BAAA, Vol. 63, 2022
R.D. Rohrmann, M.N. Gómez, C.E. Boeris & M.A. Sgró, eds.

Asociación Argentina de Astronomía
Boletín de artículos científicos

X-ray emission from the microquasar S26 observed by XMM-Newton

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Resumen / S26 es el microcuásar con los jets más poderosos observados en fuentes estelares acretantes. La potencia cinética estimada para sus jets es del orden de la luminosidad bolométrica de algunas fuentes ultraluminosas de rayos X. Si esta potencia está acoplada a la acreción de materia por el objeto compacto, S26 debe ser una binaria super-acretante, similar al microcuásar galáctico SS433. Sin embargo, investigaciones con datos del observatorio de rayos X *Chandra* parecen implicar que la luminosidad central en rayos X es cuatro órdenes de magnitud menor que la potencia cinética de los jets, y está por debajo del límite de Eddington para un agujero negro de masa estelar. Motivados por entender el origen de esta discrepancia, analizamos observaciones en rayos X de S26 utilizando datos recopilados por el telescopio espacial *XMM-Newton*. En este trabajo presentamos una imagen y el espectro de la fuente. Nuestros resultados son consistentes con los reportados anteriormente por observaciones del satélite *Chandra* respecto a la longitud de la fuente, orientación, índice espectral, temperatura del plasma, y el flujo en rayos X en el rango de 0.4-4 keV, corroborando así las extrañas características de este objeto.

Abstract / S26 is the microquasar with the most powerful jets observed in accreting stellar sources. The estimated kinetic power for its jets is of the order of the bolometric luminosity of some ultraluminous X-ray sources. If this power is coupled to the matter accretion onto the compact object, then S26 must be a super-accreting binary, similar to the galactic microquasar SS433. Nevertheless, data from *Chandra* X-ray Observatory seems to imply that the central X-ray luminosity is four orders of magnitude lower than the kinetic power of the jets, and below the Eddington limit for a stellar-mass black hole. Motivated to understand the origin of this discrepancy, we analyze X-ray observations of S26 using data collected by the *XMM-Newton* space telescope. In this work we present an image and the spectrum of the source. Our results are consistent with those previously reported with *Chandra* satellite observations regarding length of the source, orientation, spectral index, plasma temperature, and the X-ray flux in the 0.4-4 keV range, confirming the puzzling nature of the object.

Keywords / galaxies: individual (NGC 7793) — ISM: jets and outflows — X-rays: binaries

1. Introduction

Microquasars are binary systems formed by a compact object (a neutron star or a black hole) and a donor star (Mirabel & Rodríguez, 1994). In their interaction, matter from the star is transferred around the compact object forming an accretion disk, and highly collimated relativistic jets are launched from the innermost regions of the disk (Shakura & Sunyaev, 1973).

The main parameter that determines the physical properties of the accretion disk and the jet ejection is the ratio between the accretion rate and the Eddington limit. When the accretion rate is super-Eddington ($\dot{M} \gg \dot{M}_{\rm Edd}$) the disk is geometrically and optically thick (Abramowicz et al., 1980, 1988). In these systems, when the accreting object is a black hole, the bolometric luminosity is lower than the accreted power because in the inner region of the disk the photons are trapped and advected towards the compact object. This process can drastically reduce the emerging radiative flux (see e.g. Ohsuga et al., 2005).

The only known source in our galaxy that accretes at a stationary super-Eddington rate is the microquasar SS433 (Fabrika, 2004). Jets from this source have a kinetic power much higher than the observed X-ray luminosity ($L_{\rm k,jet} \approx 2 \times 10^{39}\,{\rm erg\,s^{-1}}$, $L_{\rm X-rays} \approx 10^{35-36}\,{\rm erg\,s^{-1}}$). The mechanism that explains this contrast in SS433 is probably absorption by interstellar material along the line of sight (Begelman et al., 2006).

The microquasar S26 is another extraordinary example of very powerful, radiatively inefficient, jets (Pakull et al., 2010). This source is located in the nearby galaxy NGC 7793, surrounded by a vast jet-inflated bubble of $150\,{\rm pc} \times 300\,{\rm pc}$. The source has been investigated in the radio, optical, and X-ray bands (Dopita et al., 2012).

Chandra data of S26 show three bright X-ray point-like spots that lie perfectly aligned on the major axis of the radio-optical nebula: two hotspots located at the endpoints of each jet, and the core between them (Pakull et al., 2010). Furthermore, S26 shows two radio hotspots (located 20 pc inwards from each X-ray hotspot) (Soria et al., 2010), a pair of radio lobes, and an X-ray, optical and radio cocoon.

Notwithstanding the advances in the knowledge about this source, some physical properties remain un-

Table 1: *XMM-Newton* observation of P13.

DATA	EXP T (ks)		
	PN	MOS1	MOS2
Raw	50.2	50.6	49.0
Filtered	27.8	42.1	41.8
OBS-ID			0853981001
OBS-Date			2019/11/22

certain. Jets from S26 are the most powerful observed so far in stellar sources. From optical spectroscopic observations, (Pakull et al., 2010) the kinetic power of the jets is determined to be $L_{\rm k,jet} \approx 10^{40}\,{\rm erg\,s^{-1}}$. Assuming the disk-jet coupling hypothesis (Falcke & Biermann, 1995), S26 must be a super-Eddington accretor. Nonetheless, *Chandra* data show a faint central detection of $L_{\rm X-rays} \approx 10^{36}\,{\rm erg\,s^{-1}}$, below the Eddington limit and 10^4 times lower than the power of the jets.

The explanation of this discrepancy is still under debate; some plausible mechanisms that should be explored are the effects of X-ray absorption in a massive wind launched by the disk, very low viscosity in the accretion disk, and the possibilitiy that the jet power is not coupled with the accreted material but with the rotational energy of the black hole.

We are particularly interested in the nature of the faint central X-ray emission detected from S26. In this work we present results of our investigation using data collected by the *XMM-Newton* (X-ray Multi-mirror Mission Newton) Observatory.

2. Observation

We use data obtained during the observation 0853981001 from *XMM-Newton* space telescope. It was taken on 11/22/2019, when the observatory pointed at the ultraluminous X-ray pulsar P13 in the spiral galaxy NGC 7793 (Fürst et al., 2021). The details of the observation are shown in the Table 1

We filter the event files of observations to remove periods of high background due to solar flares. To define the good time intervals, we apply a threshold rate $\leq$0.35 count s^{-1} for EPIC-MOS and $\leq$ 0.4 count s^{-1} for EPIC-pn. The resulting net exposure is approximately 27.8 ks, 42.1 ks and 41.8 ks for PN, MOS1 and MOS2 cameras, respectively.

To accomplish the data processing, we use the High Energy Astrophysics Software (HEASoft) and the Science Analysis Software (SAS).

3. Image

Fig. 1 shows a mosaic with images of the three superimposed cameras. Red was assigned to the soft band (0.2-1 keV), green to the middle band (1-2 keV), and blue to the hard band (2-4 keV). S26 is located within a centered circle on the α=23^{h}58^{m}00^s, δ=-32^{o}33'21" sky coordinates (J200) (Dopita et al., 2012), which is zoomed into the box on the right side of the figure.

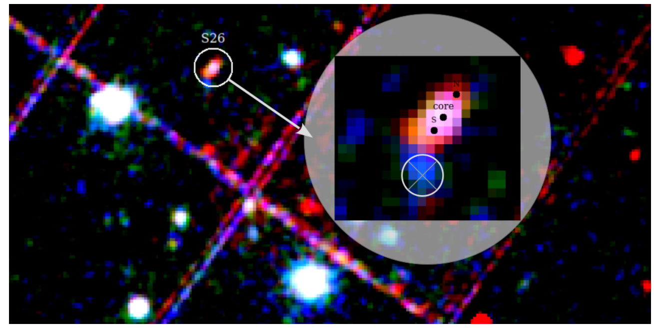

Figure 1: Mosaic divided into energy bands: soft (red; 0.2-1 keV), medium (green; 1-2 keV) and hard (blue; 2-4 keV). It has a source zoom, where the position of the X-ray northern (N) and southern (S) hotspots is displayed along with that of the core (Soria et al., 2010). As S26 is at 3-4 arcmin from the center point (on axis), the spatial resolution is 4.5 arcsec or 6.5 arcsec, depending on how the image was made*. In addition, one can see a circle with a cross inside where a source is detected very close to S26.

In addition, Fig. 1 shows a source near the south of S26, which we circle and cover with a cross in the zoomed image. It is probably an active galactic nucleous; it shines mostly at high energies and the powerlaw model gives a good fit for its spectrum.

The extended X-ray emission is confirmed in our data. We find consistency in the spatial orientation and length of the source in our image with that obtained by Pakull, Soria and Motch using *Chandra* data (Pakull et al., 2010). We conclude that the morphology of the source has not changed since it was observed with *Chandra* in 2003 (16 years).

4. Spectrum

We obtain the spectrum from S26 in the energy range 0.4-4 keV, which can be seen in Fig. 2. The XSPEC best-fitting model is TBABS*(BBODY+POWERLAW), with a C-statistic of 15.04 over 16 d.o.f and the parameters shown in Table 2.

The region that we use to extract the source spectrum is a circle of radius 0.25 arcmin, that covers it completely and does not include the area where the possible active galactic nucleous is. This election is the minimum region that can be used in the processing. Hence, we can only calculate the integrated flux of the entire source.

As the entire region of S26 is analyzed, the result is consistent with what is expected. The model indicates that there are two contributions to the radiation: one of thermal origin (bbody) and the other of non-thermal origin (powerlaw). These contributions probably come from different parts of the source, the first from the core (accretion disk/wind), the latter from the lobes.

According to this model, the flux is $F_{0.4-4\,{\rm keV}} = 1.95^{+0.19}_{-0.26} \times 10^{-14}$ erg cm^{-2} s^{-1}. Despite the small number of counts in the spectrum, the model gives a good

* https://xmm-tools.cosmos.esa.int/external/xmm_user_support/documentation/uhb/offaxisxraypsf.html

Table 2: Model fitting parameters.

Model	Parameter	Value
TB_{abs}	n_H	1.2×10^{20} (fixed)
Bbody	kT	$0.14^{+0.01}_{-0.01}$ keV
Bbody	norm	$(2.1^{+0.4}_{-0.6}) \times 10^{-7}$
Powerlaw	PhoIndex	$1.5^{+0.8}_{-0.9}$
Powerlaw	norm	$(1.94^{+1.5}_{-1}) \times 10^{-6}$
$\mathrm{Flux}_{0.4-4}$		$(1.95^{+0.19}_{-0.26}) \times 10^{-14}$ erg cm^{-2}s^{-1}
C statistic	–	15.04 (16 d.o.f.)

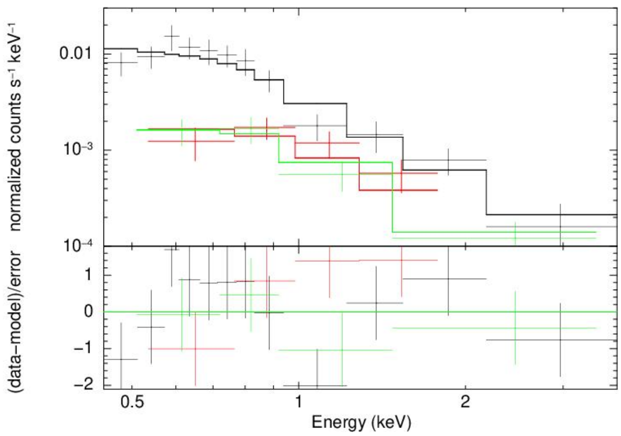

Figure 2: TBABS(BBODY+POWERLAW) fit model in the spectrum of S26. Error bars correspond to 1-σ noise. The spectral resolution of *XMM-Newton* is $R = E/\mathrm{d}E \approx 10 - 50$ in the 0.3-10 keV range.

fit and the parameters obtained agree within error with those reported with *Chandra* data.

5. Light curve

We extract light curves and analyze possible temporal variations using the task LCSTATS of the timing analysis package XRONOS**. We conclude that the source does not present temporal variations over the error bars of individual points. This is expected since the observation lasts less than a day, an insufficient interval for allowing variones of the radiation produced on the large regions of S26, which dominate the whole flux.

6. Conclusions - Future work

We investigated the X-ray emission of S26 in the 0.2-10 keV band using *XMM Newton* data, motivated by the puzzling central low luminosity of the source previously reported by *Chandra*. In this communication we have presented our observational results. Bellow we briefly summarize our results and mention some possible explanations to the open problem of the nature of the powerful jets that we are going to explore in the future.

- From our data analysis we obtained that the X-ray emission is consistent with the source length, orientation, spectral index, spectrum, plasma temperature and the X-ray flux reported with *Chandra* observations(Soria et al., 2010). This shows that the source is stable on timescales of years.
- Assuming that the distance to S26 is 3.9 Mpc, the luminosity is given by $L_{0.4-4\,\mathrm{keV}} = 3.53 \times 10^{37}$ erg s^{-1}. Therefore, S26 is not an ultraluminous X-ray source. However, if the mechanical power of its jets is coupled to accretion by the compact object, it must be a super-Eddington source.
- In the near future we will investigate the X-ray emission of S26 using *XMM-Newton* observations collected in the last 9 years, to study whether the flux present variations on different timescales.
- An alternative explication for the sub-Eddington X-ray luminosity is the existence of a *cold accretion disk* (Bogovalov & Kelner, 2005). In such a disk, the angular transport mechanism for disk formation is not energy dissipation by viscosity, but mass loss from the disk as magnetized winds. In the absence of viscosity, the radiation from the disk is faint. Hence, it might explain the low X-ray emission detected from the core. The detailed study of this model applied to S26 will be explored in a future communication.
- Another possible explantion, also to be explored in more detail, is a super-Eddington disk with a strong and dense wind that absorbs most of the X-ray emission, reprocessing it into lower energy photons by Compton scattering.
- Finally, yet another possibility would be sub-Eddington accretion but in a magnetically advected dominated region in such a way that most ot the energy of the jets comes from the rotation of the black hole.

**https://heasarc.gsfc.nasa.gov/xanadu/xronos/help/lcstats.html

Acknowledgements: The authors thank the anonymous referee for a careful and professional review, and for his/her comments that improved this work. FNR thanks Federico A. Fogantini and Jorge A. Combi for the fruitful discussions about this research. PSC and GER acknowledge support by PIP 2021-1639 (CONICET). GER acknowledges the support by the Spanish Ministerio de Ciencia e Innovación (MICINN) under grant PID2019-105510GB-C31 and through the “Center of Excellence María de Maeztu 2020-2023” award to the ICCUB (CEX2019-000918-M)

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