

Sensitivity of the NEMO detector to galactic microquasars

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Abstract. We present the results of Monte Carlo simulation studies of the capability of the proposed NEMO km³ telescope to detect TeV muon neutrinos from Galactic microquasars. In particular we determined the detector sensitivity to each known microquasar, optimizing the event selection in order to reject the atmospheric background. We also determined the expected number of source and background events surviving the selection.

Key words. Microquasars — Neutrino telescopes — NEMO

1. Introduction

Microquasars are Galactic X-ray binary systems which exhibit relativistic jets, observed in the radio band (Chaty 2005). Several authors propose microquasar jets as sites of acceleration of charged particles up to energies of about 10¹⁶ eV, and of high energy neutrino production. According to present models, neutrinos could be produced both in $p\gamma$ (Levinson & Waxman 2001; Distefano et al. 2002) and pp interaction scenarios (Bednarek 2005; Aharonian et al. 2005; Christiansen et al. 2005; Romero & Orellana 2005).

The aim of this paper is to study the possibility to detect neutrinos from known microquasars with the proposed NEMO-km³ telescope (Migneco et al 2006). In particular, for each microquasar we calculated the expected sensitivity, optimizing the event selection to reject the atmospheric neutrino and muon backgrounds.

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We also calculated, according to the present theoretical models, the expected number of microquasar events that survive the event selection. We compared the expected source signal with the remaining background to establish its detectability.

The NEMO proposal is made in the context of the KM3 project for a km³ detector in the Mediterranean sea (KM3NeT website 2007).

2. The NEMO km³ detector

The NEMO-km³ telescope, simulated in this work, is a square array of 9 × 9 towers with a distance between towers of 140 m. In this configuration each tower hosts 72 PMTs (with a diameter of 10”), namely 5832 PMTs for the whole detector with a total geometrical volume of ~ 0.9 km³. We considered an 18 storey tower; each storey is made of a 20 m long beam structure hosting two optical modules (one downlooking and one looking horizontally) at each end (4 OMs per storey). The vertical distance between storeys is 40 m. A spac-

ing of 150 m is added at the base of the tower, between the anchor and the lowermost storey.

The detector response is simulated using the simulation codes developed by the ANTARES Collaboration (Amram et al. 2002; Becherini 2006), modified for a km³ telescope (Aiello et al. 2007). In the simulation codes, the light absorption length, measured in the site of Capo Passero ($L_a \approx 68$ m at 440 nm (Riccobene 2007)), is taken into account. Once the sample of PMT hits is generated, spurious PMT hits, due to the underwater optical noise (⁴⁰K decay), are introduced, with a rate of 30 kHz for 10⁷ PMTs, corresponding to the average value measured in the Capo Passero site.

3. Calculation of the sensitivity

The detector sensitivity was calculated according to the Feldman & Cousins (1998) approach. The 90% c.l. sensitivity to a neutrino flux coming from a microquasar is given by

$$f_{\nu,90} = \frac{\bar{\mu}_{90}(b)}{N_{\mu}^m} f_{\nu}^{th}, \quad (1)$$

where $\bar{\mu}_{90}(b)$ is the 90% c.l. average upper limit for an expected background (atmospheric neutrinos + muons) with known mean value b and no true signal (Feldman & Cousins 1998), f_{ν}^{th} is the theoretical neutrino energy flux from a given microquasar that induces a mean signal N_{μ}^m . During the calculation, an event selection is applied in order to optimize the sensitivity, as described in Aiello et al. (2007). Detailed calculation of the sensitivity for the proposed NEMO km³ telescope to a generic point-like muon neutrino source are presented in Distefano (2007).

The detector sensitivity was calculated for a livetime of 1 year, simulating a neutrino flux with spectral index $\Gamma = 2$ in the energy range 1 - 100 TeV. The study was carried out for each microquasar, since the sensitivity is a function of the source astronomical declination. Results are given in Tab. 1 $f_{\nu,90}$. Fig. 1 shows the detector sensitivity for the studied microquasars as a function of the declination; the sensitivity flux limit increases with increasing declination, due

to the decrease of the time per day spent by the source below the Astronomical Horizon (with respect to the latitude of the Capo Passero site). In Tab. 1, we present only results concerning microquasars which may be observed by a telescope located in the Capo Passero site (i.e. with declination $\delta \lesssim +54^\circ$).

Table 1. Detector sensitivity to neutrinos from microquasars: the sensitivity $f_{\nu,90}$ (expressed in erg/cm² s) is calculated for an ε_{ν}^{-2} neutrino spectrum in the energy range 1 - 100 TeV, for a detector livetime of 1 year. The corresponding values of the search bin angular radius r_{bin} and the source declination δ are also given, both expressed in degrees.

Source name	r_{bin}	$f_{\nu,90}$	δ
<i>Steady Sources</i>			
LS 5039	0.9	$6.5 \cdot 10^{-11}$	-14.85
Scorpius X-1	0.7	$5.8 \cdot 10^{-11}$	-15.64
SS433	0.8	$5.7 \cdot 10^{-11}$	4.98
GX 339-4	0.5	$4.7 \cdot 10^{-11}$	-48.79
Cygnus X-1	0.7	$9.0 \cdot 10^{-11}$	35.20
<i>Bursting Sources</i>			
XTE J1748-288	0.9	$5.4 \cdot 10^{-11}$	-28.47
Cygnus X-3	0.8	$1.1 \cdot 10^{-10}$	40.95
GRO J1655-40	0.7	$5.2 \cdot 10^{-11}$	-39.85
GRS 1915+105	0.8	$7.4 \cdot 10^{-11}$	10.86
Circinus X-1	0.9	$4.2 \cdot 10^{-11}$	-56.99
XTE J1550-564	0.9	$4.4 \cdot 10^{-11}$	-56.48
V4641 Sgr	0.9	$5.6 \cdot 10^{-11}$	-25.43
GS 1354-64	1.0	$3.8 \cdot 10^{-11}$	-64.73
GRO J0422+32	0.8	$8.7 \cdot 10^{-11}$	32.91
XTE J1118+480	0.7	$1.1 \cdot 10^{-10}$	48.05

4. Expected number of microquasar events

In Tab. 2 are given the number of selected neutrino events from each microquasar, applying the event selection that optimize the sensitivity in Tab. 1 and according to the neutrino fluxes given by Distefano et al. (2002). A detailed analysis considering other neutrino pro-

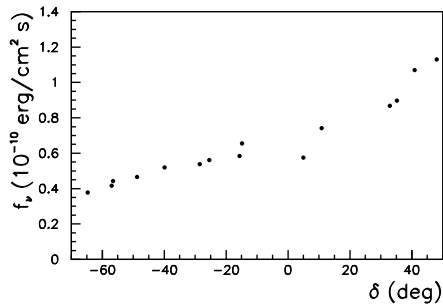


Fig. 1. NEMO-km 3 sensitivity to neutrinos from microquasars versus source declination, for a lifetime of 1 year. The worsening of the sensitivity with increasing declination is due to the decrease of the source visibility.

duction models in microquasars is reported in Aiello et al. (2007). The results in Tab. 2 refer to an integration time Δt equal to the duration of the considered burst for the transient sources and to 1 year for the steady sources. In the same table is given the background (atmospheric neutrinos + muons) in 1 year of data taking. In this analysis, it is assumed that transient sources cause one burst per year, i.e. the number of source events produced in the interval Δt is relative to 1 year observation time.

In order to estimate the event rates for non-persistent sources it is crucial to know their duty cycle. Some of these sources have a periodic bursting activity: Circinus X-1 has a period of 16.59 days Preston et al. (2007). This means therefore that we expect about 1.5 events per year. Other transient sources show a stochastic bursting activity. For such cases it is difficult to give an estimate of the expected event rate. For example, during 1994 GRO J1655-40 had three radio flares, each lasting 6 days (Hjellming & Rupen 1995); during the same year GRS 1915+105 emitted 4 bursts (Rodríguez & Mirabel 1999). A recent study (Nipoti et al. 2005) has shown that microquasars GRS 1915+105, Cygnus X-3 and Scorpius X-1 are in flaring mode 21, 10 and 3 percent of the time, respectively. The possibility to integrate over more than one burst could

therefore help to detect neutrinos from microquasars.

The search for neutrino events in coincidence with microquasar radio outbursts could be a tool to reject atmospheric background, restricting the analysis period to the flare duration Δt . Such an analysis technique, already used by AMANDA Ackermann (2005), can improve the detector sensitivity to neutrinos from transient sources. Referring to the bursts considered in Tab. 2 and integrating over the time interval Δt of the bursts, we expect an average background of about 10^{-3} events (muons) per burst. Summing on all the bursting sources, in Tab. 2 we count ~ 0.04 background events, which requires about 5 source events for a 5σ level detection with a 70% probability (Ahrens et al. 2004). Tab. 2 shows that we expect $3.4 \div 9.0$ events in the case of a burst from each of the bursting microquasars. Therefore, a cumulative analysis could provide a possible detection of microquasar neutrinos.

5. Conclusions

The possibility to detect TeV neutrinos from Galactic microquasars with the proposed NEMO-km 3 underwater Čerenkov neutrino telescope has been investigated. A Monte Carlo was carried out to simulate the expected neutrino-induced muon fluxes produced by microquasars and by atmospheric neutrinos. The expected atmospheric muon background was also simulated. We computed the detector sensitivity for each microquasar, optimizing the event selection in order to reject the background. Finally, we applied the event selection and calculated the number of surviving events. Our results show that, assuming reasonable scenarios for TeV neutrino production, the proposed NEMO telescope could identify microquasars in a few years of data taking, with a discovery potential for at least few cases above the 5σ level, or strongly constrain the neutrino production models and the source parameters.

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Table 2. Expected number of neutrino induced muons from the microquasar model proposed by Levinson & Waxman (2001): N_{μ}^m is the number of selected muons from each microquasar expected from the theoretical neutrino energy flux f_{ν}^{th} quoted by Distefano et al. (2002), during the time interval Δt . We also report the expected number of atmospheric background events b surviving the event selection and expected in 1 year of data taking.

Source name	Δt (days)	f_{ν}^{th} (erg/cm ² s)	N_{μ}^m	b
<i>Steady Sources</i>				
LS 5039	365	$1.69 \cdot 10^{-12}$	0.1	0.1
Scorpius X-1	365	$6.48 \cdot 10^{-12}$	0.2	0.1
SS433	365	$1.72 \cdot 10^{-9}$	76.0	0.1
GX 339-4	365	$1.26 \cdot 10^{-9}$	68.0	0.1
Cygnus X-1	365	$1.88 \cdot 10^{-11}$	0.5	0.1
<i>Bursting Sources</i>				
XTE J1748-288	20	$3.07 \cdot 10^{-10}$	0.8	0.3
Cygnus X-3	3	$4.02 \cdot 10^{-9}$	0.8	0.1
GRO J1655-40	6	$7.37 \cdot 10^{-10}$	0.6	0.1
GRS 1915+105	6	$2.10 \cdot 10^{-10}$	0.1	< 0.1
Circinus X-1	4	$1.22 \cdot 10^{-10}$	0.1	0.1
XTE J1550-564	5	$2.00 \cdot 10^{-11}$	< 0.1	< 0.1
V4641 Sgr	0.3	$2.25 \cdot 10^{-10} \div 3.25 \cdot 10^{-8}$	< 0.1 \div 1.4	0.1
GS 1354-64	2.8	$1.88 \cdot 10^{-11}$	< 0.1	0.1
GRO J0422+32	1 \div 20	$2.51 \cdot 10^{-10}$	< 0.1 \div 0.4	0.1
XTE J1118+480	30 \div 150	$5.02 \cdot 10^{-10}$	1.0 \div 4.8	0.2

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