ESTALLIDOS VIII

Evolutionary state of the Lyman Alpha Emitter Haro 2

Héctor Otí Floranes

Dirigido por J. M. Mas Hesse

Centro de Astrobiología (CSIC-INTA)

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LINK LOCAL EMITTERS -> HIGH-REDSHIFT SOURCES

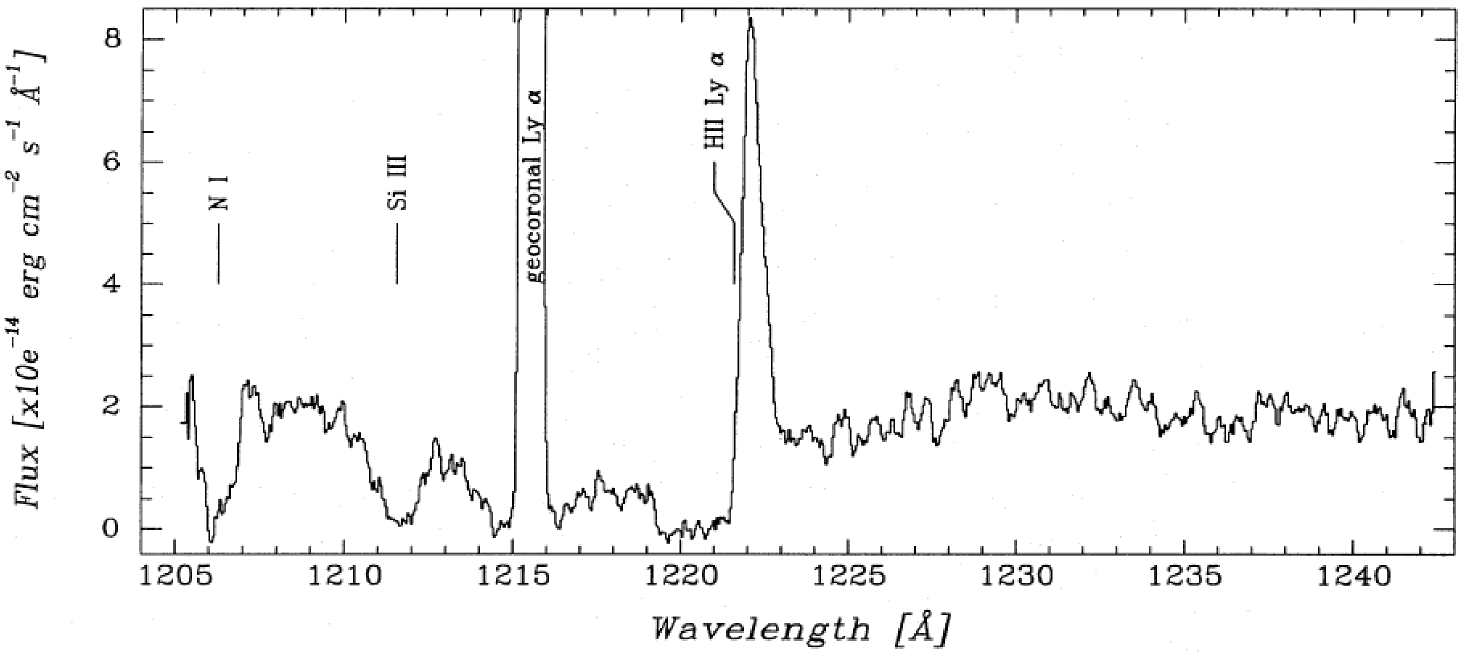
- Lyα is an intense line observed in the optical in high-z sources
  - used to quantify Star Formation Intensity
  - relevant for Cosmology
- However, that is not trivial: Lyα escape from source is a rather complex issue
- Therefore, it is crucial to understand how Lyα photons are produced, absorbed, scattered and finally escape from the source
- Haro 2 L_{bol} is similar to LAEs at z=3.1 (Gawiser et al. 2007; Gronwall et al. 2007), which are a proxy of the low-L end of LBGs
- Hence, Haro 2 is the best local prototype of Lyα-emitting galaxies at high z

BASIC PROPERTIES

- Haro 2/Mrk 33
- Blue Compact Dwarf Galaxy
- Distance = 20.5 Mpc
- 1arcsec~100 pc
- Galactic E(B-V)~0.012
- High Z for BCDGs: 12+log(O/H) = -3.5 => Z ~ Zo/2

Lyα EMISSION

- Lequeux et al. (1995)



- Despite being a metal-rich, dusty galaxy, Lyα emission was found
- Neutral gas is expanding as a superbubble at ~200 km s^{-1}, which allows the red wing of the line to escape

STAR-FORMING KNOTS

Knot SE

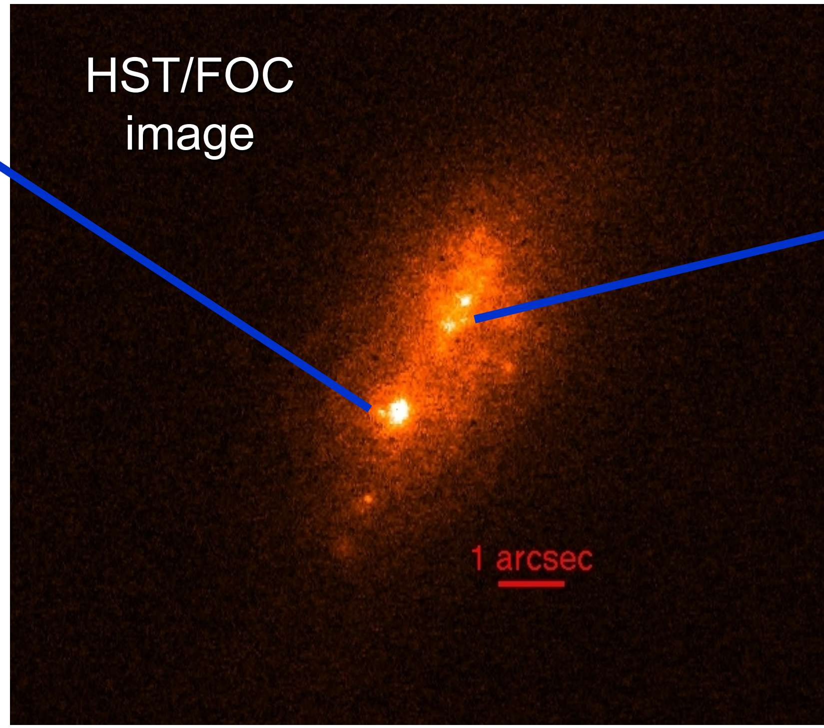
point-like source

age~4 Myr

M~7e+5 Mo

E(B-V)=0.040

50% Lyα absorbed



Knot NW

rather extended source

age~5 Myr

M~1.3e+6 Mo

E(B-V)=0.020

25% Lyα absorbed

IMF

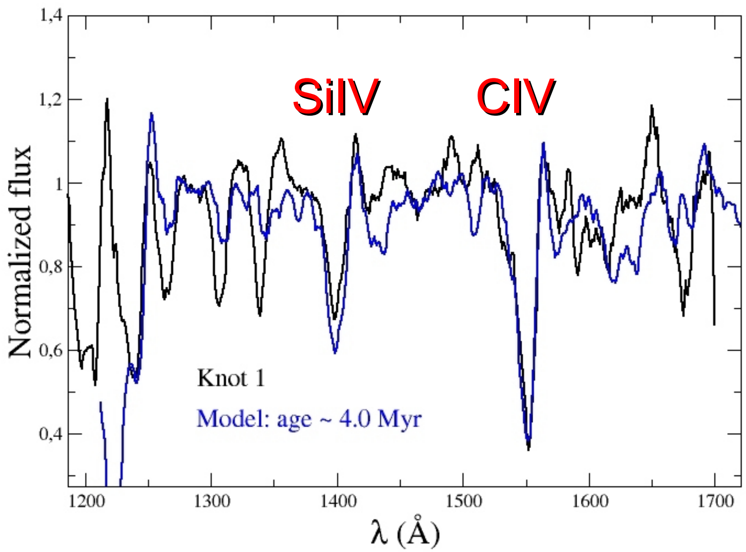
Salpeter

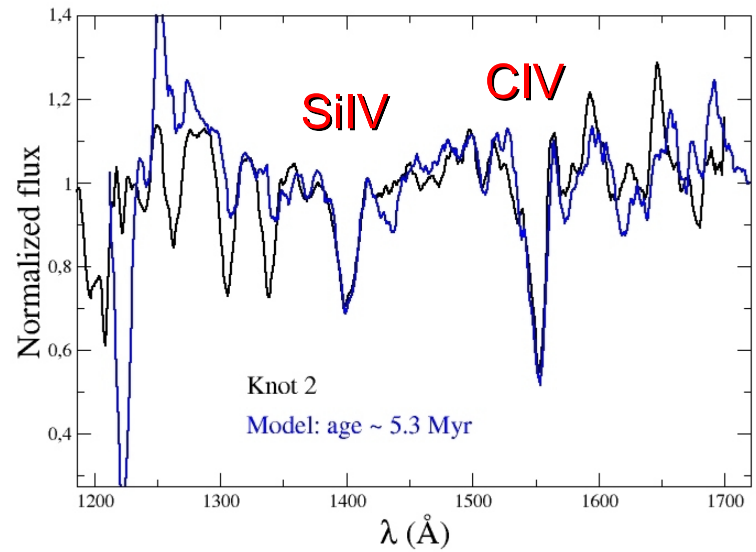
2-120 Mo

Total mass

M~2e+6 Mo

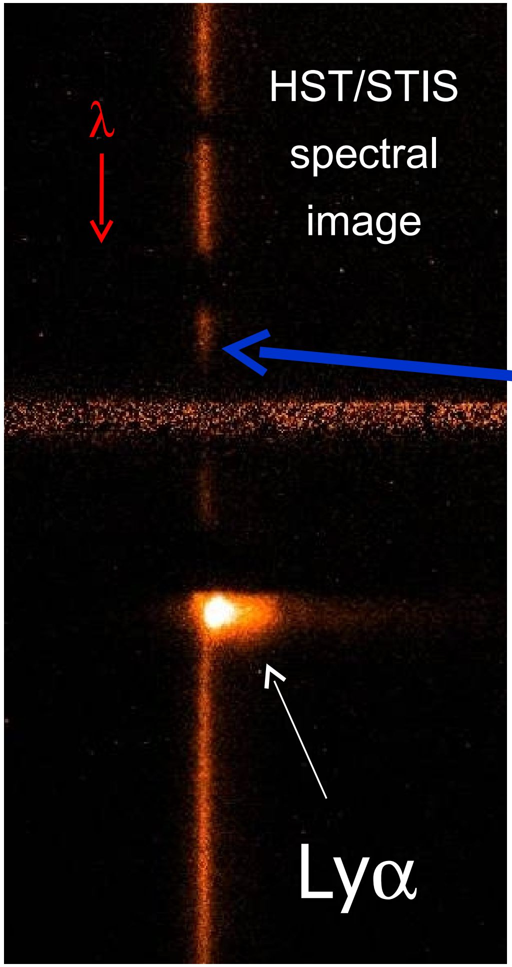
PROPERTIES OF KNOTS

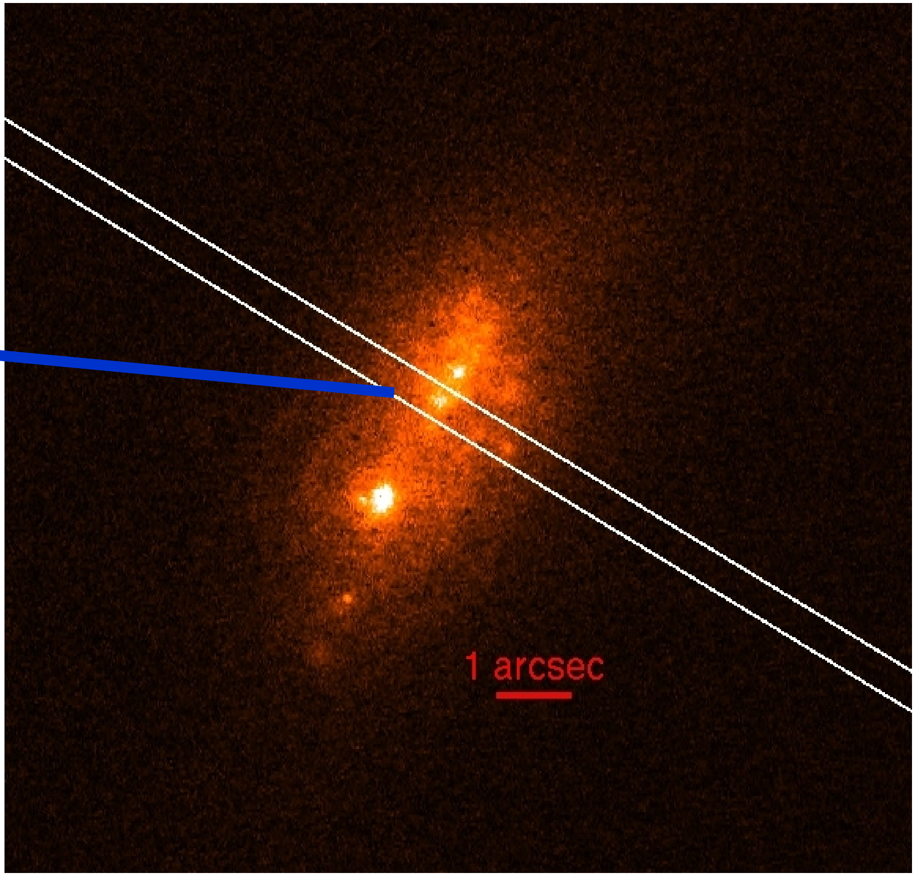




- There is a temporal shift of 1 Myr between both knots
- Age was calculated fitting SiIV and CIV UV lines in the normalized spectra with the available Starburst99 UV spectral libraries: Zo and SMC/LMC
- Different metal content in knots?
- Knot SE
  - UV line spectrum could only be fitted with Zo library
- Knot NW
  - On the other hand, knot NW could be fitted with both libraries, finding a similar value of ~5 Myr

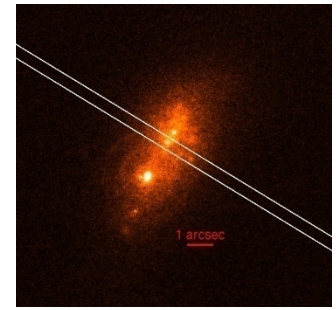
Lyα EMISSION: MINOR AXIS



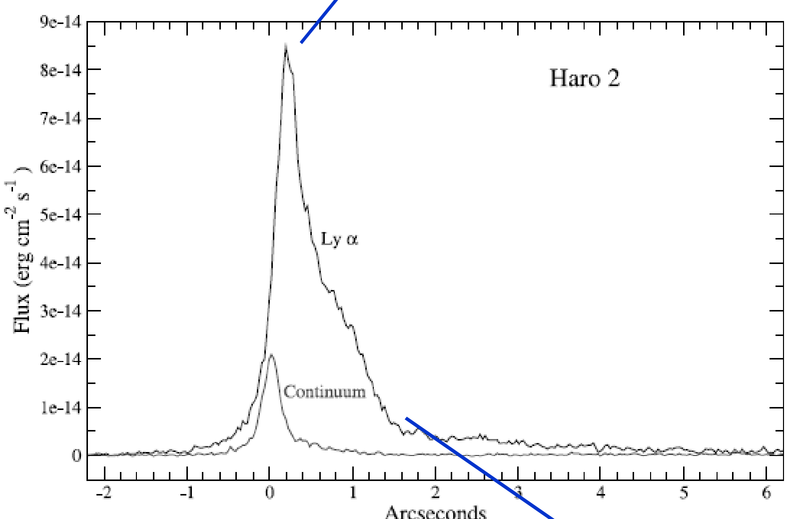


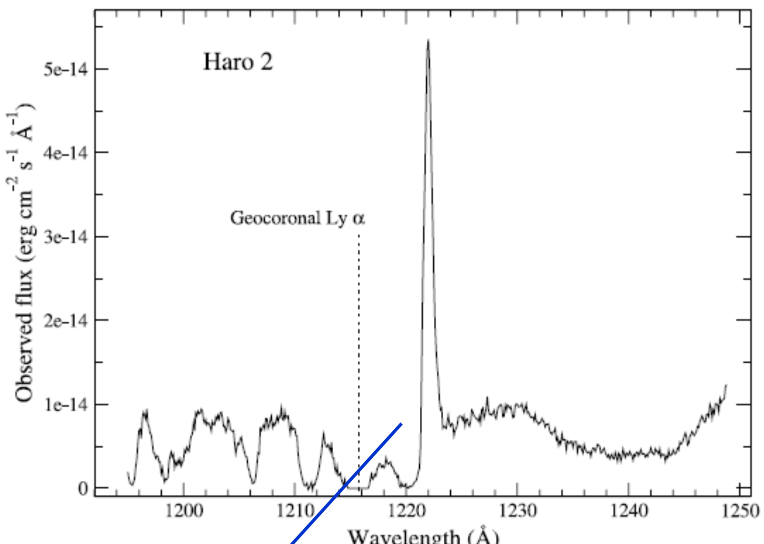
Lyα PROFILE: MINOR AXIS

- Mas-Hesse et al. (2003)



Lyα not spatially-coupled to stellar continuum



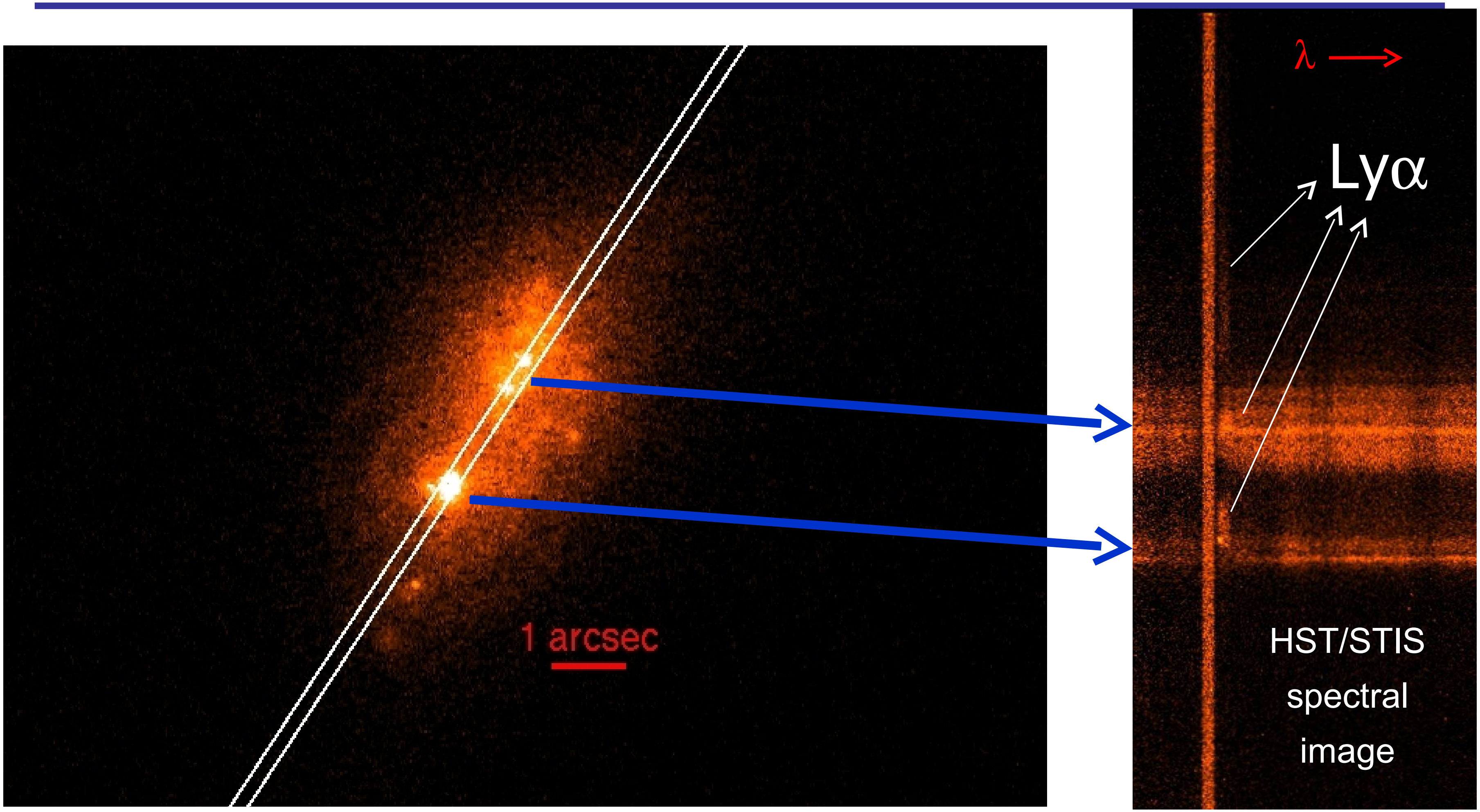


Lyα extended diffuse emission > 600 pc

P Cygni proflie

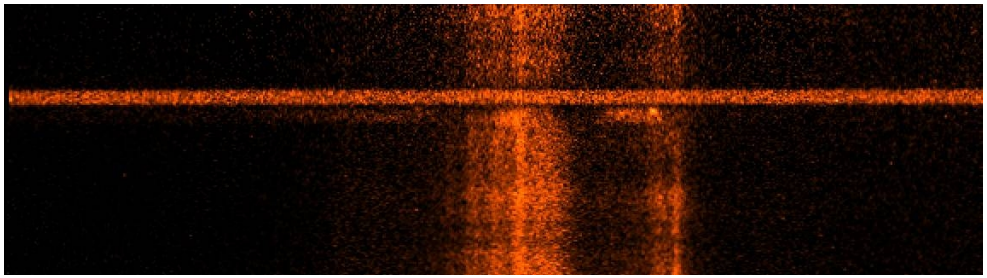
High-resolution spectrum: 0.053 Å

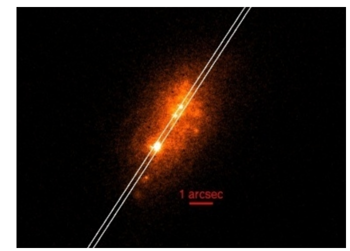
Lyα EMISSION : MAJOR AXIS

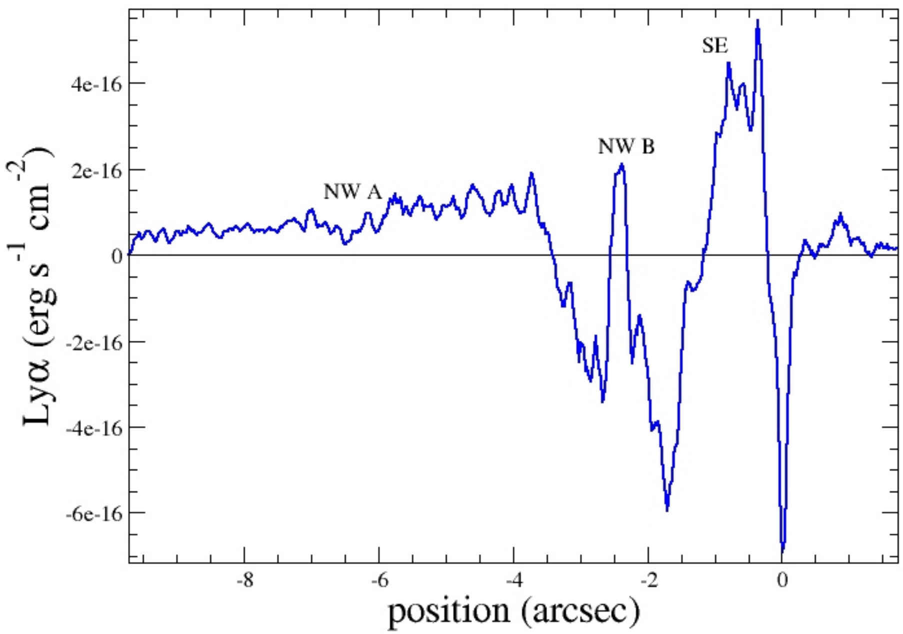


Lyα PROFILE: MAJOR AXIS

NW ← → SE

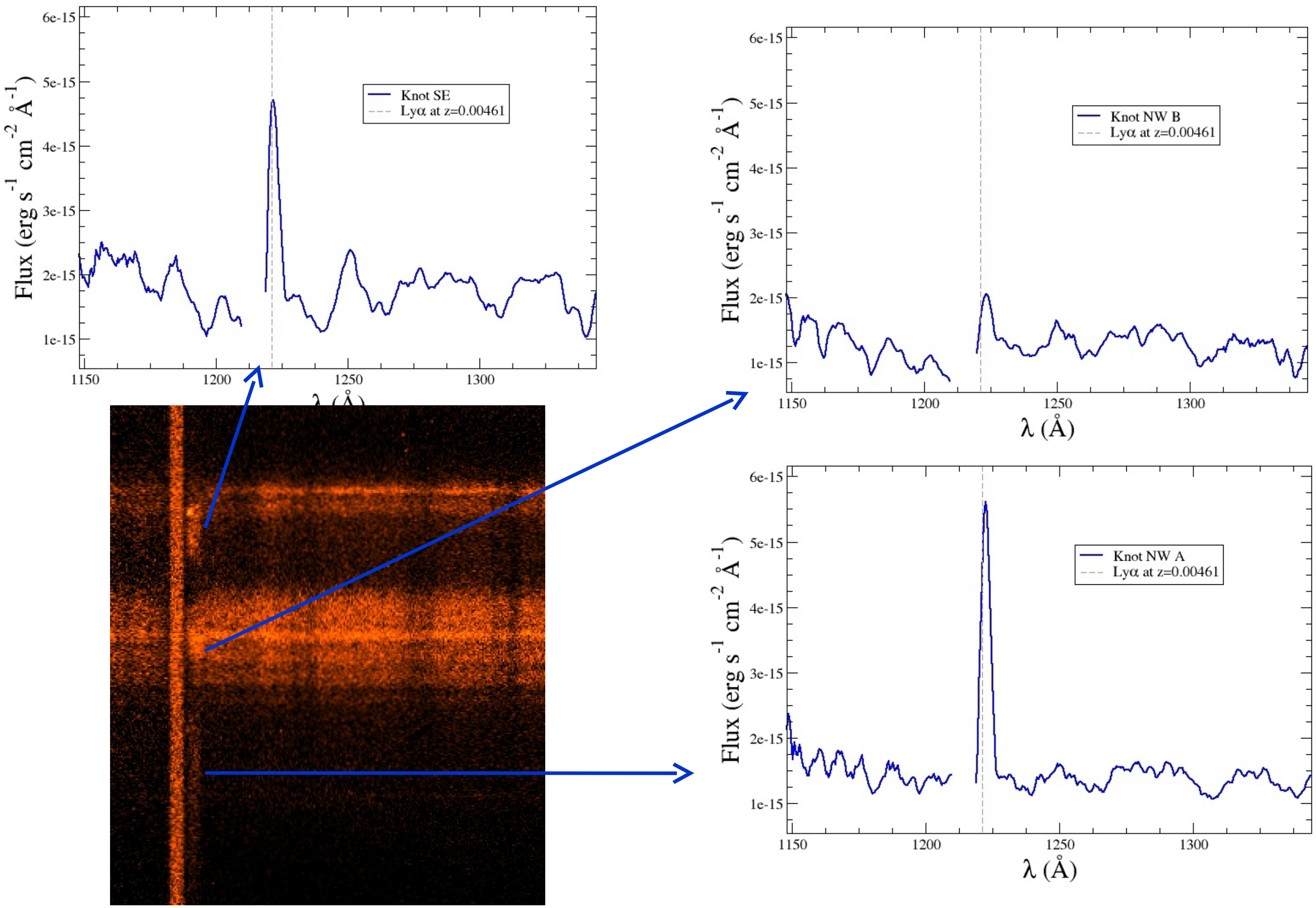






- Emission profile is rather complex, with several emitting and absorbing regions
- Diffuse emission is very large: > 600 pc

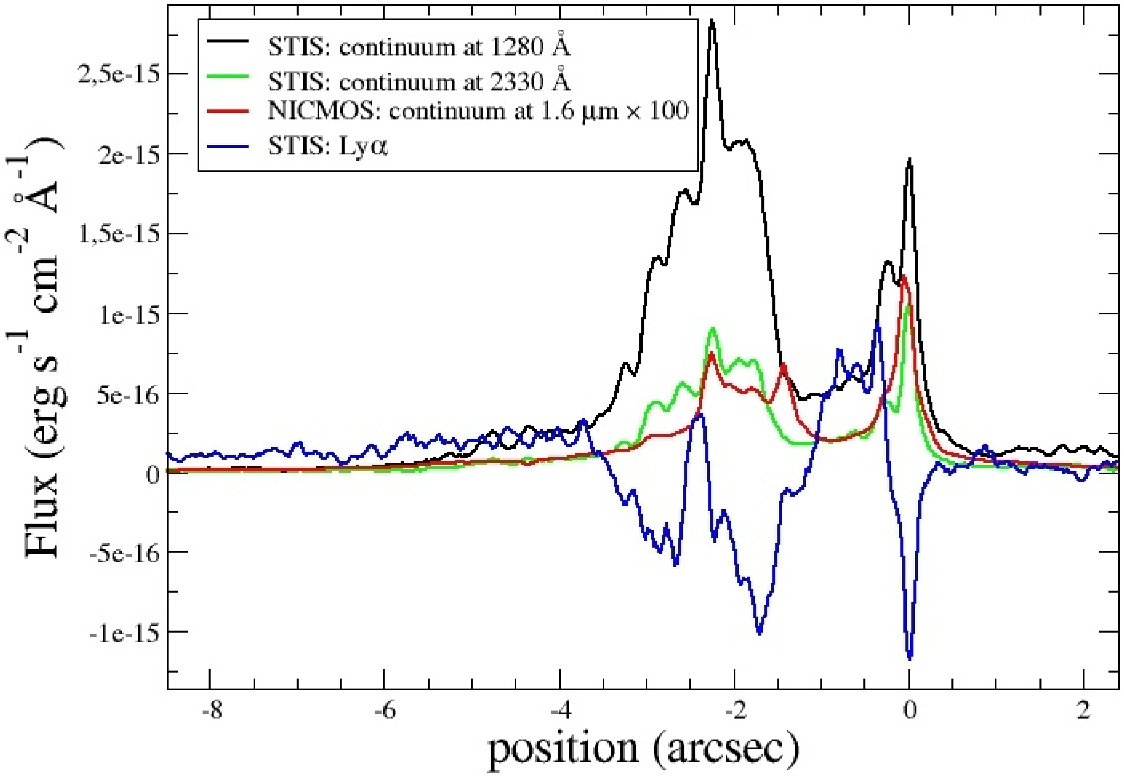
Lyα PROFILE: MAJOR AXIS



Low-resolution spectra: 0.584 Å

Lyα PROFILE: MAJOR AXIS

- Different profile of FUV and nearer UV continuum
- Lack of coupling between Lyα emission and continuum
- Absence of continuum in region showing diffuse Lyα emission → Lyα photons escape after multiple scattering
- In knot NW there is a weak Lyα emission within a continuum-dominated region

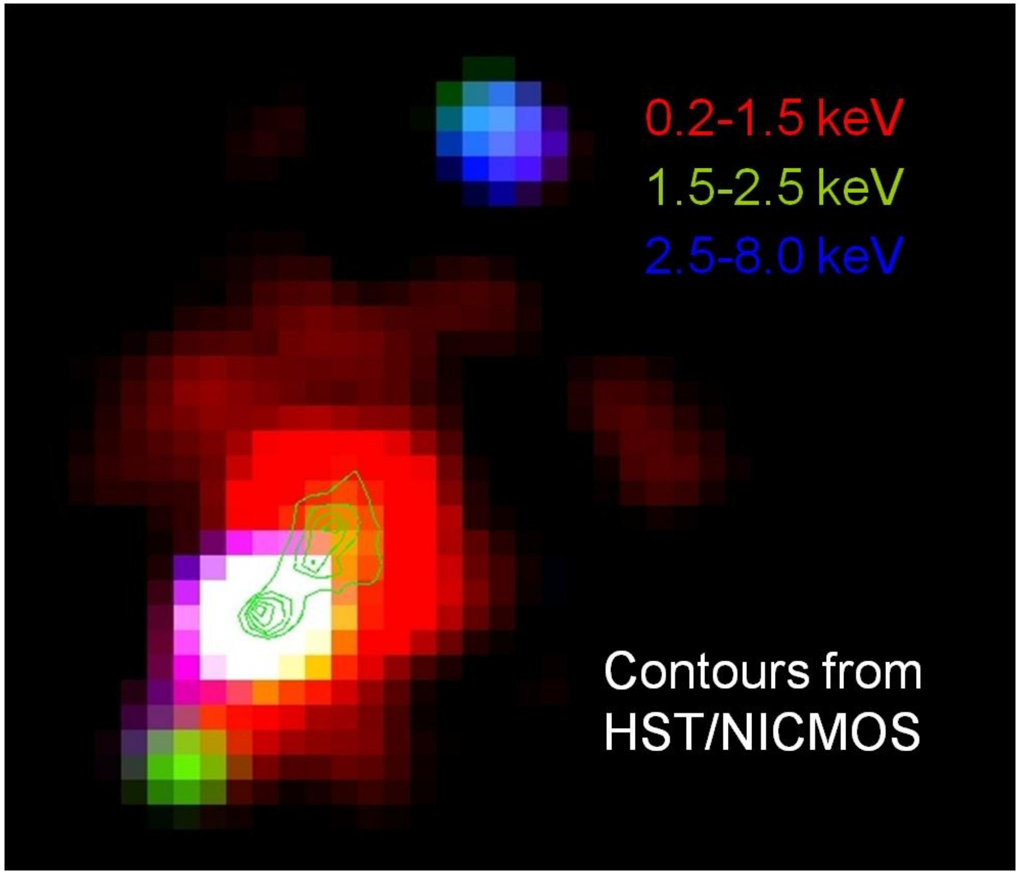


Lyα PROFILE: MAJOR AXIS

- Diffuse emission is as intense as the emission associated to knot SE.
  - Hayes et al. (2007) observed in Haro 11 a diffuse Lyα emission which resulted to be higher than the localized emission
- Very extended diffuse emission, as large as > 600 pc $\rightarrow$ Lyα photons escape after multiple scattering
- Collisional emission?
- Age of knots ($\sim$ >4 Myr) and Lyα emission properties, as predicted by model from Tenorio-Tagle et al. (1999)
- Extended, diffuse Lyα emission seems to be originated by the older burst ($\sim$5 Myr)

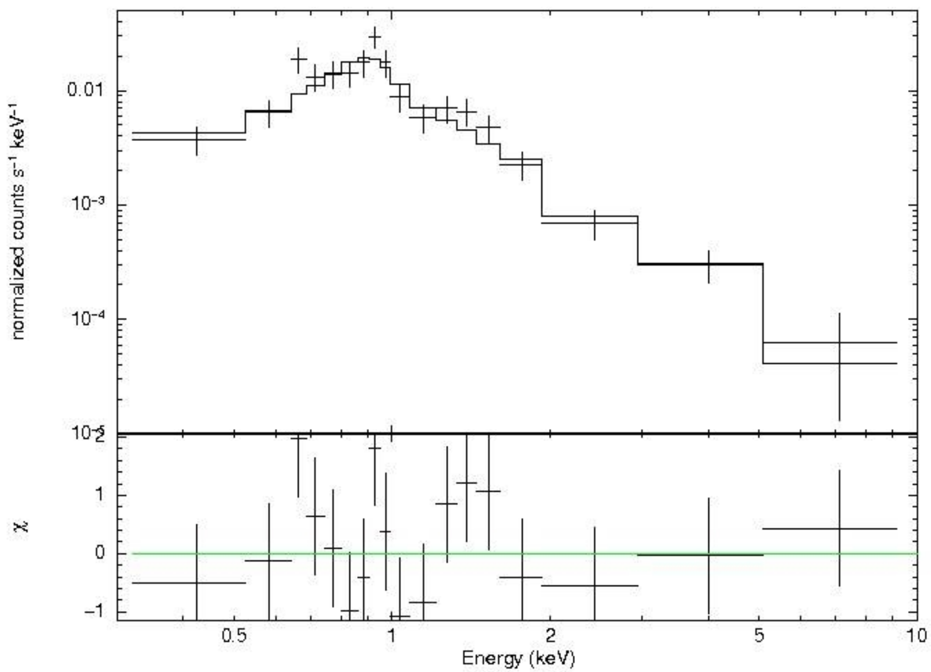
X-RAY IMAGE

- X-ray emission is confined in a region of radius ~600 pc
- Hard X-ray emission is located around the SE knot
- Soft X-ray emission is more extended, especially in knot NW
- Diffuse Lyα emission extends over the soft X-ray emitting NW region
- Older burst (→ more time the superbubble to expand) shows diffuse emission
- A hard X-ray source is found northwest of nucleus. Too weak to extract spectrum. Not included in analysis



X-RAY SPECTRUM

Model: Gal. Abs. * Intr. Abs. * (hot plasma + power law)



$\varepsilon_{Xeff} \sim$ **1-5%**

Fixed parameters:

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

Intrinsic absorption: N(HI)=7×10^{19} cm^{-2}

Values of the free parameters:

Hot plasma temperature: kT=0.7±0.1 keV

Power law index: Γ=1.8±0.4

Values of the luminosities (D=20.5 Mpc)

when integrating over the whole region:

L(0.2-1.5 keV)=2.5×10^{39} erg s^{-1}

L(1.5-2.5 keV)=5.0×10^{38} erg s^{-1}

L(2.5-8.0 keV)=1.1×10^{39} erg s^{-1}

L(0.4-2.4 keV)=2.4×10^{39} erg s^{-1}

L(2.0-10.0 keV)=1.6×10^{39} erg s^{-1}

X-RAY SPECTRUM: VARIABLE ABUNDANCES

Model: Gal. Abs. * Intr. Abs. * (hot plasma w/ free abun. O & Mg + power law)

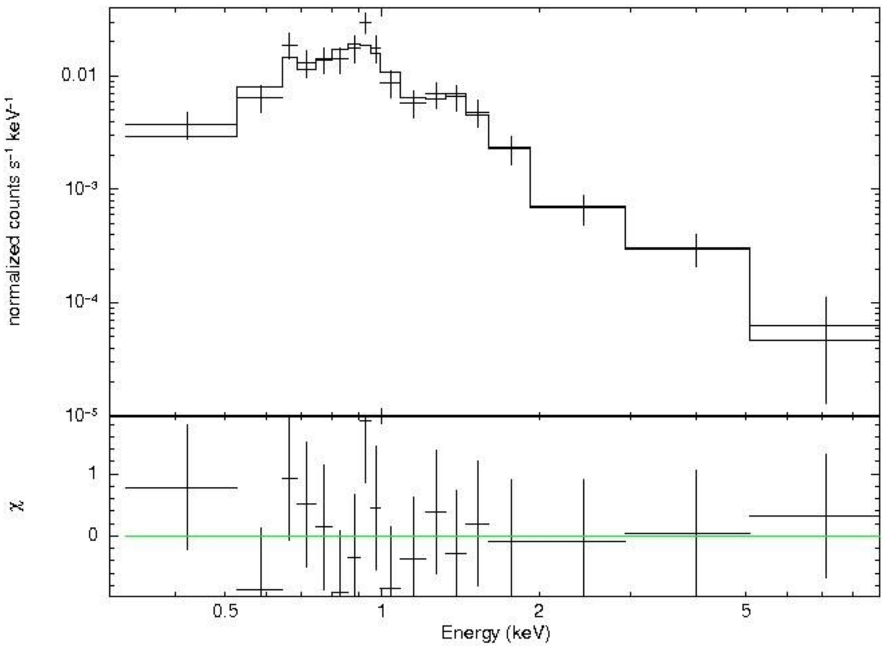
Test *f* yields 97% of statistical significance with respect previous model

Probably overparameterized (χ^2/d.o.f ~ 0.7) and large uncertainties in parameters

Fixed parameters:

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

Intrinsic absorption: N(HI)=7×10^{19} cm^{-2}



Values of the free parameters:

Hot plasma temperature: kT=0.7±0.7 keV

Power law index: Γ=1.4±1

O abundance: 1.5±1.1 → OVERSOLAR

Mg abundance: 2.4±1.7 → OVERSOLAR

Values of the luminosities (D=20.5 Mpc)

when integrating over the whole region:

L(0.2-1.5 keV)=2.4×10^{39} erg s^{-1}

L(1.5-2.5 keV)=4.5×10^{38} erg s^{-1}

L(2.5-8.0 keV)=1.2×10^{39} erg s^{-1}

L(0.4-2.4 keV)=2.5×10^{39} erg s^{-1}

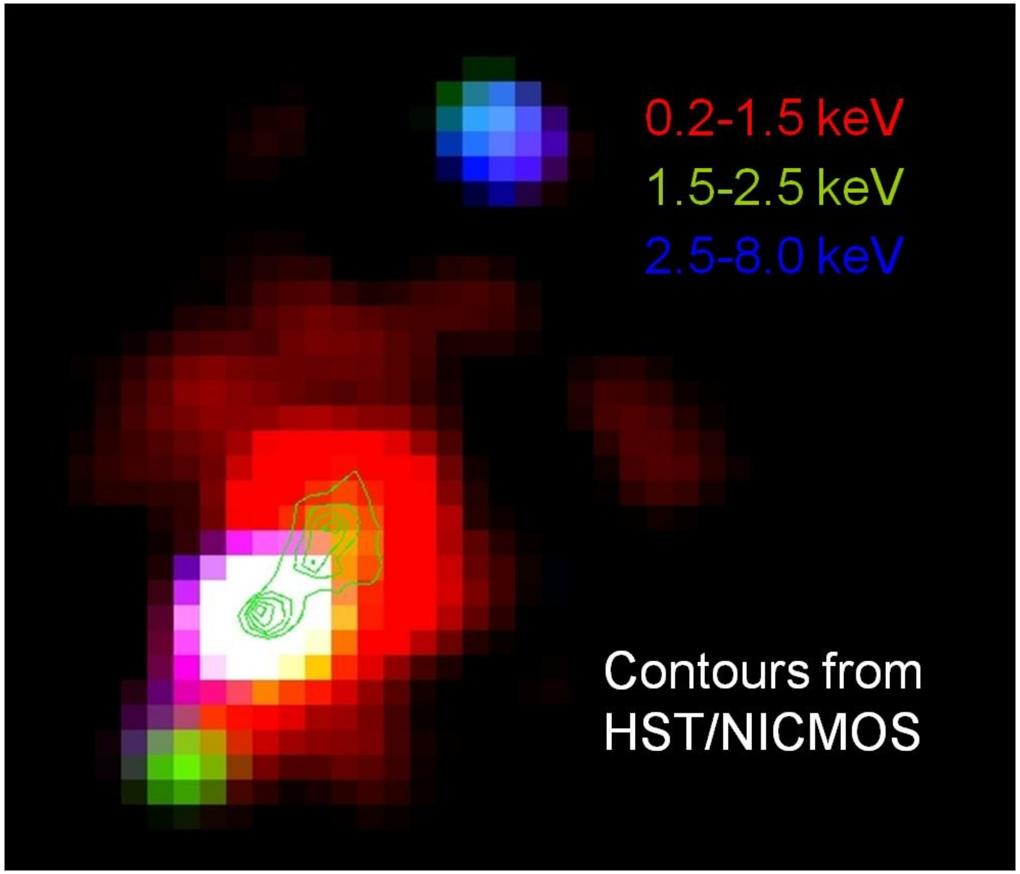
L(2.0-10.0 keV)=1.7×10^{39} erg s^{-1}

Oxygen abundance over solar values in superbubbles blown by starburts is predicted by Silich et al. (2001)

X-RAY IMAGE

- Our CMHK02 synthesis evolutionary models predict the L_{softX} with ε_{Xeff} ~ 1-5%, i.e. typical range (Strickland & Stevens 1999; Summers et al. 2001, 2004)

- On the other hand, L_{hardX} is underestimated by one order of magnitude: stochasticity of X-ray binaries



CONCLUSIONS

- We identify in Haro 2 two starbursting knots
  - NW: 5 Myr and E(B-V)=0.020
  - SE: 4 Myr and E(B-V)=0.040
- A rather complex spatial profile of Lyα emission along its major axis
  - A large, strong diffuse emission extending > 600 pc northwest of knot NW
  - A weak emission within continuum region of knot NW
  - A strong, localized emission close to knot SE
- X-ray data
  - Fitting: hot plasma (heated gas) and a power law (HMXB?)
  - Diffuse, soft emission coinciding spatially with the diffuse Lyα radiation
    $\varepsilon_{Xeff} \sim$ 1-5% $\rightarrow$ in agreement with predictions by synthesis models
- Future
  - ACS image?