orbital motion (and so the orbital motion of the compact component). Until recently, no spectral lines produced by the second member of the binary (the mass donor) were seen.

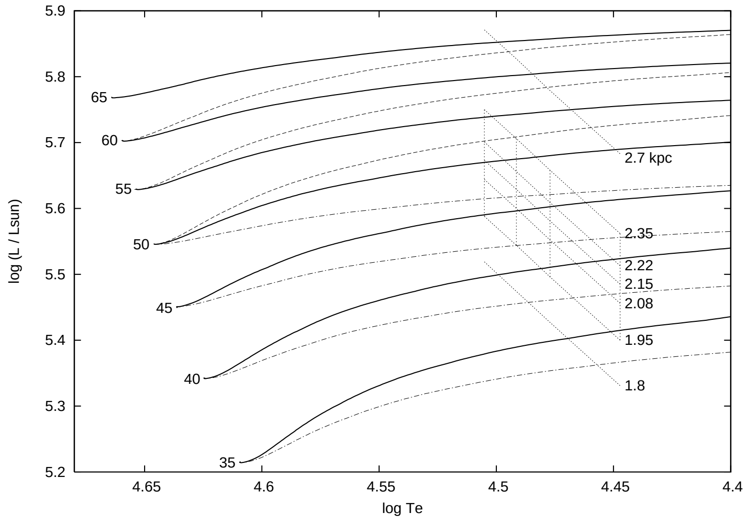

Fig. 2 The evolutionary tracks in the H-R diagram. The tracks are labeled with the initial mass of the star (in solar units). The solid lines describe the tracks computed with the stellar wind mass loss rates according to HPT (Hurley et al. 2000) formula. The broken lines and the dash-dotted lines describe the tracks computed with the mass loss rates smaller by a factor of two and larger by a factor of two, respectively. The slanted dotted lines correspond to the position of HDE 226868 for different assumed values of its distance (the assumed value of the distance in kpc is given at the right end of each line). The vertical dotted lines correspond to the effective temperatures of HDE 226868 equal (from left to right) to 32, 31, 30 and 28 $\times 10^3$ K. The most likely position of HDE 226868 lies within the large parallelogram ($\pm 3\sigma$ error in distance).

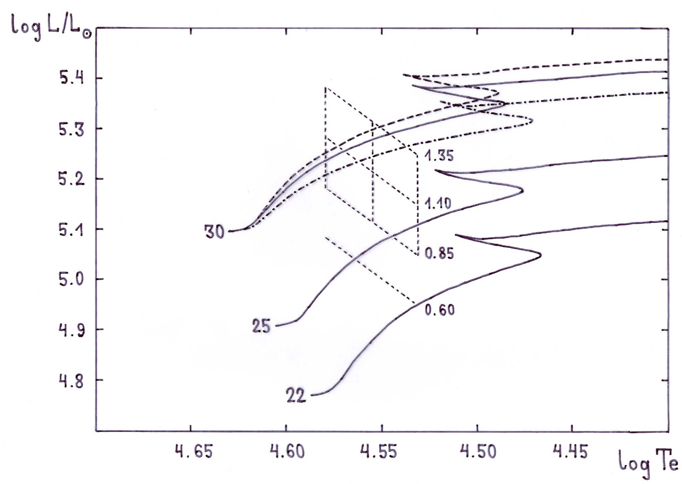

Fig. 3 The evolutionary tracks in the H-R diagram. The slanted dotted lines correspond to the position of Star 32 for different assumed values of its visual extinction (the assumed value of the extinction A_V is given at the right end of each line). The vertical dotted lines correspond to the effective temperatures of Star 32 equal (from left to right) to 38, 36 and 34 $\times 10^3$ K. All other symbols have the same meaning as in Figure 2. The most likely position of Star 32 lies within the large parallelogram.

Therefore, atypically, only the mass function $f(M_{\rm opt})$ (where $M_{\rm opt}$ is the mass of the unseen donor) could be estimated. Different estimates were made, but the most convincing (and the most generally accepted) one, was the analysis of the emission lines from the disc performed by Fabrika & Bychkova (1990), who measured the semiamplitude of radial velocities as $K_{\rm X} = 175 \pm 20$ km s^{-1}. This corresponds to the mass function $f(M_{\rm opt}) = 7.7(+3.0, -2.4)\ M_\odot$. The inclination of the orbital plane is known very precisely from the kinematic model of the jets: $i = 78.82^\circ\ \pm 0.11^\circ$. Unfortunately, until recently, masses of the components could not be calculated since the second mass function was missing (no radial velocities of the mass donor could be measured because no lines from this component were visible).

Three years ago, the spectrum of the second component was finally seen. Gies et al. (2002) detected the absorption lines of the mass donor and were able to measure their radial velocities. They classified the spectrum as A-type supergiant ($\sim$ A7 Ib) and measured the semiamplitude of the radial velocities: $K_{\rm opt} = 100 \pm 15$ km s^{-1} (which corresponds to $f(M_{\rm x}) = 1.36(+0.71, -0.52)\ M_\odot$). Taking the semiamplitude of the radial velocities of the emission lines from Fabrika & Bychkova ($K_{\rm X} = 175 \pm 20$ km s^{-1}) and using the known value of the inclination ($i = 78.8^\circ\ \pm 0.1^\circ$), they estimated the mass ratio $M_{\rm x}/M_{\rm opt} = 0.57 \pm 0.11$ and the masses $M_{\rm opt} = 19 \pm 7\ M_\odot$ and $M_{\rm x} = 11 \pm 5\ M_\odot$.

Unfortunately, it appeared soon that the estimate of the semiamplitude of the radial velocities was not very reliable. The measurements covered only small part of the orbital cycle and they were not confirmed by subsequent observations (Charles et al. 2004). The measurements are not easy, since the visibility and the apparent velocity of the lines are variable on two basic timescales: the binary orbital period ($P_{\rm orb} = 13.087 \pm 0.003$ d) and the period of the precession of the accretion disc and jets ($P_{\rm prec} \approx 162.5$ d), which makes the full picture of variability quite complicated. Gies and collaborators repeated the observations at the optimal disc precession phase and, after careful spectroscopy, they got $K_{\rm opt} = 45 \pm 6$ km s^{-1} (Hillwig at al. 2004). Together with $K_{\rm X} = 168 \pm 18$ km s^{-1}, this leads to the mass ratio $M_{\rm x}/M_{\rm opt} = 0.27 \pm 0.05$ and the masses $M_{\rm opt} = 10.9 \pm 3.1\ M_\odot$ and $M_{\rm x} = 2.9 \pm 0.7\ M_\odot$ (still a black hole, but marginally so).

This was, however, not the end of the story. Cherepashchuk et al. (2005), after large international campaign, involving the 6 m optical BTA telescope and the orbital observatories INTEGRAL and RXTE, found $K_{\rm opt} = 132 \pm 9$ km s^{-1} (corrected for strong heating effect) and (with $K_{\rm X} = 175 \pm 20$ km s^{-1}) $M_{\rm opt} \approx 30\ M_\odot$ and $M_{\rm x} \approx 9\ M_\odot$.

Clearly, the situation is confusing. However, in the conclusion, I would like to note that all four papers agree that:

- $K_{\rm X} \approx 170$ km s^{-1}
- Optical Sp $\sim$ A4 I $\div$ A7 I
- Compact object is a black hole
- $M_{\rm BH}\ \epsilon <\sim 3 \div 9 M_\odot >$

Perhaps SS 433 should not be included yet in the list of "confirmed black holes" (see Table 2), but most likely it does contain a black hole.

6.4 GRS 1915+105

This unusual microquasar, noted for its exceptional variability and high accretion rate, was also known as harboring one of the most massive stellar mass black holes in the Galaxy ($M_{\rm x} = 14 \pm 4\ M_\odot$, Greiner et al. 2001). This mass became a subject of controversy last year. Kaiser et al. (2004) claimed that two IRAS sources at the distance d = 6.5 kpc are products of the microquasar jets. This would imply that the distance to the microquasar is 6.5 kpc rather than 11 kpc obtained from the earlier determinations. This smaller distance leads, in turn, to the smaller orbital inclination (from the kinematical model of the jets): i = 53° instead of 66° and larger mass of the compact object: $M_{\rm x} = 21 \pm 9\ M_\odot$. In this way, GRS 1915+105 became, for a short time, the most massive stellar mass black hole in the Galaxy. However, quite recently, Zdziarski et al. (2005) reanalysed the problem and demonstrated that IRAS sources have spatial motion completely different from that of GRS 1915+105. All other arguments support the distance $d \sim 11$ kpc. Therefore, the mass of the black hole in the system became, again, $M_{\rm x} = 14 \pm 4\ M_\odot$.

6.5 SGR A*

This supermassive black hole in the center of our Galaxy has a mass of about $3.6 \times 10^6\ M_\odot$ (determination from the stellar orbits) and, possibly, a substantial angular momentum ($a \approx 0.994$, according to Aschenbach et al. 2004). The black hole is, at present, very quiet (accretion rate is very low and the persistent X-ray luminosity is only $\sim 2 \times 10^{33}$ erg s^{-1}). However, it was not always the case. The nearby molecular cloud Sgr B2 is bright in 6.4 keV iron line, but only on one side $-$ that facing Sgr A* (Murakami 2005). It is, clearly, an X-ray reflection nebula, but no irradiating source is seen today. The only explanation is that Sgr A* had to be much brighter in recent past. INTEGRAL discovered recently that Sgr B2 emits also in hard ($\gtrsim$ 20 keV) X-rays (Murakami 2005, Hermsen 2005). The spectrum of this Compton scattered radiation indicates that some 300 years ago an illuminating source with the spectrum similar to that of a low luminosity AGN had to be present nearby. It could be only Sgr A*.

7 CONFIRMED BLACK HOLES

Table 2 contains the up to date list of 21 dynamically confirmed black holes (those with dynamically estimated masses greater than about 3 $M_\odot$) in the X-ray binaries.

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