X-ray and Lyα emission of Haro 2=Mrk 33

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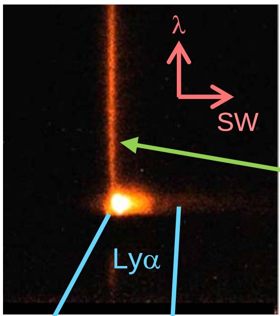
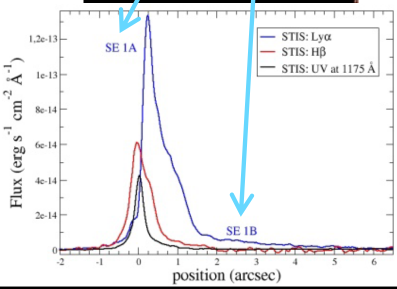
Haro 2 is one of the few galaxies of the local universe that shows a prominent Lyα emission. We have performed X-ray and UV spectral analysis on Haro 2 with spatial resolution, using Chandra and HST data. Our results show that the two starbursts present in the central region of the galaxy are in different evolutionary states, with a difference in age >~1 Myr. Attending to the CIV and SiIV line profiles, evolutionary population synthesis models yield ages of ~4 Myr and ~5 Myr for each one of them. We have also investigated the Lyα spatial profile, which turns out to be rather complex, showing in the major axis of the galaxy three Lyα-emitting components decoupled from the young stellar clusters, together with absorption regions. One of these Lyα-emitting regions appears as a diffuse emission to the NW, extending ≥6 arcsec (≥600 pc). Also, whereas both knots emit in the soft X-ray energy range 0.2-1.5 keV, it is observed that hard emission in 1.5-8 keV is only present in the younger burst.

All the facts described, the somewhat evolved state of the starbursts and the Lyα emission found, together with its decoupling from stellar emission, are compatible with the current model for the outflow of neutral gas in galaxies with Lyα emission, which states that mechanical energy released by the central starbursts must have been injected into the medium, sweeping up the surrounding neutral gas, allowing Lyα photons to escape.

HST/STIS high resolution spectrum





Knot NW

Age ~ 5 Myr

M ~ 1.3×10^6 $M_\odot$

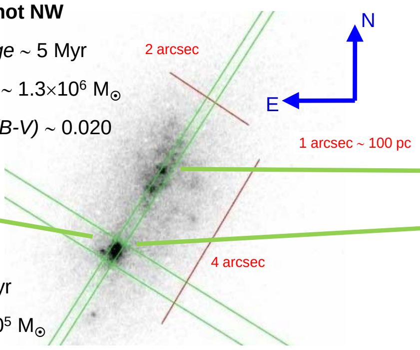
E(B-V) ~ 0.020

Knot SE

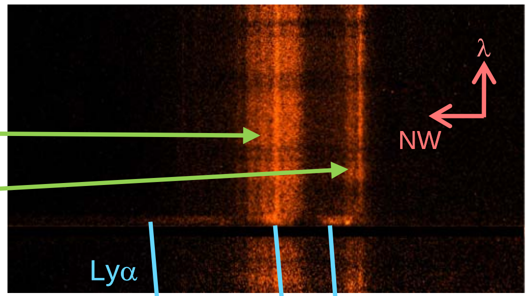
Age ~ 4 Myr

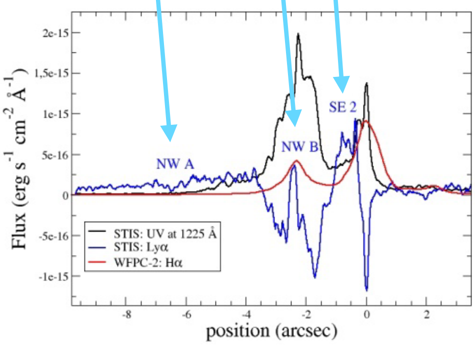
M ~ 7.0×10^5 $M_\odot$

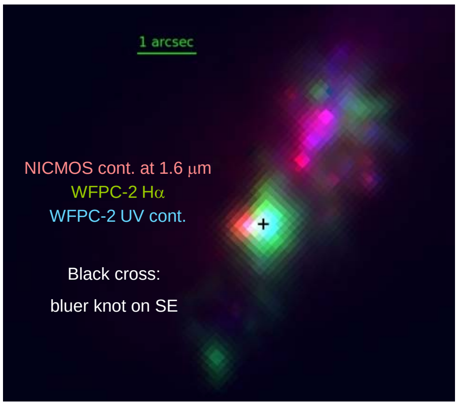
E(B-V) ~ 0.050



HST/STIS low resolution spectrum







Bursts NW and SE were characterized with Staburst99 using UV spectral and photometric images of Haro 2. However, the full Hα, FIR and UV emissions can only be accounted as a whole by a **composite of starbursts** with a range of ages and extinctions within **3-4.5 Myr** and **E(B-V)=0.035-0.3**, respectively.

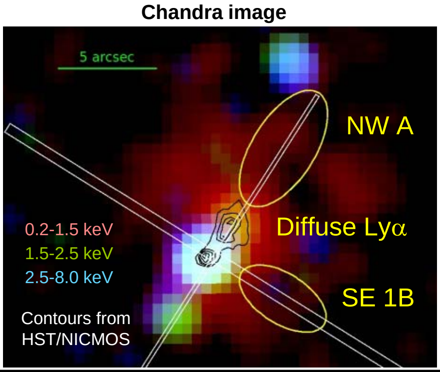
⇒ **THE STARBURST WAS NOT STRICTLY INSTANTANEOUS, BUT LASTED ~1.5 Myr, WITHIN A VERY INHOMOGENEOUS DISTRIBUTION OF GAS AND DUST.**

We observe **three Lyα-emission components** in the low-resolution slit direction (major axis of the galaxy), together with absorption regions. This spatial profile shows that the distribution of the HI kinematics and its structure are rather complex.

- **NW A:** a diffuse and extended (>600 pc) component northward of knot NW. It turns out that, although being diffuse, it is the strongest component, as found also by Hayes et al. (2007) for Haro 11. $F_{Ly\alpha}=1.8\times10^{-14}$ erg s^{-1} cm^{-2}, *EW*(Lyα)~13 Å
- **NW B:** the weakest component lies somewhat in the direction of knot NW. $F_{Ly\alpha}=5\times10^{-15}$ erg s^{-1} cm^{-2}, *EW*(Lyα)~5 Å
- **SE 2:** clearly detached from the stellar emission of knot SE. $F_{Ly\alpha}=1.6\times10^{-14}$ erg s^{-1} cm^{-2}, *EW*(Lyα)~13 Å

All Lyα spectral profiles from these regions show the typical blue-edge absorption, as well as the redshifted peak emission due to the presence of HI.

Chandra image



X-RAY ANALYSIS

Values of the fixed parameters

Galactic absorption: *N*(HI) = 6.3×10^{19} cm^{-2}

Intrinsic absorption: *N*(HI) = 7.0×10^{19} cm^{-2}

Power law index was FIXED: Γ = 1.0, 1.2

Values of the free parameters

Hot plasma temperature: kT = 0.7±0.1 keV

Values of the luminosities (D=20.5 Mpc)

When integrating over the whole region:

L(0.4-2.4 keV) ~ 2.3×10^{39} erg s^{-1}

L(2.0-10.0 keV) ~ 2.4×10^{39} erg s^{-1}

- **Extended, diffuse Lyα** is decoupled from Balmer lines and stellar continuum, but coupled to **diffuse, soft X-ray emission**. This may indicate an enhancement of the **diffuse Lyα emission** by collisional excitation, and hence a common origin of both **diffuse Lyα** and **soft X-ray emissions**: interactions between gas phases at different temperatures. Moreover, this interaction might also push outwards the neutral gas, leaving a free kinematical path through which Lyα photons can escape. However, further observational data are needed in order to reject other models.

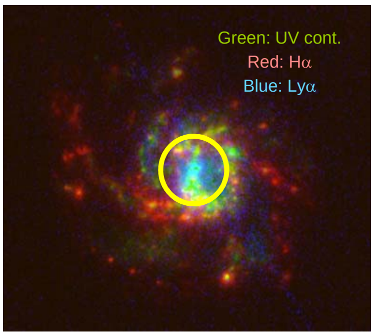
- **Hard emission** is mainly originated in the younger burst SE, whereas both knots contribute to the soft component. The **soft emission** is spatially more extended in knot NW, which agrees with this knot being older than SE, and hence the bubble created by the burst having had more time to expand.

- It was found that a model with a **hot-plasma emission**, a **power-law component** and Galactic absorption could account for the observed X-ray spectrum of the source. Although its statistical significance is not conclusive, an intrinsic absorption was included too, driven from our results in the UV-optical range, as well as from previous analysis in the literature. The value obtained for the plasma **temperature** (**kT=0.7 keV**) is somewhat high, but consistent with diffuse thermal emission in BCGs.

- The **soft X-ray luminosity** value found agrees with CMHK02 models (Cerviño et al. 2002) for an efficiency in the conversion of mechanical energy into X-ray luminosity of **ϵ_{Xeff}=1-3%**, which lies in the range observed in other starbursts (Summers et al. 2004). However, the **hard X-ray emission** is underestimated by one order of magnitude. This may be due to the presence of an **active binary star** with *L*(2-10 keV)~10^{39} erg s^{-1}, which might be the cause of the hard, point-like structure located in knot SE, contributing with a power-law component to the X-ray spectrum.

Other Lyα sources

HST/ACS images have been obtained for the local Lyα emitters IRAS 08339+6517, ESO 338-IG04, Haro 11, NGC 6090, SBS 0335-052 and Tololo 65. A wide morphology and very different properties have been observed. We show here the results for IRAS 08339+6517



IRAS 08339+6517

In the central region of the galaxy we find:

- Strong **UV continuum** emitted by a Super Stellar Cluster (SSC)
- No **Hα** at all, but a relative strong **Lyα** component, co-spatial with the SSC
- Were Lyα caused by local recombination, Hα should be present ⇒ What is the origin of this Lyα emission? Scattering, collisional excitation,...? No X-ray image with spatial resolution available.

IRAS 08339+6517

- Integrated Hα, FIR and UV fluxes can be accounted by a **composite of coeval starbursts** (**5.5 Myr**) and extinctions within **E(B-V)=0.020-0.25**.
- The soft X-ray emission can be reproduced by our models assuming an efficiency in the conversion of the mechanical energy into X-ray emission of **ϵ_{Xeff} = 5%**, which lies in the range observed for this type of galaxies.
- X-ray spectral analysis shows an overabundance of α–elements over Fe-elements:

Values of the fixed parameters

Galactic absorption: *N*(HI) = 4.5×10^{20} cm^{-2}

Intrinsic absorption: *N*(HI) = 7.9×10^{19} cm^{-2}

Power law index was FIXED: Γ = 1.1

Values of the free parameters

Hot plasma temperature: kT = 0.67±0.07 keV

α–elements abundance: Z(α) = 0.5 $Z_\odot$

Fe–elements abundance: Z(Fe) = 0.13 $Z_\odot$

Values of the luminosities (D=80.2 Mpc)

L(0.4-2.4 keV) ~ 1.4×10^{41} erg s^{-1}

L(2.0-10.0 keV) ~ 1.3×10^{41} erg s^{-1}