Part VI

PROSPECTS FOR THE FUTURE

Future X-ray timing missions

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Abstract. Thanks to the Rossi X-ray Timing Explorer (RXTE), it is now widely recognized that fast X-ray timing can be used to probe strong gravity fields around collapsed objects and constrain the equation of state of dense matter in neutron stars. We first discuss some of the outstanding issues which could be solved with an X-ray timing mission building on the great successes of RXTE and providing an order of magnitude better sensitivity. Then we briefly describe the "Experiment for X-ray timing and Relativistic Astrophysics" (EXTRA) recently proposed to the European Space Agency as a follow-up to RXTE and the related US mission "Relativistic Astrophysics Explorer" (RAE).

Keywords: general relativity, X-ray timing

1. Introduction

In the last few years the predicted sub-millisecond plasma orbital periods and millisecond spin periods of accreting low-magnetic-field neutron stars (NS) have finally been detected by RXTE. The same satellite also found 0.1 kHz Quasi-Periodic Oscillations (QPOs) in black hole candidates (BH) and, the first (and so far only) accreting millisecond pulsar (see van der Klis 2000 for a review). RXTE has opened up a completely new field of investigation and it is now widely recognized that fast timing provides one of the most powerful tools for such objectives *(a)* to test General Relativity (GR) in strong gravity fields, *(b)* to constrain the fundamental properties of collapsed stars (EOS of NS, mass and spin of BH).

The RXTE discoveries were made possible by its large X-ray detector area (0.67 m^2, sub-μs time resolution and high data rates. The RXTE All Sky Monitor (ASM) and the flexibility of operation and rapid response also played a major role in the success of the mission (Bradt et al. 1993).

For X-ray timing, the signal to noise ratio at which non-coherent variability such as a QPO is detected scales as the source count rate (i.e. the detector area) in the strong source limit (for a photon counting experiment). Based on this, here we describe how an instrument with *ten times* the detector area of RXTE could help to solve some of the outstanding issues in the astrophysics of collapsed stars.

2. The science of a future X-ray timing mission

High-frequency QPOs have been seen in both BHs and NSs. In BHs, the QPO models proposed invoke GR effects in the inner accretion disk and depend strongly on the BH spin, making these QPOs effective probes of spacetime near the event horizon (see e.g. McClintock 1998). In NSs, three types of QPOs are commonly observed (see Fig. 1, ν_{LF}, 15–60 Hz, ν_1, 200–800 Hz and ν_2). Evidence is building that there exists a close relationship between the QPO properties of NS and BH X-ray binaries. In particular a remarkable correlation between the centroid frequency of QPOs (or peaked noise components) has been found which extends over nearly 3 decades in frequency and encompasses both NS and BH systems (Psaltis, Belloni & van der Klis 1999). In the relativistic precession model (Stella & Vietri 1998), ν_{LF}, ν_1, ν_2 observed across a wide range of objects are identified with three fundamental frequencies characterizing the motion of matter in the strong field of a point mass as predicted by General Relativity (GR). The low-frequency QPO at ν_{LF} is thought to be due to *nodal precession*, dominated by the inertial-frame dragging predicted by GR in the vicinity of a fast rotating collapsed object. The lower frequency kHz QPO at ν_1 is identified with relativistic *periastron precession*, an early crucial test of GR. Unlike the cases of Mercury and the relativistic binary pulsar PSR1913+16, for which weak field expansions apply, the periastron precession close to a collapsed star is dictated by strong field effects, requiring a full general relativistic treatment. Finally ν_2 is the orbital ("Keplerian") frequency; its value alone restricting the allowed range of mass and radius of the NS (Miller et al. 1998). Other models rely on a beat-frequency interpretation for both ν_1 and ν_{LF} (Alpar and Shaham, 1985, Miller et al. 1998).

With an order of magnitude better sensitivity, QPOs from a few Hz to 1600 Hz should be detected from many objects with a high enough significance to use the data for crucial tests. Regardless of the physical origin of the QPOs at ν_{LF} and ν_1, the increased sensitivity and range will have dramatic benefits. At higher frequencies, either

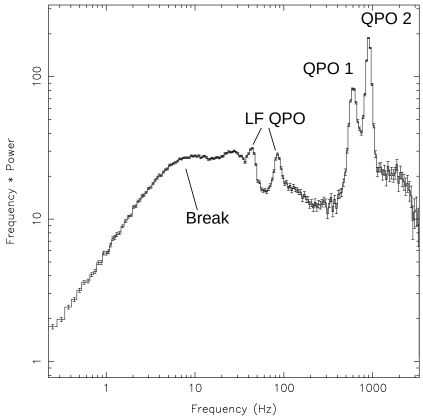

Figure 1. Power spectrum of Sco X-1 obtained with RXTE showing the kHz QPOs at ν_1 and ν_2 and the LF QPO (plus its harmonic). With EXTRA, about twenty kHz QPO sources will be measured at signal-to-noise similar to this (the fainter sources have stronger kHz QPOs). For Sco X-1 the signal-to-noise will improve tenfold.

strong signatures of the innermost stable circular orbit (ISCO), which sets an upper bound on ν_2, will be discovered from several sources (evidence has been found for one source so far: 4U1820-30, Zhang et al. 1998), or the frequencies themselves will allow the elimination of several candidate equations of state of dense matter (Miller et al. 1998). In the *relativistic precession* interpretation, there are several predictions that could be tested. First, the epicyclic frequency $\Delta\nu = \nu_2 - \nu_1$ steeply falls to zero as ν_2 increases and the orbital radius approaches the ISCO. The behaviour of the epicyclic frequency in the vicinity of BH and NS is dominated by strong-field effects and drastically different from any Newtonian or post-Newtonian approximation. Hence it provides a powerful test of the strong field properties of the metric (see Stella & Vietri 1999). According to the model $\Delta\nu$ should also decrease for low values of ν_2. Second, ν_{LF} should scale as ν_2^2 over a wide range of frequencies (until "classical" terms due to stellar oblateness become important). Observing such scaling would provide an unprecedented test of the $1/r^3$ radial dependence of ν_{LF} predicted in the Lense-Thirring interpretation (Stella & Vietri 1999). We note that in the hydrodynamical model of the disk inner boundary developed by Psaltis & Norman (2000), the test particle frequencies (the same as in the relativistic precession model plus a few other additional frequencies, see also Psaltis 2000) are selected by the response of the inner disk, when this is subject to a wide-band input noise.

In the above models, the QPO frequencies depend sensitively on the mass (M) and angular momentum (J) of the compact star, as well as on the radius at which the QPOs are produced. M and J could

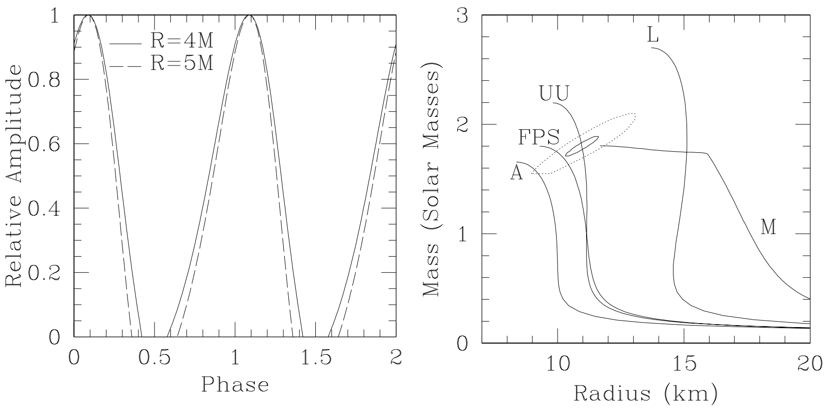

Figure 2. left) Simulated cycle waveforms for burst oscillations on a 1.8 $M_\odot$ neutron star with a spin frequency of 364 Hz of radius $R = 4GM/c^2$ (solid line) and radius of $R = 5GM/c^2$ (dashed line). The more compact star (with smaller R/M) has a broader waveform, because it has stronger gravitational light deflection. The less compact star has larger waveform asymmetry because its surface rotation velocity is higher. Therefore, mass and radius can be determined independently by fitting the waveform. *right)* Constraints on mass and radius from waveform fitting. The contours show the 1 σ confidence regions from RXTE (dotted) and from an instrument 10 times bigger than RXTE (drawn). The mass-radius relations labeled as in Miller et al. (1998) are also shown. (Courtesy of Cole Miller).

be independently estimated from waveform measurements at ν_2, thus overdeterminating the problem so that the underlying theories can be tested in critical ways. The increased sensitivity will enable QPOs to be detected within their coherence times. The cycle waveform, which it will be possible to reconstruct, depends on the Doppler shifts associated with the local velocity of the radiating matter in the emitting blob or spot, as well as on curved-spacetime light propagation effects. If the frequency ν_2 of the orbit is known, QPO waveform fitting yields the mass M (and Kerr spin parameter) of the compact object.

Nearly coherent oscillations at $\sim$ 300 Hz or $\sim$ 600 Hz have been observed during type I X-ray bursts from about 10 NS so far (see Strohmayer et al. 1998 for a review). These oscillations are probably caused by rotational modulation of a hot spot on the stellar surface. The emission of the hot spot is affected by gravitational light deflection and Doppler shifts (e.g. Miller & Lamb 1998). With the next generation timing mission, the oscillation will be detected within one cycle.

The composition and properties of the NS cores have been the subject of considerable speculation, and remain a major issue in modern physics: at the highest densities, matter could be composed of pion or kaon condensates, hyperons, quark matter, or strange matter (e.g.

Heiselberg & Hjorth-Jensen 2000). By fitting the waveform it will be possible to constrain simultaneously the mass and radius of the star (Fig. 2), and hence determine the equation of state of its high density core.

Beside the few examples described above, with its increased sensitivity, a future timing mission will also address a broad range of other astronomical issues (accreting millisecond pulsars, micro-quasars, X-ray pulsars, CVs, Novae, Soft gamma-ray repeaters, Anomalous X-ray pulsars, ...). For instance, there is only *one* accreting millisecond pulsar known so far: SAXJ1808-3658 (Wijnands & Van der Klis 1998, Chakrabarti & Morgan 1998). Its properties suggest that all NS systems should show pulsations at some level. In most models, pulse amplitudes cannot be suppressed below $\sim$0.1% (rms) without conflicting with spectroscopic or QPO evidence. With an instrument 10 times larger than RXTE, the sensitivity to persistant millisecond pulsations will be well below this level (pulsations at the level of 0.01% rms would be detected in 10000 seconds in Sco X-1). Detection of such pulsations in objects also showing kHz QPOs and burst oscillations would immediately confirm or reject several models for these phenomena involving the NS spin (e.g. Miller et al. 1998). In addition, it has been suggested that such objects could be among the brightest gravitational radiation sources in the sky, emitting a periodic gravitational wave signal at the star's spin frequency (Bildsten 1998). Measuring the spin period very accurately would be therefore of great importance for periodicity searches with gravitational wave antennas (e.g. Brady et al. 1997).

Similarly for micro-quasars, the link between the very fast disk transitions observed in X-rays and the acceleration process could be studied on very short time scales, allowing the non steady state disk properties and their link to the formation of relativistic jets to be explored (Belloni et al. 1997, Fender et al. 1999). This would be of direct relevance to understanding the properties of AGNs, where presumably similar jet formation mechanisms operate on a much larger scale.

3. Proposed advanced timing missions: EXTRA and RAE

The "Experiment for X-ray Timing and Relativistic Astrophysics" (EXTRA) was proposed to ESA in January 2000 as a F2/F3 flexi-mission. This mission was not at that stage selected, but studies continue. In addition the "Relativistic Astrophysics Explorer" (RAE), a closely related concept, is being discussed in the US (Kaaret et al. 2000). The objectives and requirements of the two missions are essentially identical and the two will be discussed together here.

Both EXTRA and RAE have a main instrument consisting of a very large X-ray detector array, together with an all-sky monitor to provide source monitoring and alerts to transients.

The main detector array has a geometric area of about 10 m^2, giving about $\sim$ 6 m^2 effective area at 6–10 keV. An area of this size can be accommodated within the fairings available with a low-cost launchers (Starsem Soyuz-ST or Delta II) without the need for deployable mechanisms (Fig. 3). The arrays are highly modular and in each case Si PIN diodes are being considered for the main detector. Si PIN diodes can now be manufactured with high yield at acceptable cost and provide a superior alternative to the proportional counters used on XTE. The absence of absorption edges in the critical 4–6 keV range is important for spectral studies. Furthermore, they are rugged and require neither high voltages nor special handling conditions. Similar Si PIN diodes have been proposed for the first layer of the ASTRO-E Hard X-ray Detector (Sugizaki et al. 1997).

By operating the detectors at reduced temperature, needing only passive cooling through the front face of the detector array, the leakage current can be reduced to a low level even for an area of $\sim$ 1 cm^2 per element. The associated capacitance is reduced by using a thick detector (1–2 mm), also needed for good high energy response. In this way good energy resolution can be obtained with an off-chip pre-amplifier, allowing the silicon and processing to be optimised for X-ray detection. Resolution of 600 eV or better can be expected – a factor of two better than the RXTE PCA.

For both missions Silicon Drift Detectors (SDDs) are being considered as a possible alternative to PIN diodes, potentially offering even better energy resolution and perhaps larger area for a single detector, so reducing the total number of electronic channels. SDDs are, however, at a less advanced stage of development.

The number of electronic channels will be large ($\sim$52416 for EXTRA) and the resulting electronic complexity requires careful optimisation and effective use of a modular construction concept. Similar numbers of channels are, however, being dealt with for the IBIS instrument on INTEGRAL and on AGILE.

The detector background is reduced because charged particles passing through the relatively dense detectors will normally deposit an energy larger than the upper limit of the operating range. Simulations show that particle interactions in the collimator and surrounding material often produce showers of secondaries, so the background can be further reduced by operating nearby pixels in anti-coincidence with each other. Nevertheless, because of the unprecedented area the total background rate may approach 2500 Counts s^{-1} between 1 and 50 keV.

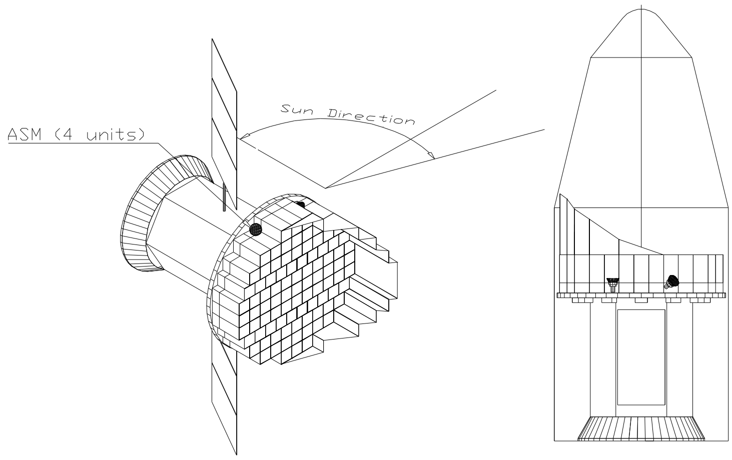

Figure 3. Left: The EXTRA science payload with the Matra Marconi Space LEOSTAR platform. One of the four ASM modules (WATCH design) is shown. *Right:* EXTRA in the STARSEM-Soyuz ST Ariane 4 type fairing.

The missions are intended to study bright sources and the data rates will often be high, requiring careful optimisation of the on board electronics and data systems. With the proposed detector area, the Crab will produce about 400000 cts/s. A low, near equatorial, orbit is to be preferred in order that the background be low and stable and also because of considerations of data recovery. The objective is to telemeter information about the time and energy of every event, leading to considerable volumes of data. Nevertheless this turns out to be feasible with only minimal constraints. For example, the EXTRA studies led to the proposal to use the Matra-Marconi Space LEOSTAR bus, which provides 160 Gbit solid state memory. By reorienting to direct a X-band antenna toward the ground station during passes, the full memory can be dumped during a single pass, using a 240 Mbits s^{-1} link. Observations of the brightest sources ($\sim$ 10 Crab) would thus be restricted to orbits followed by ground station passes.

4. Conclusions

The need for a follow-up to RXTE has been clearly identified; fast timing studies are now widely recognized as a powerful tool to study the spacetime around collapsed stars, and to derive constraints on the fundamental properties of neutron stars and black holes. The studies carried out for EXTRA have demonstrated that a mission using solid-state detector technologies providing an order of magnitude improvement over RXTE can be done within the limits of a modest size mission. It has also shown that there are existing platforms with resources matching the specific needs of such a mission. More importantly, the large number of active astronomers that gathered around the proposals demonstrates that there is a very large community supportive of such a mission.

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The Ballerina Experiment on the Rømer Mission *

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Abstract. The Rømer mission has recently been approved as the next mission within the Danish Small Satellite Program. The scientific payload will consist of two separate experiments, the MONS and the Ballerina payloads. The primary objective of Ballerina is to provide accurate, real-time positions relayed to ground for ≈ 70 Gamma Ray Bursts (GRBs) per year, and to study the temporal and spectral evolution of the early GRB X-ray afterglow. As an additional goal, Ballerina will detect and study bright X-ray transients, in particular X-ray novae and micro-quasar systems. Rømer is currently scheduled for launch in late 2003.

Keywords: gamma ray bursts, X-ray transient

1. Introduction

The Rømer mission has been selected for the next mission within the Danish Small Satellite Program (DSSP). Rømer is currently in the systems definition phase, and is expected to be launched in late 2003. Rømer is the result of merging two mission proposals with similar requirements for the spacecraft capabilities.

The MONS experiment will measure stellar oscillations in nearby solar-like stars, using a 40 cm telescope and a photometric detector, to probe the stellar interior for determination of its composition, age, mixing and internal rotation (MONS). MONS will typically require observation of the same target for ≈ 30 days. These observations will be interrupted by the autonomous re-orientations of the spacecraft as response to the detection of a gamma ray burst. The Ballerina experiment will study gamma ray bursts, X-ray transients, and monitor the brighter, persistent X-ray sources.

The merged mission promises a 90% science return for each of the two experiments onboard compared to individual missions. Some of the Rømer parameter are summarized in Table I.

2. The Ballerina Experiment

A crucial turning point in GRB research occurred in 1997 with the discovery of X-ray, optical, and radio afterglows of GRBs (Costa et al.

* On behalf of the Ballerina Collaboration

Table I. The Rømer spacecraft

Spacecraft dimensions	$\approx 60 \times 60 \times 80$ cm^3
Mass	120 kg
Attitude stability	$> 0.5'$
Attitude slew rate	90 degrees in $\approx$ 20 sec
Orbit	12 hour period, 63 degree inclination
Observation efficiency (Ballerina)	60%, $\approx$ 7 hours per orbit
Launcher	Russian SOYUZ/FREGAT (secondary payload)

1997). The observations confirmed that GRBs are indeed located at very large distances with a typical redshift of $z \approx$1-2 and higher. There are two main avenues in the study of GRBs: The first is the quest for the understanding of the event itself. What is the progenitor, and how does the "central engine" work? Are GRBs caused by the collapse of a massive star and the formation of a black hole (hyper-nova model), or are GRBs the result of the merging of two neutron stars and the formation of a black hole? The second line of research, and the cause for GRB research now entering center-stage of astrophysics, is the use of the bright afterglow to study the structure and evolution of the high red shift Universe.

The concept of the Ballerina experiment is to combine an all-sky monitor, providing rapid GRB alerts (5-30 seconds) with good, but limited accuracy ($\approx$ 1 deg) with a rapid moving X-ray telescope and a small optical monitor to study the earliest phase of the afterglow, and giving high precision ($<$ 30") positions within a few minutes. In addition, real-time telemetry will ensure rapid dissemination of positions for follow-up observations. The system will also allow uplink of positions for new targets of opportunity from other sources.

2.0. The Ballerina Science Objectives

The primary objective of Ballerina is the study of gamma ray bursts, through rapid reaction on-board, and by enabling multiwavelength campaigns of observations of the afterglow. Ballerina will be able to study $\approx$ 70 GRBs per year.

An important secondary objective of the Ballerina experiment is to detect bright X-ray transients, in particular X-ray novae and micro-quasar systems. These systems are prime laboratories for the study of stellar mass black holes. The Ballerina all-sky monitor will also monitor the brighter persistent X-ray sources for time variability and state changes. In addition to the capabilities in its own right, Ballerina

Table II. The Ballerina all-sky monitor

Number of cameras	4 rotation modulation collimators (RMC)
Detector type	NaI/YAP scintillator mosaic
Field of view (per camera)	65 degrees radius
Energy range	6-120 keV
Source position accuracy	< 1 degree
GRB detection efficiency	160/year of efficient operation
X-ray transient detection sensitivity	50 mCrab in one day

on Rømer will be an important complement to current and upcoming missions such as Chandra, XMM, Integral, and Swift.

2.0. The All-sky Monitor

The all-sky monitor on the Rømer mission is based on the WATCH wide field X-ray monitor. WATCH has a proven record of detection of GRBs (Sazonov et al. 1998) and X-ray transients from the GRANAT and EURECA missions, like the discovery of the first micro-quasar, GRS 1915+105 (Castro-Tirado et al. 1994), and the black hole candidate Nova Muscae 1991 (Brandt et al. 1992).

Four WATCH X-ray cameras will cover the full sky, and determine the position of GRBs and X-ray transients with and accuracy better than 1 degree. The WATCH rotation modulation collimators will also double as momentum wheels for attitude stabilization, and performance of fast slews in response to GRBs. The capabilities of the WATCH all-sky monitor is summarized in Table II.

2.0. The X-ray Telescope

The purpose of the Ballerina narrow-field X-ray telescope (see Table III) is to provide accurate positions of the GRBs after the spacecraft has made a fast slew to the position determined by the all-sky monitor. After the fine position is determined and relayed to the ground, the objective is to study the temporal and spectral evolution of the X-ray afterglow. This study will last for the remainder of the current orbit, typically 4 hours. In the following orbit the control of the spacecraft will be given back to the MONS stellar oscillation experiment. As the objective is the study of the relatively bright early GRB afterglow, a coded mask telescope has been selected over focusing X-ray optics. This choice ensures full utilization of the spectral capabilities of the X-ray CCD, which has a flight heritage derived from the XMM program.

Table III. The Ballerina coded mask X-ray telescope

"Focal" length	60 cm
Field of view (at zero response)	3×3 degrees
Mask area	6×6 cm^2
Mask pixel size	0.5×0.5 mm^2
Detector type	Pn-CCD
Detector area	6×6 cm^2
Quantum efficiency	$> 90\%$ (0.35-10 keV)
Source position accuracy	< 30"

2.0. The Optical Monitor

The optical monitor on Rømer is a dual use instrument for the MONS and Ballerina payloads. This monitor has a 5 cm aperture and a 40 cm focal length. This will enable the possible detection of the optical emission of GRBs in the transition between the gamma ray burst and the afterglow phase. So far this has only been observed in one case, in GRB 990123 (Akerlof et al. 1999). The sensitivity of the optical monitor will be $m_V \approx 15$ for a 10 second integration time.

3. Conclusion

The Ballerina experiment on the Rømer mission promises exciting returns in the fields of gamma ray bursts, and the study of black hole X-ray transients. It is interesting to speculate that a common denominator, and a key to progress in these two fields, may be the understanding of highly relativistic jets.

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Microquasars: Open Questions and Future Perspectives

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Abstract. The discovery and subsequent study of microquasars lead to major progress in our understanding of: 1) the nature of relativistic jets seen elsewhere in the universe, and 2) the connection between the accretion onto compact objects and the formation of collimated jets. A detailed account of the major progress accomplished until present was published in Annual Review of Astronomy & Astrophysics (Mirabel & Rodríguez, 1999). Here I review the questions that remain unanswered, as well as the future perspectives that this new field of research is opening.

Keywords: X-ray:stars, X-ray binary, superluminal, microquasar

1. Major progress accomplished

In relativistic sources located in the Milky Way, two-sided moving jets can be observed, and therefore can be overcome several of the ambiguities that had dominated the physical interpretation of extraglactic jets, where so far only the motions of one-side of the jets could be followed. From the observation of two-sided moving jets in microquasars, the system of equations can be solved. For first time, an upper limit of the distance to a microquasar was derived from the proper motions using special relativity constraints (see Mirabel & Rodríguez 1999).

Major progress has also been made in the understanding of the accretion/ejection phenomenology. From multiwavelength observations, the connection between accretion flow instabilities -observed in the X-rays- with the ejection of relativistic plasma -observed at radio, infrared, and possibly optical and X-ray wavelengths-, has been established on a firm basis. After the softer component of the X-ray emitting plasma disappears, the inner accretion disk is rapidly re-established and the plasma that produces the hard X-ray component, is blown away (Mirabel et al. 1998) in the form of collimated relativistic jets (Dhawan, Mirabel & Rodríguez, 2000).

The X-ray source GRS 1915+105 (Castro-Tirado et al. 1994) has become a main target to study accreting black holes of stellar mass. However, the discovery and study of other microquasars is important not only to enhance the statistical sample, but also to make progress on the different aspects of the diverse phenomenology that each new object of this class has revealed (Mirabel & Rodríguez 1999).

2. Open questions

What is a microquasar ?
By this term we usually design stellar-mass black holes that mimic, on a smaller scale, many of the phenomena seen in quasars. The question is whether under this concept we should also include neutron star systems with jets. Although the physical meaning of the quasar-microquasar analogy as proposed by Mirabel & Rodríguez (1998) is valid for black holes, because in many cases the nature of the compact object is unknown, we may currently include in this subclass of stellar sources, neutron star binaries that produce relativistic jets.
Are all accreting black holes of stellar mass microquasars ?
All microquasars are accreting compact objects of stellar mass, but is the reverse true? Do all X-ray black hole binaries produce jets? From the theoretical point of view jets are needed to liberate angular momentum. On the other hand, observations show that X-ray emitting black holes, in addition to possible synchrotron emission associated to sporadic outbursts, always exhibit flat-spectrum compact counterparts of synchrotron emission. It has been proposed (Fender 2000) and demonstrated by high resolution images (Dhawan, Mirabel & Rodríguez 2000), that these flat spectrum compact radio counterparts are thick collimated jets of AU size scales. Furthermore, from multiwavelength observations at radio, infrared, and X-ray wavelengths of the large-scale jets in SS433/W50, we know that in some circumstances jets exist without being seen. Therefore, the answer to this question is that probably all accreting black holes of stellar mass are microquasars.
Are the Lorentz factors of the bulk motions in the jets from quasars different from those in microquasars ?
E.g. is the quasar-microquasar analogy valid? The microquasar jets observed so far have bulk speeds that are statistically smaller than in quasars. For instance, in quasars jets have bulk speeds of up to ~20c, but no microquasar with such jets has so far been found. Is this due to some fundamental difference that would invalidate the physical analogy between quasars and microquasars, or is it rather due to selection effects related to the Doppler favoritism needed in order to measure the proper motion of the ejecta in distant quasars? Although from the observational point of view this remains an open question, theoretically it is not clear why the bulk motion in jets from supermassive black holes would be different from that in the jets from stellar mass black holes.
Could the terminal velocity of the jet be a diagnostic for the nature of the collapsed object (NS versus BH) ?
In all areas of astrophysics there have been increasing evidences that accretion is always related to the production of collimated jets. The

observed outflow speeds seem to be of the order of the escape velocity from the surface of the accreting object. Objects as diverse as very young stars, nuclei of planetary nebulae, and accreting white dwarfs have jets with non-relativistic velocities ($\sim$100-10000 km s^{-1}), whereas neutron stars and black holes produce jets with relativistic speeds V $\geq$ 0.1c (Livio 1999; Mirabel & Rodríguez 1999). If the present trends between the escape velocities from the accreting objects and the velocity of the outflows were confirmed as a strong correlation, it would imply that gravity is important and dominates over MHD mechanisms (Meier et al. 1997). However, it is not clear whether we can *discriminate between neutron stars and black holes by knowing the terminal velocity of the collimated outflows.* For instance, Sco X-1 which probably contains neutron star, has lobes moving with an average velocity of 0.45c (Fomalont, Geldzahler & Bradshaw 2000). Since only a handful of relativistic jet sources have been discovered so far in the Galaxy (Mirabel & Rodríguez 1999), we need the discovery and study more sources to obtain a statistically significant number to answer this question.

Why are QPOs in microquasars and not in AGNs ?

The scale of time of the instabilities in the accretion disk of black holes is proportional to the mass of the black hole. QPOs with periods of $\sim$1 sec in black holes of 10 M$_\odot$ would correspond to QPOs of $\sim$1 day to $\sim$3 years in black holes with masses of 10^6 and 10^9 M$_\odot$ respectivelly. QPOs of 1 sec in microquasars correspond to typical fluctuations of $\sim$5% of the X-ray flux. At X-rays the companion binary stars are much dimmer than the accretion disk. On the other hand, the accretion disk in AGNs is cooler (Mirabel & Rodríguez, 1999), and QPOs should be observed in the UV and optical, wavelengths at which stars mostly radiate, and interstellar absorption is important. Since AGNs may be blurred by nuclear starbursts, it may be difficult to detect fluctuations of $\sim$5% from AGNs that are embedded in starburst nuclei.

One then may ask about the analogous of the large scale oscillations of the flux ($\geq$ 50%) with periods of $\sim$30 min regularly observed in GRS 1915+105 (Greiner, Morgan & Remillard, 1996). In black holes with masses in the range of 10^6 to 10^9 M$_\odot$ analogous QPOs would correspond to periods in the range of 5 to 500 years, which are difficult to monitor in human time-scales (Sams, Eckart & Sunyaev, 1996).

To image the jet close to the black hole, do microquasars offer an advantage with respect to AGNs ?

No. The Schwarzschild radii (r$_s$) of BHs are proportional to their mass and in these units nearby AGNs can be imaged closer to the BH than microquasars. For instance, M87 (in the Virgo cluster at 15 Mpc and containing a BH of 3 10^9 M$_\odot$) has been imaged with a resolution of $\sim$50 (r$_s$) (Junor, Biretta & Livio 1999). A given angular size projected on the supermassive BH of M87 is in terms of r_s 10^4 smaller than the same distance projected on a BH of 10 $M_{\odot}$ at a distance of 2 kpc from the Sun. Therefore, relative to supermassive BHs in the Local Universe, the study of stellar mass BHs presents an advantage because of the time scales, but not as far as the length dimension is concerned.

What is the connection between accretion and ejection ?
In GRS 1915+105 large amounts of X-ray emitting plasma ($\sim 10^6$ $L_{\odot}$) disappear in less than a few seconds and soon after synchrotron jets are formed (Fender & Pooley 1998; Eikenberry et al. 1998; Mirabel et al. 1998). Recent analysis shows that the X-ray flux that suddenly disappears only corresponds to the softer component (2-20 keV). The formation of the jets starts later, at the time of a spike that consists of a sudden increase in the flux of the soft component simultaneous with a decrease of the flux of the harder component (20-60 keV). In the context of current models these observations imply that the inner accretion disk first disappears (Belloni et al. 1997), and when the inner accretion disk is re-established, a shock is produced which triggers the blow up of plasma that was emitting hard X-rays in the form of collimated jets at relativistic speeds (Dhawan, Mirabel & Rodríguez, 1999). In GRS 1915+105, an analogous correlation between the sudden disappearance of the 20-100 keV measured by BATSE and major ejection events seen in the radio with the VLA had been observed (see Mirabel & Rodríguez, 1999 for references and the discussion of this issue).

What fraction of the inflow goes into the jets ?
The observations described above indicate that the matter and energy emitting in the soft X-rays that suddenly disappears is perhaps advected into the BH, since it is not immediately translated neither in hard X-rays nor in synchrotron jets. Because of the uncertanties in estimating the mass of the X-ray emitting plasma it is difficult to estimate the fraction of the inflow that goes into the jets. On the contrary, assuming equipartition, the amount of mass and energy of the jets can be calculated (Fender & Pooley, 1998; Mirabel et al. 1998).

Now there are increasing evidences that the power of the jets may be a large fraction of the accretion power. For instance, in its very high state, GRS 1915+105 may have a short-term jet power of $\sim 10^{39}$ erg s^{-1} (Mirabel & Rodríguez, 1999; Fender, 2000), which is a large fraction of the observed accretion power. This is consistent with the model for a rapidly rotating BH with a high accretion rate by Meier (2000).

What is the mechanism that launches the jets ?
MHD power which was nicely reviewed by Meier (2001) and may play an important role. However, it is still unclear the relative importance of the rotating thin accretion disk mechanism by Blandford & Payne (1982) and that from the frame-dragged accreting matter inside the er-

gosphere of a rotating BH (Blandford & Znajek, 1977). The X-ray spectral properties of microquasars with powerful jets (e.g. GRS 1915+105, GRO J1655-40) indicate that these are rotating BHs with spins near maximum (Zhang, Cui & Chen, 1997), which is consistent with the Blandford & Znajek mechanism. On the other hand, the Blandford & Payne mechanism is consistent with the following two recent observations: 1) the large opening angle of $\sim 60°$ of the jet in M87 (Junor, Biretta & Livio, 1999) which seems to be the two dimensional image of a jet with a magnetic polar field angle $\geq 30°$. The M87 jet strongly collimates at 30-100 (r_s) from the BH, collimation continuing out to $\sim 1000\ r_s$. 2) The semicontinuous emanation of the jets in the infrared and radio during time intervals of the order of minutes, as observed in GRS 1915+105 (Eikenberry et al. 1998; Fender & Pooley, 1998; Mirabel et al. 1998).

Despite several numerical simulations there are still no definitive tests to discriminate the relative role of these two MHD mechanisms.

What are the QPOs of maximum fix frequency ?

Because QPOs with maximum fix frequency have been observed many times in some microquasars (e.g. 67 Hz in GRS 1915+105; Morgan, Remillard & Greiner 1997), it is believed that they are related to fundamental properties of the BHs, such as its mass and spin. The problem is that there are more than 3 alternative explanations in terms of General Relativity (see Mirabel & Rodríguez, 1999). Theories should provide observational tests that would discriminate among these models.

Are the jets discrete plasmons or semi-continuous flows with internal shocks ?

In the internal shock models (Bodo&Ghisellini 1995; Kaiser, Sunyaev & Spruit 2000) the plasma velocity is smaller than the pattern velocity, and the jets are lit up by shock fronts travelling along the jets during outbursts, as proposed for gamma-ray bursts (Mészáros & Rees 1997). The shocks accelerate relativistic particles which emit synchrotron radiation. Although the integrated energy in both models is the same, the internal shock model relaxes the requirements on the power of the central engine because much of the energy underlying the outbursts may be stored in the continuous jet. So far there has been no observational test to discriminate between these two physical interpretations.

Despite the large differences in Lorentz factors, the jets in microquasars and GRB afterglows show analogous phenomenologies. It is interesting that the internal shock model for GRBs originally developed for GRBs by Mészáros & Rees (1997) was applied later to microquasars by Kaiser, Sunyaev & Spruit (2000). Conversely, the plasmon model originally proposed to interpret the microquasar jets has been proposed in the "cannonball" model of GRBs by Dar&De Rújula (2000).

Have extragalactic microquasars been identified ?
Ultraluminous X-ray compact sources were identified in several nearby spiral galaxies (Colbert&Mushotzky, 1999; Makishima et al. 2000) as well as in dwarf galaxies (Mirioni & Pakull, 2000). These enigmatic sources have luminosities in the range of $L_X = 10^{38-40}$ erg s^{-1}, and Colbert & Mushotzky (1999) proposed that they are BHs of 10^{2-4} $M_\odot$. Makishima et al. (2000) propose that some of these superluminous sources are BHs as the microquasars GRS 1915+105 and GRO J1655-40, with masses below $\sim$100 $M_\odot$ and high disk temperatures because rapid rotation gets the disk closer to the BH, hence hotter. Unfortunately, the VLBA array does not have the sensitivity to image in its plateau state extragalactic "super-microquasars" as GRS 1915+105.

Why superluminal microquasars have unbroken power law photon spectra ?
Microquasars with superluminal jets have power-law gamma-ray states with an index of 2.5-3 (Grove 1999). Contrary to Cygnus X-1 and 1E 1740.7-2942, the microquasars GRO J1655-40 and GRS 1915+105 have unbroken power laws up to almost 1 MeV with no indication of Comptonization. A similar photon spectrum has been observed by SAX in XTE 1118+48 (Frontera et al. 2001). Since we don't know the origin of the electrons that produce the gamma-ray photons it is still unclear why some BHs have broken, whereas others have unbroken power law photon spectra. The sensitivity of INTEGRAL in this energy domain will certainly provide new perspectives on this issue.

Will microblazars be found ?
In most microquasars where θ (the angle between the line of sight and the axis of ejection) has been determined, large values are found ($\theta \geq 70°$). Namely, except some exceptions (as in the case of Sco X-1 where $\theta = 45°$; Fomalont, Geldzahler & Bradshaw, 2000), the axis of ejection in most cases is close to the plane of the sky. This is consistent with the statistical expectation since the probability of finding a source with a given θ is proportional to $sin\ \theta$. We then expect to find as many objects in the $60° \leq \theta \leq 90°$ range as in the $0° \leq \theta \leq 60°$ range. However, this argument suggests that we should eventually detect objects with a small θ. For objects with $\theta \leq 10°$ we expect the timescales to be shortened by $0.5\gamma^2$ and the flux densities to be boosted by $8\gamma^3$ with respect to the values in the rest frame of the condensation. For instance, for motions with $v = 0.98$c ($\gamma = 5$), the timescale will shorten by a factor of $\sim$50, the flux densities will be boosted by a factor of $\sim 10^3$, and the photon spectrum of the source will be very hard. Then, for a galactic source with relativistic jets and small θ we expect fast and intense variations in the observed flux. Microblazars may be hard to detect in practice, because both the low probability of small θ and the fast flux decline.

Could microquasars be unidentified sources of gamma-rays detected by EGRET ?
There is indication that the synchrotron component of microquasar jets could reach the X-ray domain (Markoff, Falcke & Fender 2000). This would require the ejection of plasma containing electrons with Lorentz factors $\geq 10^7$, as in blazars. In this context, the recent observation by Paredes et al. (2000) of persistent radio jets from LS 5039, which is located in the error box of an EGRET source raises the possibility that microquasars could be persistent sources of gamma-rays.
Could microquasars be sources of $\geq 10^{20}$ eV cosmic rays ?
Due to opacity by cosmic infrared photons, the sources of $\sim 10^{20}$ eV cosmic rays must be within 50 Mpc from the Galaxy. AGNs have been proposed as possible sources of such high energy particles. As shown above, the bulk and intrinsic Lorentz factors of the electrons in microquasars are comparable to those in AGNs. Since they are much closer and numerous than the later, the very high energy cosmic rays could be produced by shocks in microquasar jets.
Are Gamma-ray-bursts extreme microquasars ?
Gamma-ray bursts are at cosmological distances and ultra-relativistic bulk motion and beaming appear as essential ingredients to solve the enormous energy requirements (Castro-Tirado et al. 1999). Beaming reduces the energy release by a factor $f = \Delta\Omega/4\pi$, where $\Delta\Omega$ is the solid angle of the beamed emission. Additionally, the photon energies can be boosted to higher values. BHs formed by core collapse producing outflows with bulk Lorentz factors >100 have been proposed as GRB sources (Mészáros & Rees 1997). Recent studies of GRB afterglows suggest that they are highly collimated jets since breaks and a steepening of the light curve from a power law to $t^{-1.2}$, ultimately approaching $t^{-2.5}$ have been observed (Castro-Tirado et al. 1999).

Interestingly, the power laws describing the light curves of the ejecta in microquasars show similar breaks and steepening of the radio flux density (Rodríguez & Mirabel, 1999). In microquasars, these breaks and steepenings have been interpreted (Hjellming & Johnston 1988) as a transition from slow intrinsic expansion to free expansion in two dimensions. Linear polarizations of about 2% were recently measured in the optical afterglows, providing strong evidence that the afterglow radiation from gamma-ray bursts is, at least in part, produced by synchrotron processes. Linear polarizations in the range of 2-10% have also been measured in microquasars at radio (Rodríguez et al. 1995; Hannikainen et al. 2000), and optical (Scaltriti et al. 1997) wavelengths.

In this context, microquasars in our own Galaxy seem to be less extreme local analogs of the super-relativistic jets associated to the more distant GRBs, which are jets with Lorentz factors 2 orders of magnitude larger. Therefore, the physical mechanism that launches the jets in GRBs are likely different to microquasars. Furthermore, GRBs do not repeat and seem to be related to catastrophic events, and have much larger super-Eddington luminosities. Therefore, the scaling laws in terms of the black hole mass that are valid in the analogy between microquasars and quasars do not seem to apply in the case of GRBs.

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