Extragalactic jets from every angle
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Are jet ubiquitous in ULXs?

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Abstract. A jet model represents well different X-ray states of the bright ULX IC342 X-1.

Keywords. galaxies: individual (IC 342), X-ray: galaxies, acceleration of particles

1. Introduction

Ultra Luminous X-ray sources (ULXs) are point-like, off-nuclear X-ray sources with inferred luminosity (if assumed to be isotropic) in excess of the Eddington limit for spherical accretion onto a 10 $M_\odot$ compact object (see e.g., Fabbiano 2006, for a review). IC 342 is a nearby starburst galaxy (3.9 Mpc; Tikhonov & Galazutdinova 2010) that contains two ULXs: X-1 and X-2, the first ULXs reported to transition between distinct spectral states (Kubota *et al.* 2001): X-1 went from an apparently disc-dominated state to a power-law-dominated state while the spectrum of X-2 coincidentally carried out the reverse transition. The source X-1 is surrounded by a large optical and radio nebula that may be an X-ray ionized bubble driven by strong outflows from the ULX (Pakull & Mirioni 2002; Roberts *et al.* 2003; Feng & Kaaret 2008). Radio observations of the bubble have been performed with the JVLA at 5 GHz (Cseh *et al.* 2012): an extended source is detected, with about the same extent of the optical bubble, and a possible unresolved source, albeit not confirmed by Marlowe *et al.* (2014). The upper limit of the point source is 14 mJy at 5.5 GHz.

Could the properties of the ULX X-1 be explained by the presence of a jet?

2. Results

We have collected spectral measures at all the available wavelengths in order to construct an overall spectral energy distribution (SED). This SED of IC 342 X-1 is plotted in Figure 1*: left*. In order to test the jet hypothesis we first compare the SED with a known jet source, the Galactic microquasar GRS 1915+105, known to be a superluminal (Mirabel & Rodriguez 1994) and complexly variable (Fender & Belloni 2004 for a review) bright source. To mimic this source as pointing towards our line of sight, at an angle of 3°, we boosted the X-ray and radio power by a factor δ^4 with $\delta = 2.8$. Given the strong agreement we deem that a jet is a viable description of the X-ray emission of this ULX.

We use a model (see Ghisellini & Tavecchio 2009, for details) that has $M_{\rm BH} = 50\ M_\odot$ and $L_{\rm Edd} = 9 \times 10^{38}$ erg/s. The disk luminosity is $L_{\rm disk}$ =12% of $L_{\rm Edd}$, while the jet, at 100 $R_{\rm S}$, has an angle to the line-of-sight $\theta_{\rm v} = 3°$ and $\Gamma_{\rm bulk} = 4$. The magnetic field is $B = 2 \times 10^6$ G. We include also a corona at 30% of the disk luminosity and compare it with the SED and in particular with the different X-ray observations from 2004 (see Figure 1*: right*). The overall X-ray emission is well described by this model in the optical and X-ray energy range; the model never exceeds the upper limit from Fermi in the TeV band. Different X-ray states of IC 342 X-1 can be explained by changing only the injected power (lowest = 30% of highest) and slightly the electron distribution.

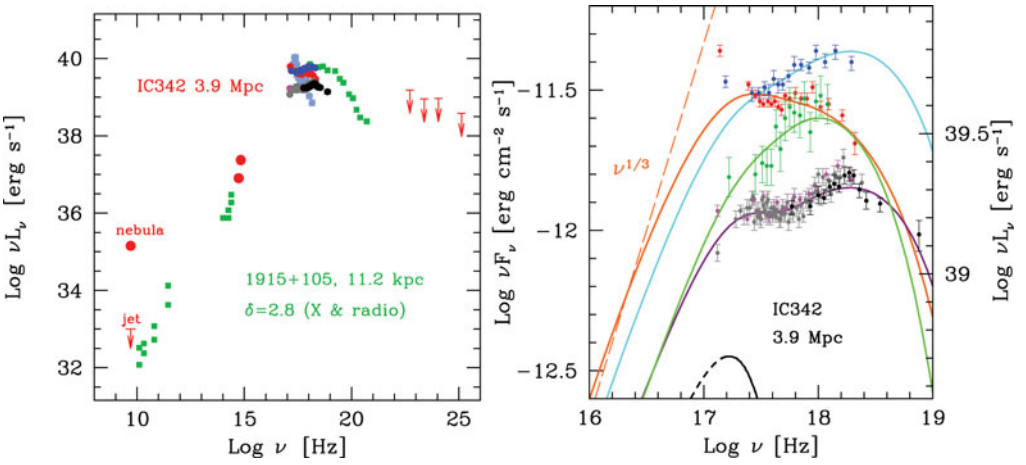

Figure 1. *Left:* The SED of IC342 X-1 in radio, optical, and 95% upper limit in the gamma-ray band (red). Fermi data are the upper limit front Aug 2008-Apr 2014 data version (*P7_REP*; SOURCE class events; Galactic diffuse model v05_rev1; Γ=2 in each of the 4 bands (Atwood *et al.* 2009)). The various datasets for XMM-Newton and Swift are represented in pink, blue, pale blue and gray. NuStar data in black. See Pintore *et al.* (2014); Rana *et al.* (2014) and references therein. The comparison SED of GRS 1915+105 is shown in green. *Right*: Zoom of the X-ray band with the models describing different states.

Another Galactic analogue of such a system is the W50 nebula, thought to be inflated by the relativistic jets of the microquasar SS433 (Dubner *et al.* 1998), which has similar energetic requirements to the IC342 X-1 nebula. Other indications of the presence of jets in ULXs: NGC 2276 3c/S6 (Mezcua *et al.* 2013; Wolter *et al.* 2014) with two lobes of radio emission; Holmberg II X-1 (Cseh *et al.* 2014) with an apparent triple radio structure and attributed to a BH with $M_{\rm BH} \geqslant 25 M_{\odot}$. The interpretation with a jet of the X-ray emission is worth of further investigation both with new multi-wavelength observations of this source and the analysis of other ULXs with radio detections.

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