

# Distance and internal composition of the neutron star in EXO 0748-676 with XMM-Newton

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## Abstract

Obtaining independent measurements of distances to low-mass X-ray binaries (LMXBs) remains a big challenge. Besides the case in which the source is in a globular cluster, one way to estimate the distance is using type-I X-ray bursts. An alternative way is through observations of quiescent X-ray emission from the neutron star surface. During the quiescent state, X-ray emission probably originates in the atmosphere of the neutron star. By fitting the quiescent X-ray spectrum of the system with a neutron-star atmosphere model, one can estimate the distance to the system, as well as the mass and radius of the neutron star. Recently, the neutron star X-ray transient EXO 0748-676 started a transition to quiescence. We analyzed an XMM-Newton observation of this source from November 2008. We fitted the spectrum with a neutron-star atmosphere model. From the fits we constrained the allowed parameter space in the mass-radius diagram for this source, for an assumed range of distances to the system. Comparing the results with different neutron-star equations of state, we constrain the distance to EXO 0748-676.

## 1. EXO 0748-676

A LMXB discovered in 1985.

From a strong X-ray burst, Wolff et al. (2005) derived a distance of 7.7 kpc for a helium-dominated burst photosphere and 5.9 kpc for a hydrogen-dominated burst photosphere

Based on the gravitational redshift, Özel (2006) suggested that the distance in EXO 0748-676 is  $9.2 \pm 1.0$  kpc,

Galloway, Özel & Psaltis (2008) analyzed several type-I X-ray bursts from the source and estimated a distance of  $7.1 \pm 1.2$  kpc.

## 2. Fitting results of the Spectrum

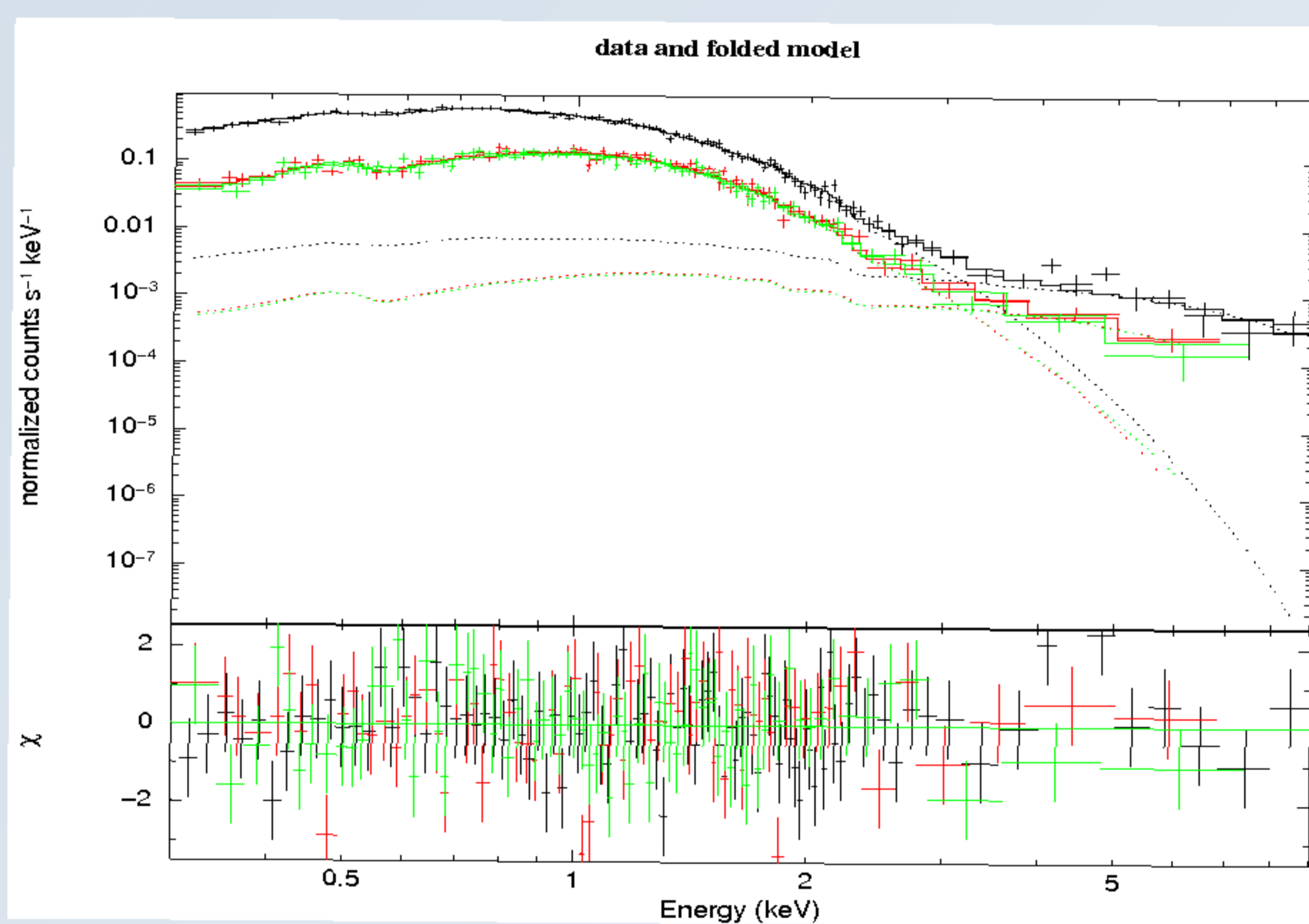


Figure 1. Combined XMM-Newton PN, MOS1 and MOS2 spectrum of EXO 0748-676 in the 0.3– 10.0 keV energy band. The spectrum was fit with a neutron-star hydrogen atmosphere model (NSATMOS) and a power law.

model	$N_H$ ( $10^{20} \text{ cm}^{-2}$ )	$T_{\text{eff}}^{\infty}$ (eV)	$M_{\text{NS}}$ ( $M_{\odot}$ )	$R_{\text{NS}}$ (km)	$F_{\text{pow}}$ $10^{-13} \text{ ergs cm}^{-2} \text{ s}^{-1}$	$F_X$ $10^{-12} \text{ ergs cm}^{-2} \text{ s}^{-1}$	$\chi^2$
NSAGRAV	$0.61 \pm 0.20$	$114^{+24}_{-3}$	$1.62 \pm 0.11$	$15.8 \pm 0.4$	$1.10 \pm 0.15$	$1.14 \pm 0.13$	0.977
NSATMOS	$0.60 \pm 0.15$	$113 \pm 4$	$1.55 \pm 0.12$	$16.0^{+0.7}_{-3.8}$	$1.10 \pm 0.16$	$1.10 \pm 0.06$	0.976

Table 1. The quoted errors represent 90% confidence levels.  $N_H$  is the hydrogen column density.  $T_{\text{eff}}$  is the unredshifted effective temperature at the neutron-star surface.  $M_{\text{NS}}$  and  $R_{\text{NS}}$  are the mass and radius of the neutron star.  $F_{\text{pow}}$  is the flux of the power-law component in the 0.5-10 keV energy band.  $F_X$  is the total unabsorbed X-ray flux in the same energy band. The reduced  $\chi^2$  describes the quality of each fit. The last column gives the reduced  $\chi^2$  for 219 degrees of freedom.



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## 3. Source distance based on EOS

We use two neutron-star atmosphere model, NSAGRAV and NSATMOS, to fit the data, respectively, then use the “steppar” command in “XSPEC” to vary the mass, radius and distance parameters simultaneously, allowing other parameters free to find the best fit at each step. The distance is allowed to vary from 5.0 kpc to 10.0 kpc for each of the two models. Figure 2 shows two confidence levels in the mass-radius diagram obtained from our fit, for a distance of 7.25 kpc. As indicated in the figure, the contours are for  $\log(\Delta\chi^2)$  of 1.05 and 0.796, respectively, which correspond to confidence levels of, respectively, 90% and 99% for 3 parameters (mass, radius and distance).

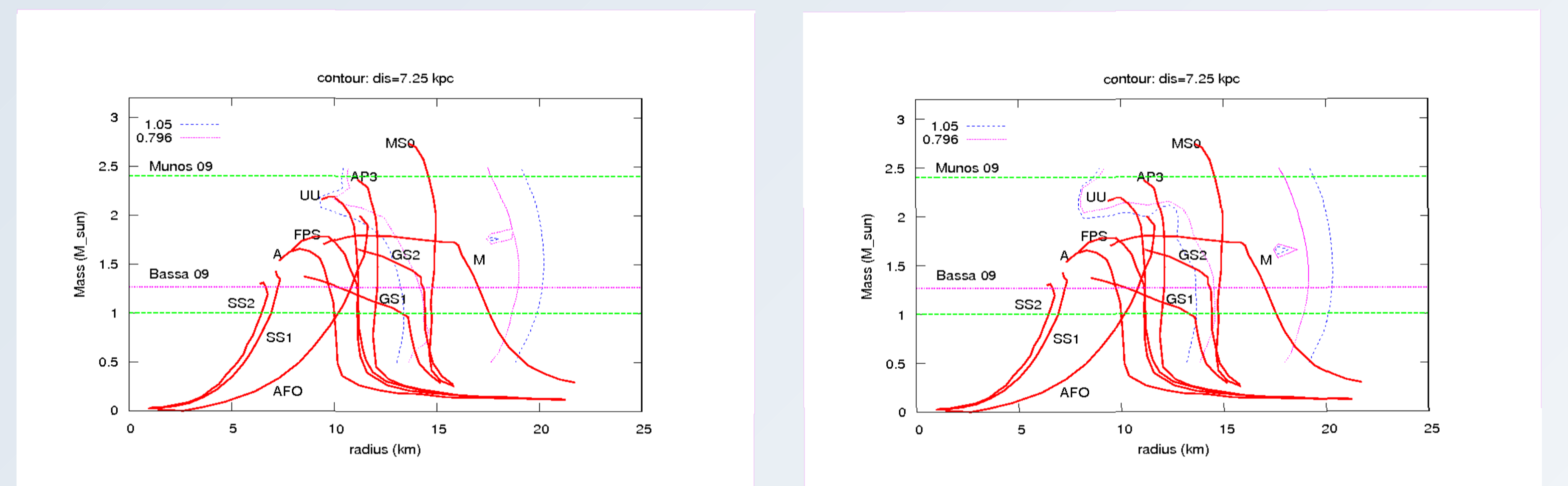


Figure 2. Contour plots showing the results of modelling neutron star EXO 0748-676 with the ‘XSPEC’ models NSAGRAV(left) and NSATMOS(right).

EOS	SS1	AP3	M
models			
NSAGRAV (90% confidence)	<5.0 kpc	8.3 kpc	9.1 kpc
NSAGRAV (99% confidence)	<5.0 kpc	8.9 kpc	9.6 kpc
NSATMOS (90% confidence)	<5.0 kpc	8.2 kpc	9.0 kpc
NSATMOS (99% confidence)	<5.0 kpc	8.5 kpc	9.5 kpc

Table 2. From the fits results with two NS atmosphere models, we find the distance upper limit of the source based on three typical EOSs..

## 4. Discussion

- EXO 0748-676 went into quiescence in 2008. We fitted the quiescent X-ray spectrum of this source observed with XMM-Newton, and constrained the allowed mass and radius of the neutron star in this system, as a function of the distance to the source.
- Both NSAGRAV and NSATMOS models show similar results and good constraints on  $R_{\text{NS}}$ . As the distance of the neutron star decrease, more EOSs satisfy the mass-radius constraints from these two models.
- EOS ‘AP3’ and ‘M’ are consistent with the results deduced from type-I X-ray bursts. If the compact object in EXO 0748-676 is a strange star described by the ‘SS1’ equation of state, the source should be closer than 5.0 Kpc