B-JETTY: Baryonic Jet Energetics with Cloudy

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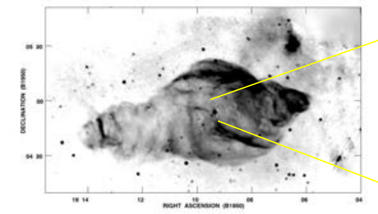
I. What is SS 433?



W 50 Nebula (Dubner et al. 1998)

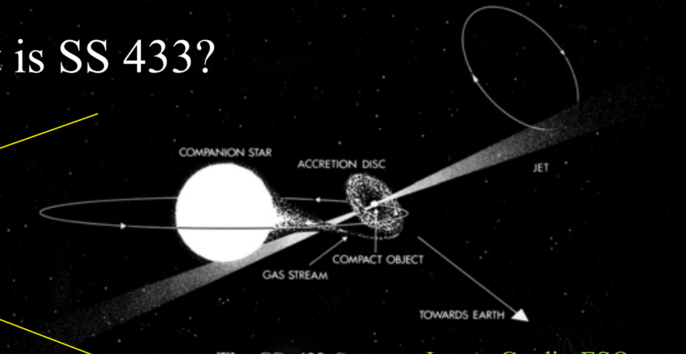
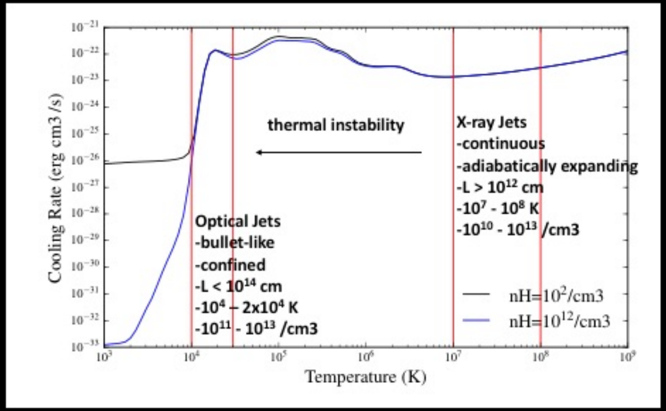


Image Credit: ESO

$$L_{Edd} \sim 10^{38} (M/M_{\odot}) \text{ erg/s}$$

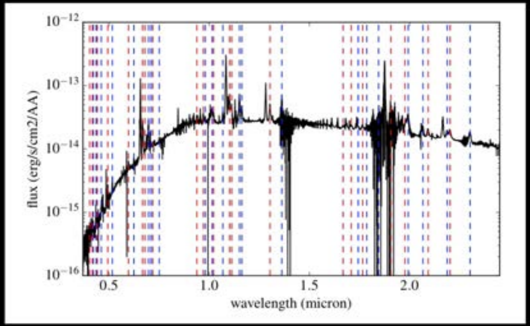
SS 433 is an X-ray binary and the only known steady super-Eddington accretor in the Galaxy. It is also the only astrophysical system known to contain relativistic (0.26c) baryonic jets, evidenced through its famous "moving" emission lines of H I and He I. The jets can also be seen in the X-ray through emission lines of highly ionized metals, as well as spatially resolved as moving "blobs" in the radio. The formation of the line-emitting optical bullets occurs through thermal instabilites as the hot, continuous X-ray jet flow cools and expands.



Cooling Rate as a function of temperature for low and high density gas.

An important question is: how super-Eddington is SS 433? A lower limit can be established unambiguously from the kinetic power of the jet bullets, as long as key parameters of the gas can be reliably measured.

$$L_{kin,jet} = \frac{1}{2} M (0.26c)^2 \frac{c}{l} [\frac{erg}{s}]$$

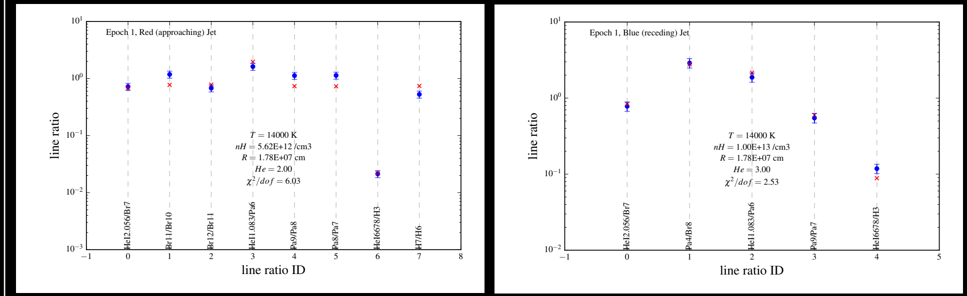


XSHOOTER spectrum of SS 433. Baryonic jet lines are marked in blue and red.

$$L_{H\alpha}[\frac{erg}{s}] = \int \alpha_{H\alpha} n^2 dV$$

II. Cloudy Model

To measure the total mass of the bullets from the emission line luminosities, we need to know the line emissivity, gas density, bullet size and total luminosity. Our goal here is to use Cloudy to measure these quantities through modeling of the H I and He I emission line ratios from our XSHOOTER spectra. We use a coronal model to construct a 4D grid on temperature (T), hydrogen density (nH), bullet size (R) and He abundance. In order to cancel extinction and systematic errors, we use strategic line ratios that are very close in wavelength such as HeI1.083m/Pa6, Pa4/Br8, HeI6678/H3 etc.



Best fit results for the line ratios.

	Approaching Jet	Receding Jet
Temperature [K]	14,000	14,000
Hydrogen Density [cm-3]	5.6×10^{12}	1.0×10^{13}
Radius [cm] / Optical Depth Hα	1.8×10^{7} / 110.5	1.8×10^{7} / 165.5
He abundance [x solar]	2.00	3.00
Number of Bullets	9.0×10^{11}	4.0×10^{11}
Filling Factor	2.0×10^{-5}	8.0×10^{-6}
Jet Kinetic Power [erg/s]	3.0×10^{38}	2.0×10^{38}

III. Results and Discussion

To estimate the kinetic power, we use the line intensity of the Br7 line (least affected by extinction), and we assume a jet length 10^{14} cm as recently resolved by optical interferometry (GRAVITY Collaboration et al 2017).

We find that the combined kinetic luminosity of the jets is ~ 5×10^{38} erg/s i.e. 5 Edd for a neutron star and 0.5 Edd for a black hole. This is a lower limit (total jet mass may be higher than optical bullets, radiative output etc) and is independent of beaming factor. Could accretion alone power such an outflow?