Lyman α emitters in the Local Universe

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Summary

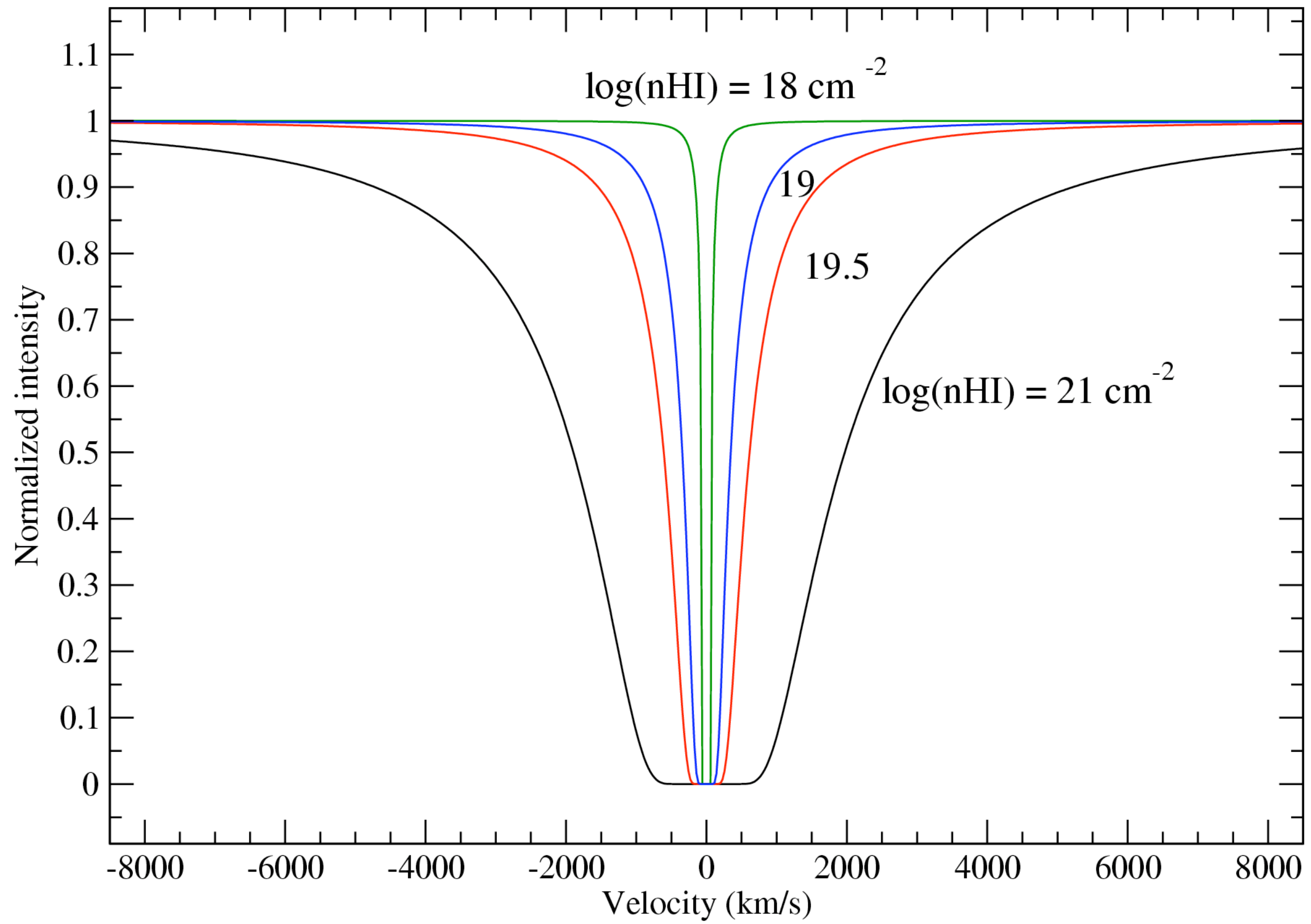
- Introduction
- Spectroscopy: The IUE era
- A deeper insight with HST/GHRS+STIS
- Lyman α imaging with HST/ACS
- Lyman α emitters: the high energy view
- Bridging the gap to high redshift galaxies: GALEX
- Summary: the future

Introduction

- Lyman α is, in principle, the strongest Hydrogen emission line originating in an HII region:
  - L(Lyman α) / L(Hα) ~ 7 - 12 in typical HII region conditions, Cases B – A, assuming no reddening.
  - EW(Lyman α) $\leq$ 300 Å in young, powerful starbursts (Valls-Gabaud, 1993; Charlot and Fall 1993; Leitherer, IAP, Oct. 2007).

- These predictions do not include the effects of Lyman α radiation transfer in the medium surrounding the starburst:
  - Resonant trapping reduces the mean free path of Lyman α photons, increasing significantly the probability of being destroyed
    - absorbed by dust
    - shifted in frequency
    - converted to two-photon emission

Introduction

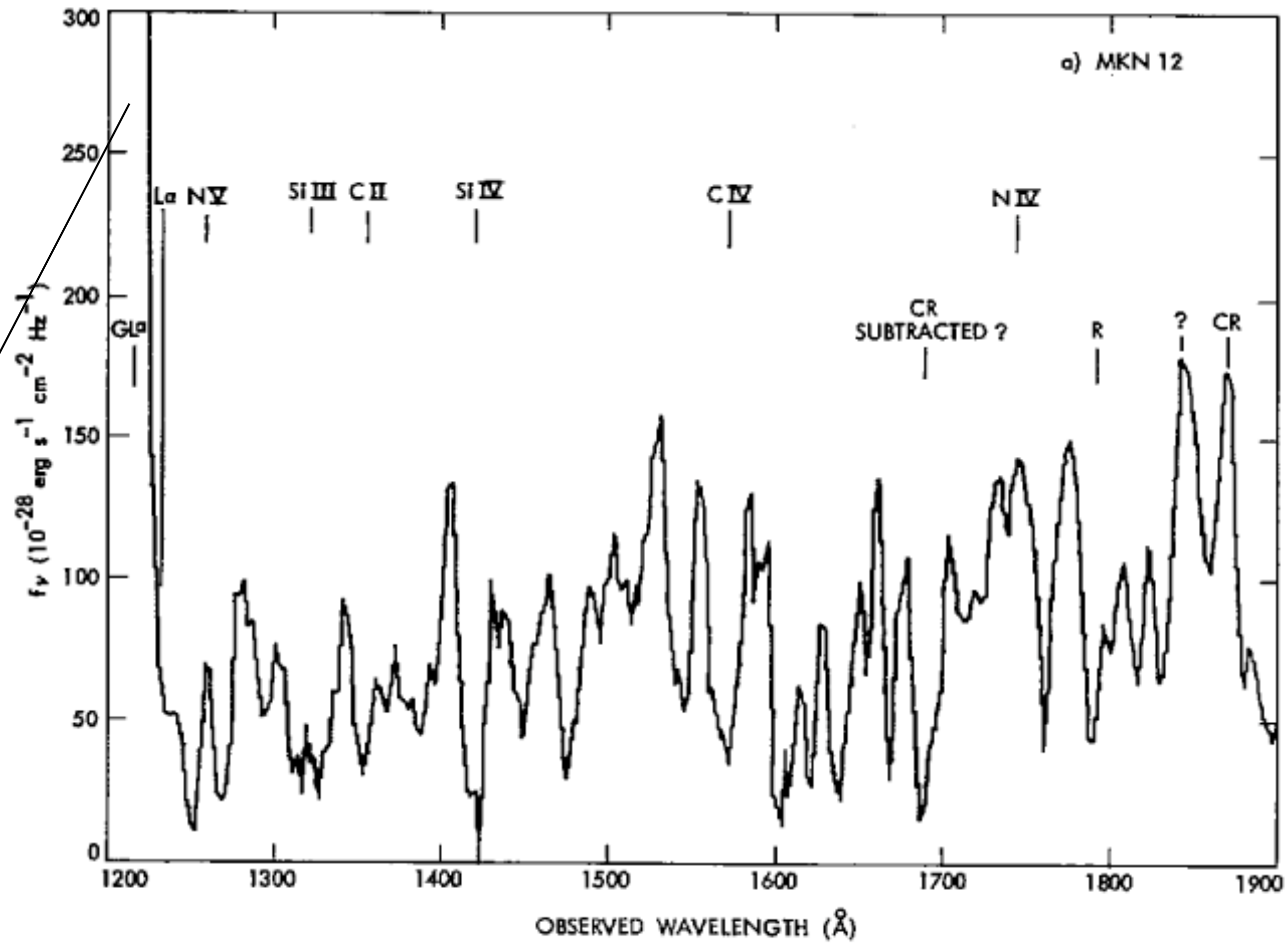


HI Voigt absorption profiles, not considering frequency shifts (Mas-Hesse et al. 2003).

Introduction

- Observability of Lyman α in the nearby Universe is difficult:
  - *Geocoronal emission is very strong, blinding any object at very low redshift.*

Introduction



Geocoronal Lyman α

Meier and Terlevich (1981)

Introduction

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  - *Interstellar HI in our Galaxy produces a damped absorption which hides the potential emission of star-forming galaxies with redshifts below several 100's of km in many lines of sight.*

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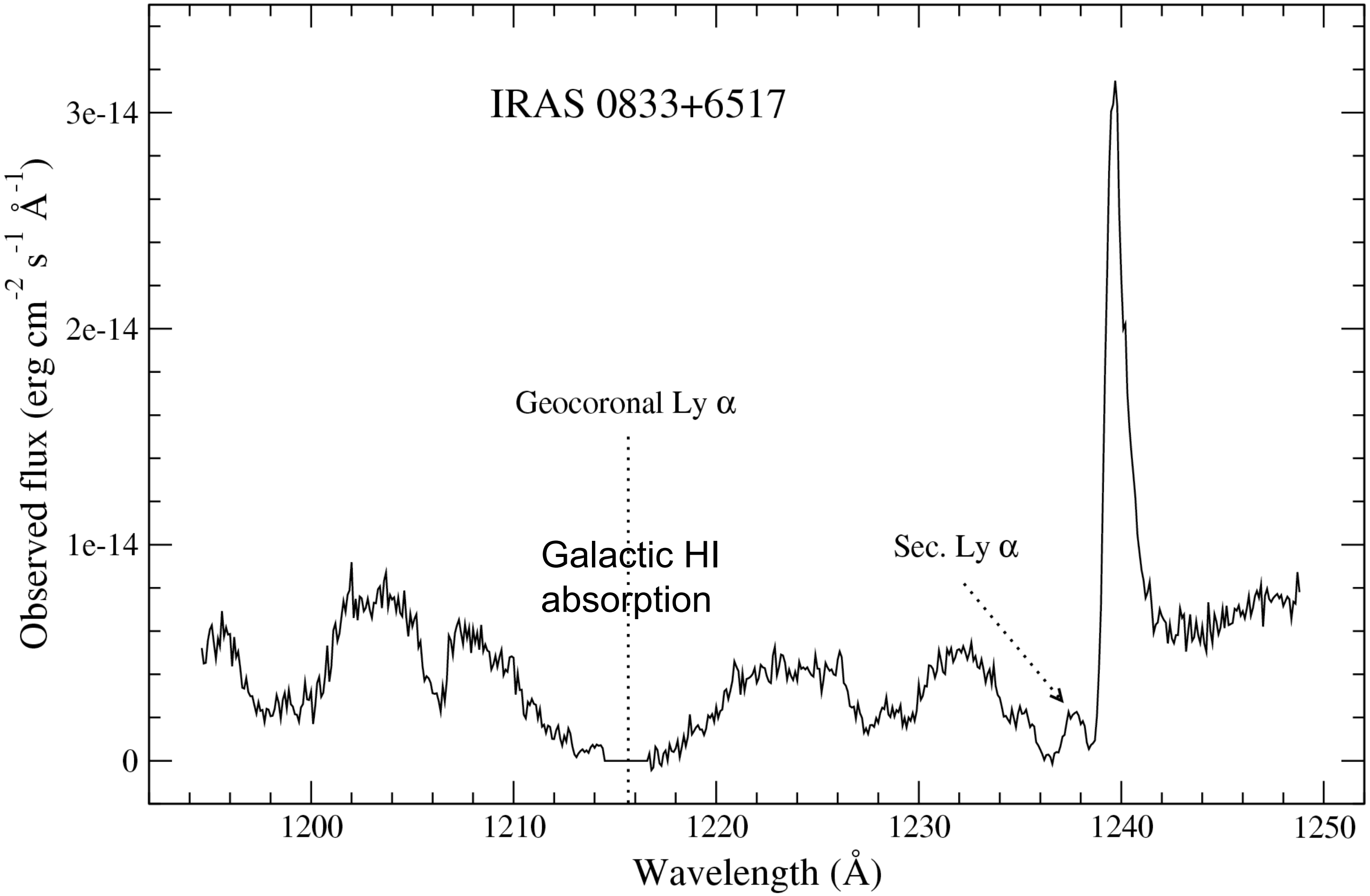


Mas-Hesse et al. (2003)

Introduction

- Observability of Lyman α in the nearby Universe is difficult:
  - *Geocoronal emission is very strong, blinding any object at very low redshift.*
  - *Interstellar HI in our Galaxy produces a damped absorption which hides the potential emission of star-forming galaxies with redshifts below several 100's of km in many lines of sight.*
  - *Reddening in the far UV is much stronger than in the optical range.*
    - Moreover, the shape of the extinction law in starburst regions is not well known below 1300 Å.
  - *The number of facilities with access to the 1200-1300 Å range has been very limited (IUE, HST, GALEX).*

Introduction

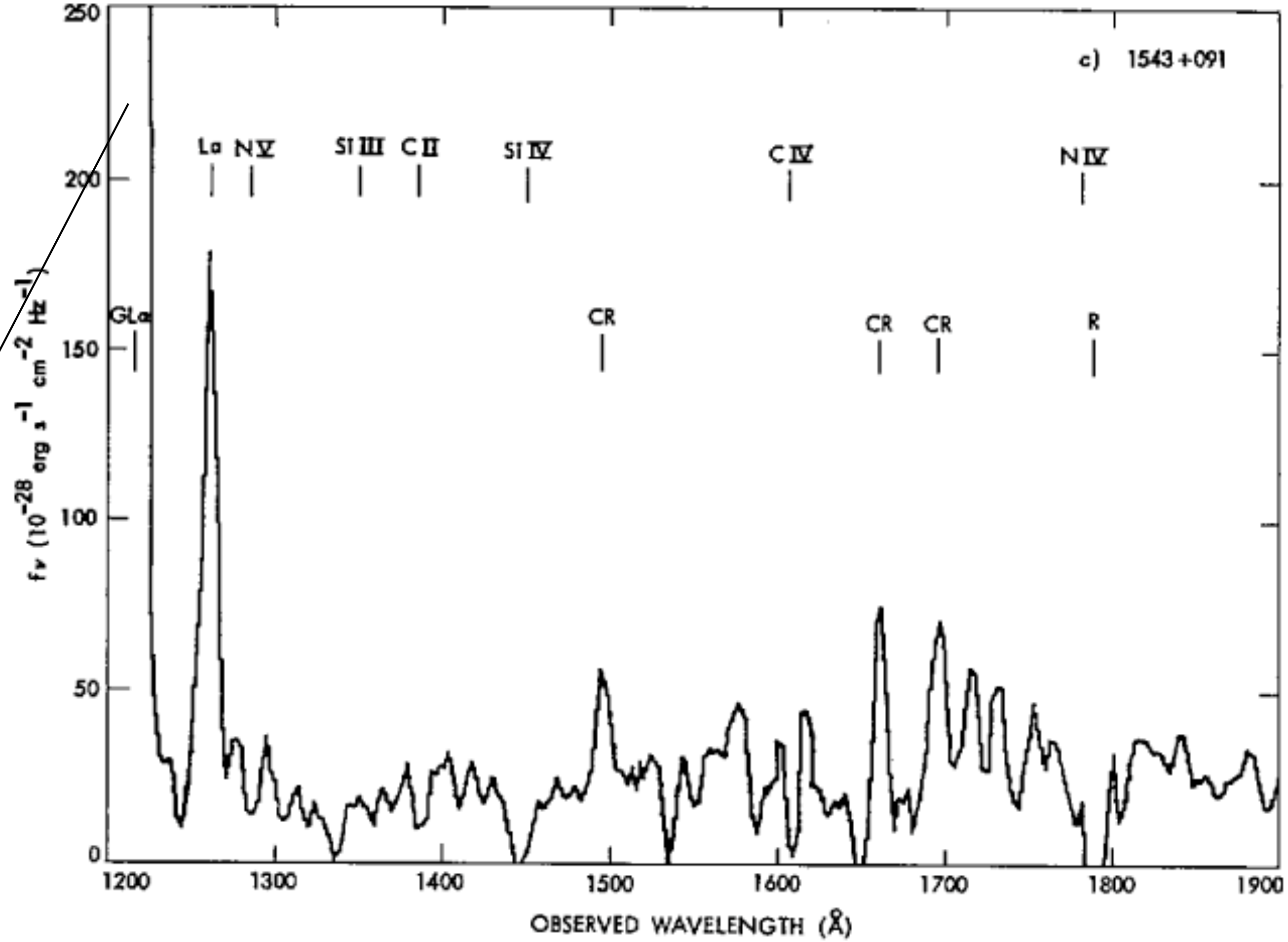
- Nevertheless, Local Universe galaxies are an excellent testbed to analyze the properties of Lyman α emission, offering
  - *High fluxes*
  - *High spatial resolution*
  - *Lots of ancillary data*

Local Lyman α emitters: the IUE era

- The International Ultraviolet Observatory (NASA, ESA, SERC, 1978-1997) opened the UV range (1100 – 3000 Å) for systematic observations at low resolution ($\Delta\lambda \sim 6$ Å at 1200 Å).

- Meier and Terlevich (1981) presented the first Lyman α observations of 3 HII galaxies observed with IUE.

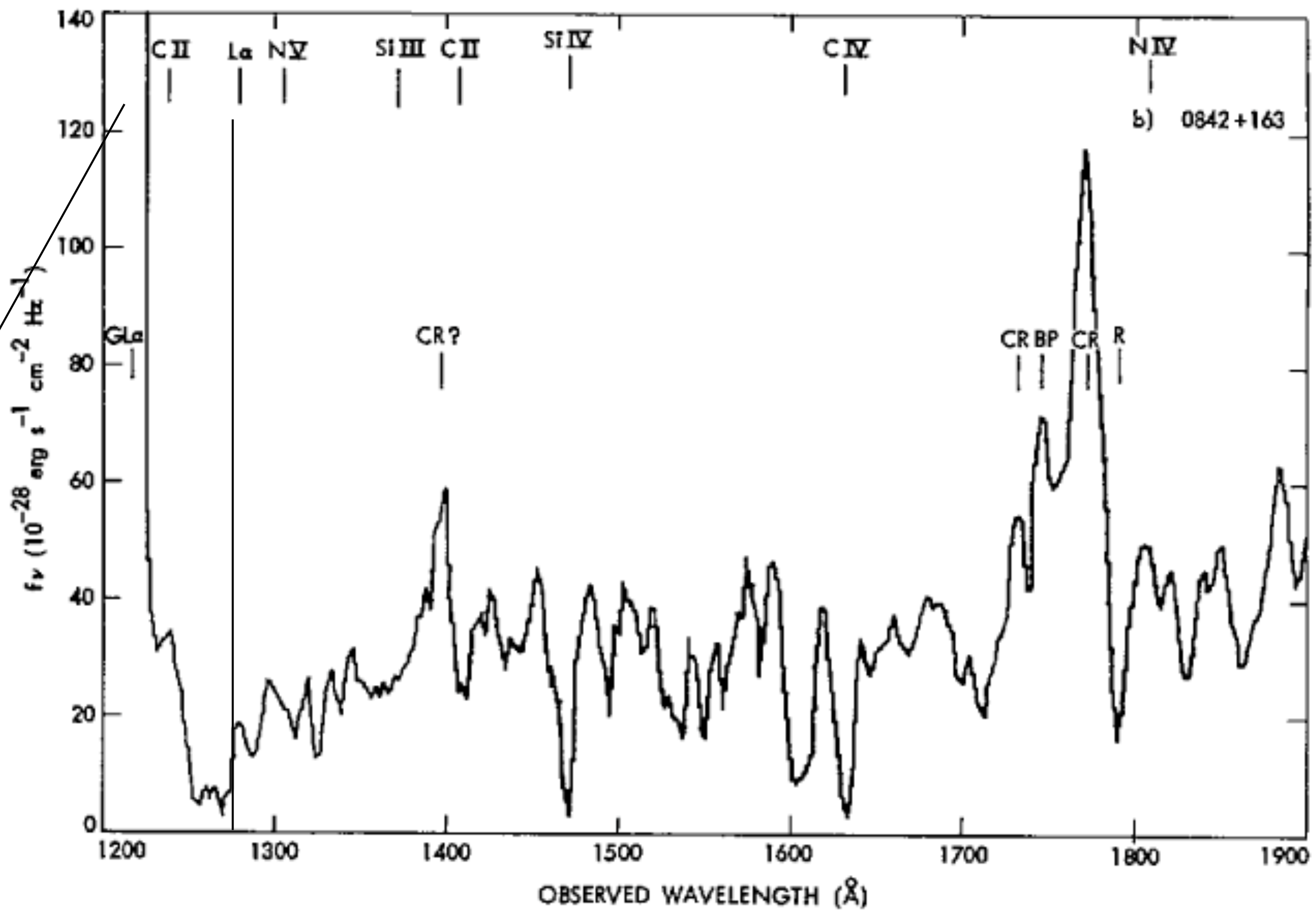
Local Lyman α emitters: the IUE era



Geocoronal Lyman α

Meier and Terlevich (1981)

Local Lyman α emitters: the IUE era



Geocoronal Lyman α

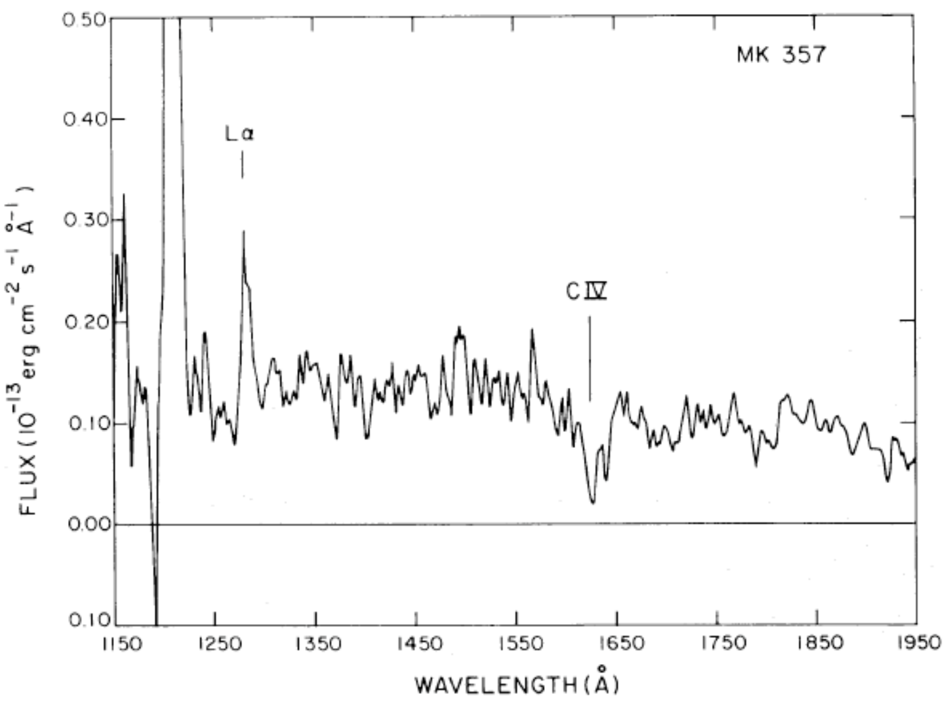
Meier and Terlevich (1981)

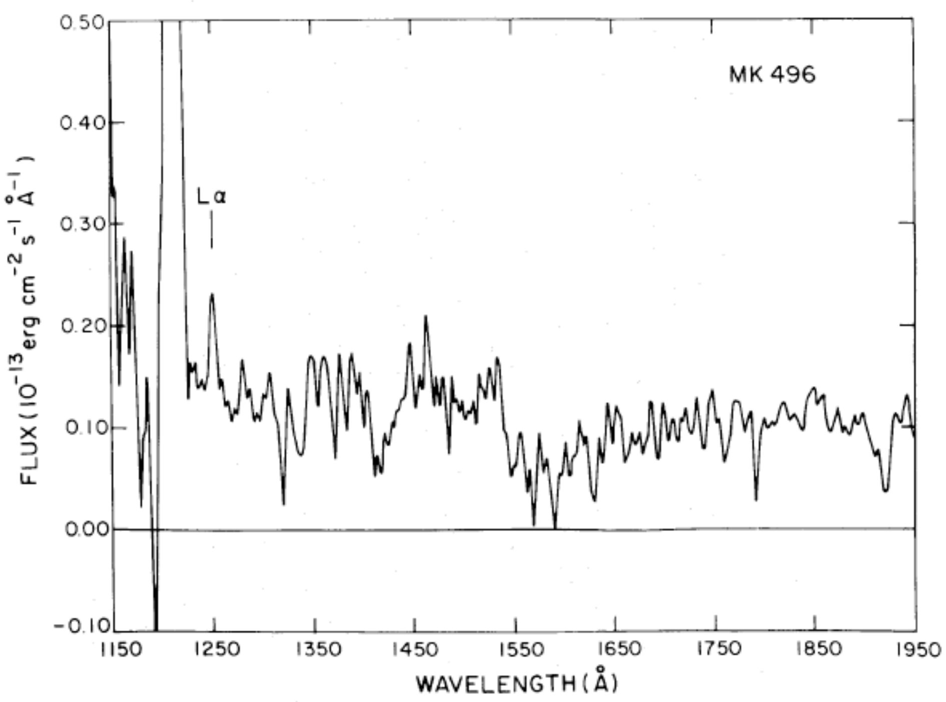
Local Lyman α emitters: the IUE era

- Meier & Terlevich (1981) noted that the only object (out of 3) with strong Lyman α emission (F(Lyα)/F(Hα) ~ 2) was a low metallicity ($Z=Z_{\odot}/10$) HII galaxy (1543+091).

- Hartmann et al. (1984 “How to find galaxies at high redshift”, and 1988) extended the sample with 13 more star-forming galaxies covering a wide range of metallicities.
  - *They also found a wide range of Lyman α intensities (from strong emission to damped absorptions).*

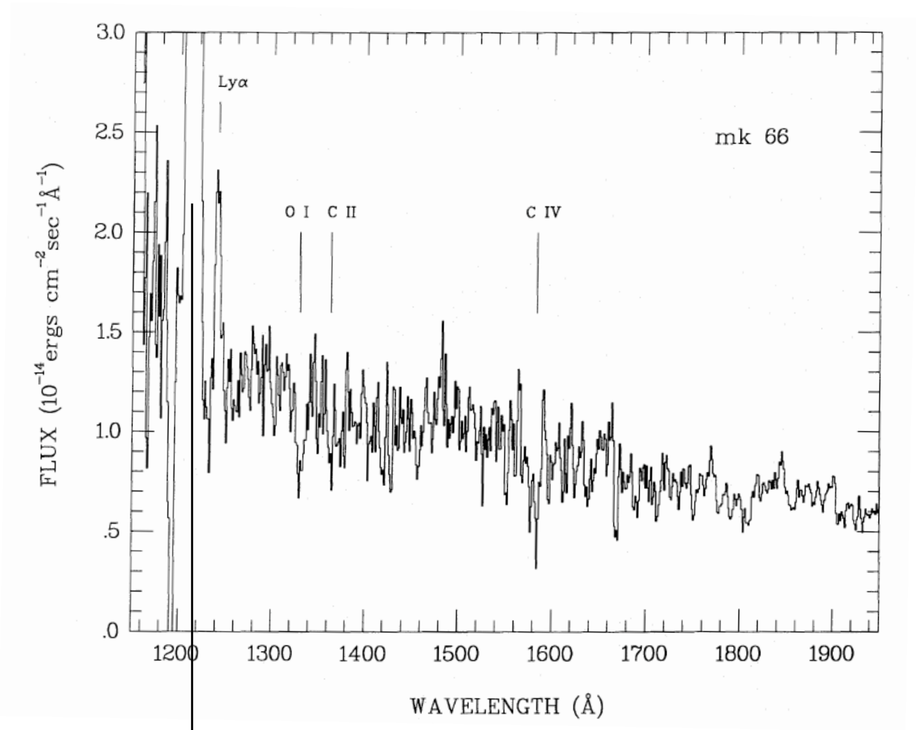
Local Lyman α emitters: the IUE era

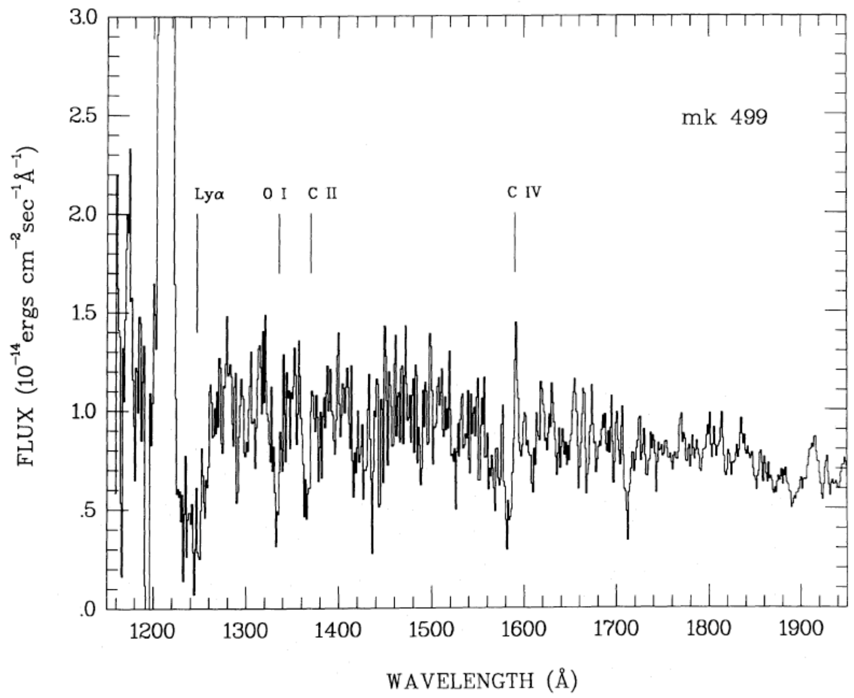




Hartmann et al. (1984)

Local Lyman α emitters: the IUE era





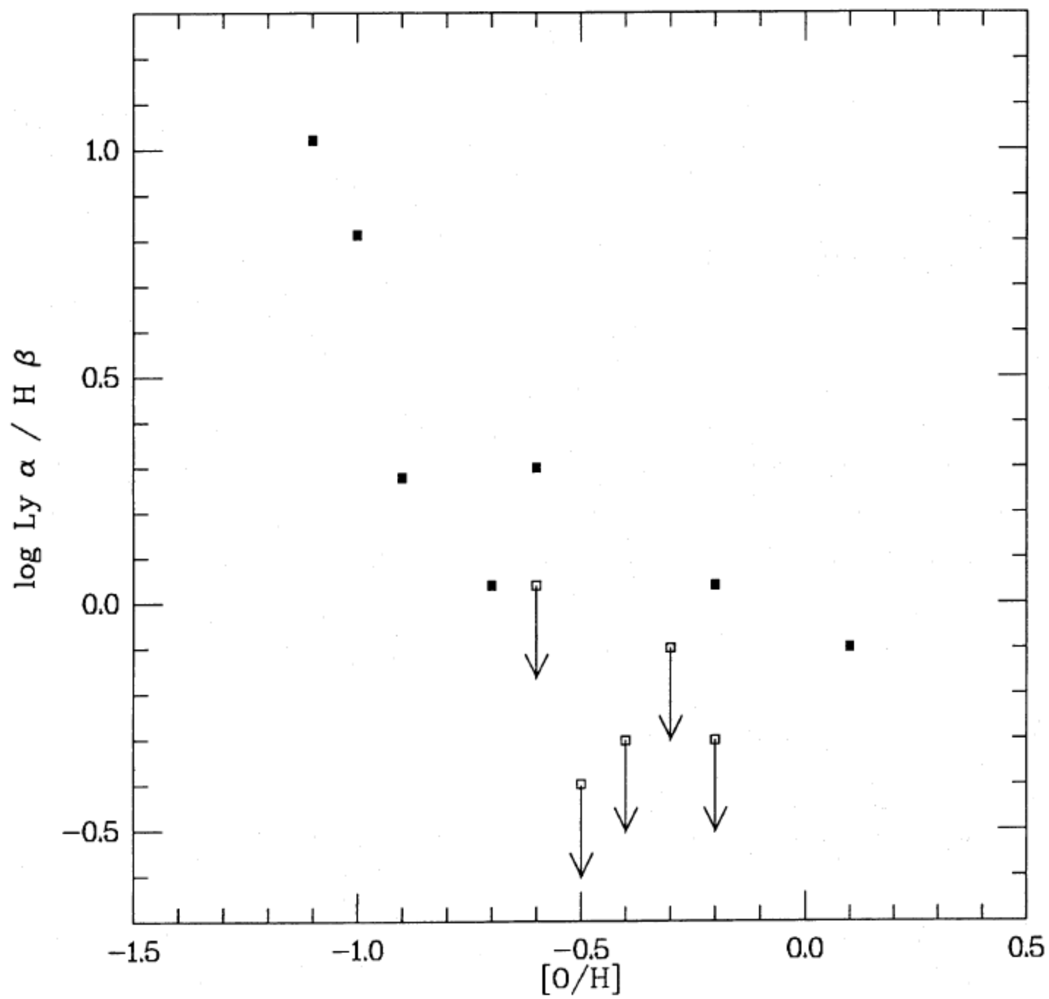
Geooronal Lyman α

Hartmann et al. (1988)

Local Lyman α emitters: the IUE era

- Hartmann et al. (1988) confirmed the apparent anticorrelation between Lyα relative intensity and metallicity.

- This led to the conclusion that dust (directly linked to metallicity), was driving the visibility of the line.

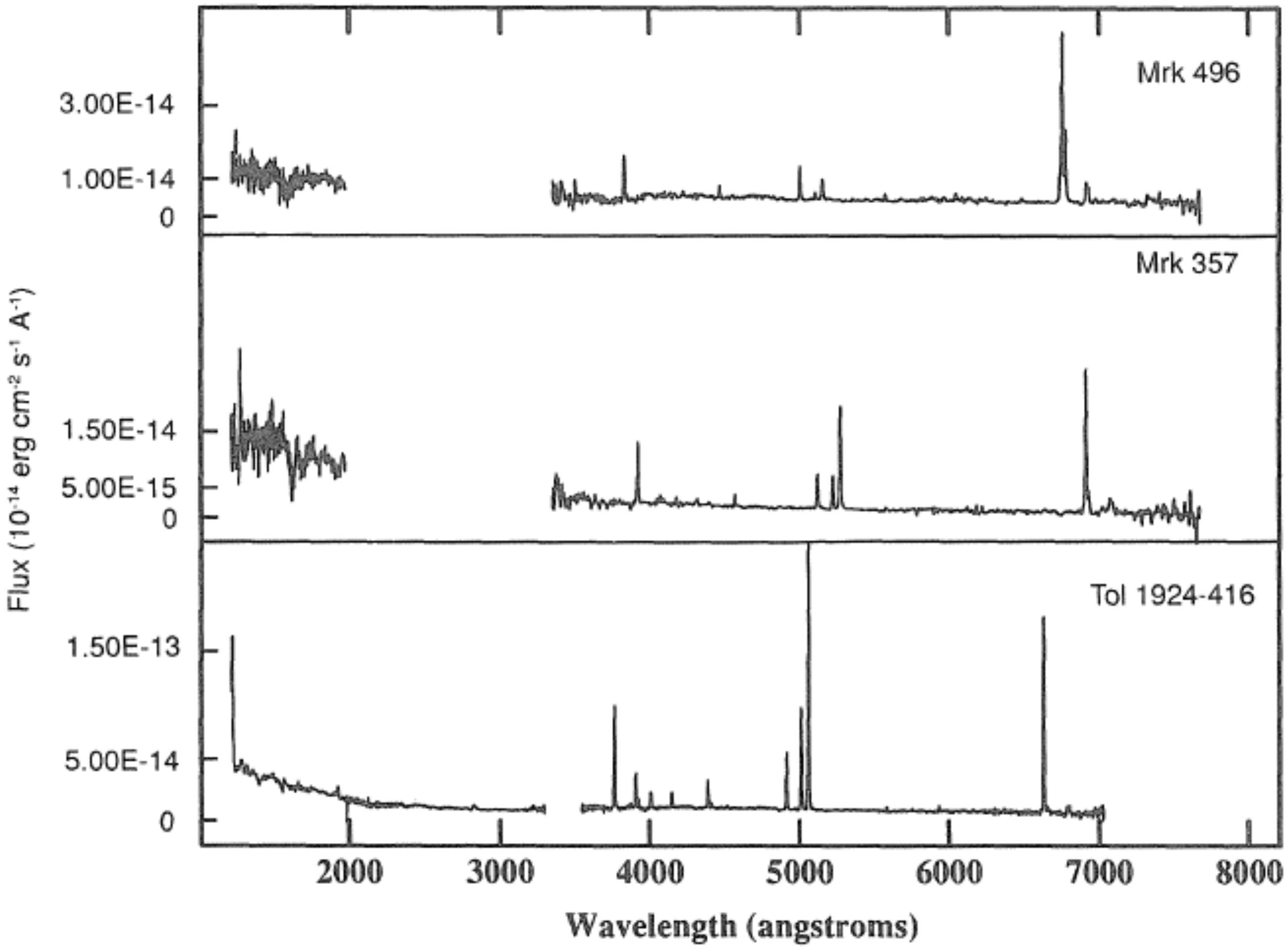


Hartmann et al. (1988)

Local Lyman α emitters: the IUE era

- Calzetti and Kinney (1992) presented aperture-matched UV+optical spectra of 3 star-forming galaxies.
  - *The IUE large aperture was an oval of around 10”×20” aperture. Matching Lyman α with Hα fluxes required special optical setups.*

Local Lyman α emitters: the IUE era



Calzetti & Kinney (1992)

Local Lyman α emitters: the IUE era

- Calzetti and Kinney (1992) concluded that applying the correct extinction laws, the derived F(Lyα)/F(Hβ) were consistent with the predictions.

  They proposed that the apparent correlation with metallicity was due just to erroneous extinction correction.

  - *But their sample consisted of only 3 objects…*

Local Lyman α emitters: the IUE era

DERIVED PHYSICAL PROPERTIES

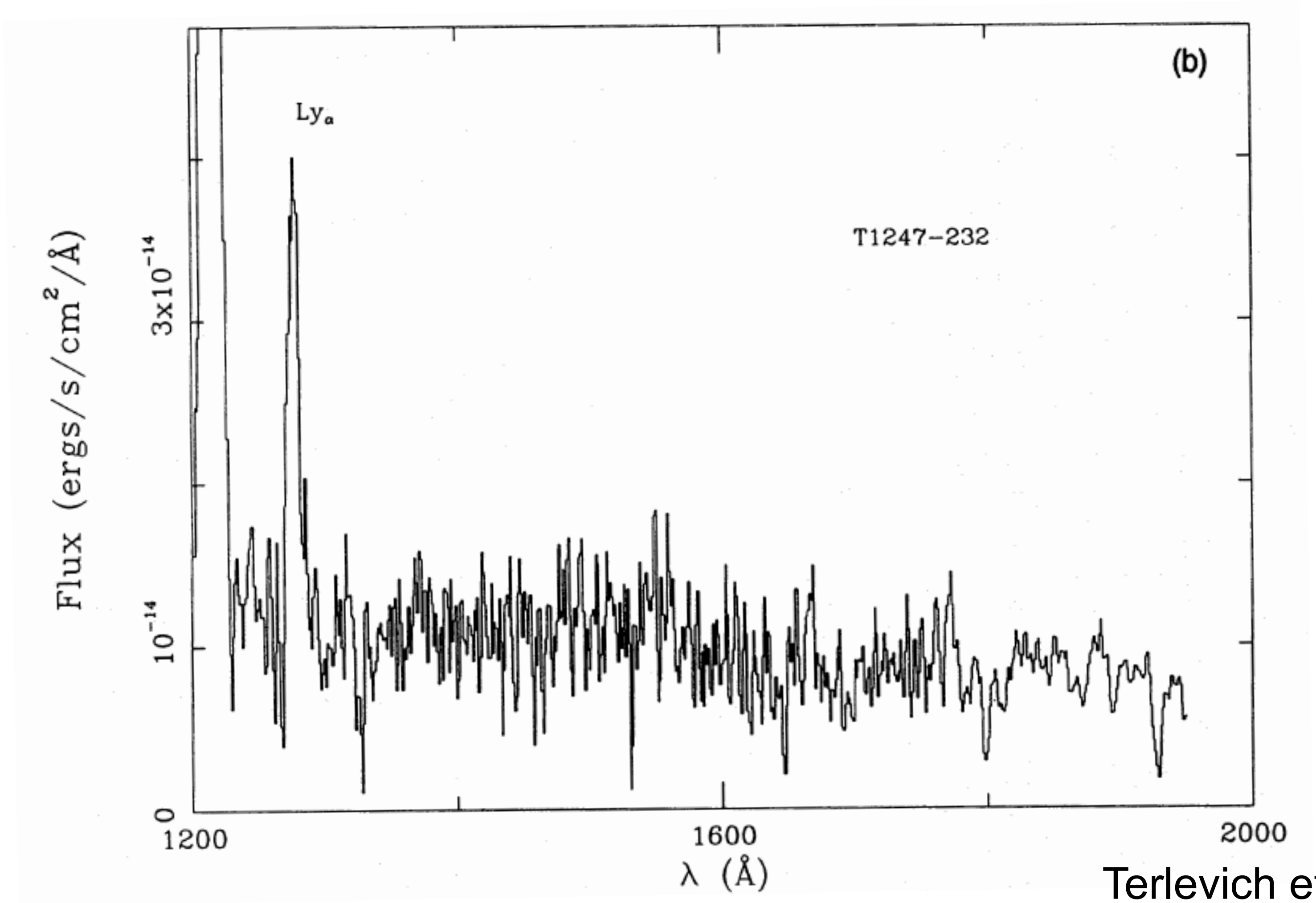
Galaxy Name	$E(B-V)^a$ Galactic	$E(B-V)$ Intrinsic	$H\alpha/H\beta$	$Ly\alpha/H\beta$ Undereddened	$Ly\alpha/H\beta^b$ Galactic Extinction	$Ly\alpha/H\beta^b$ LMC Extinction	$Ly\alpha/H\beta^b$ SMC Extinction
Mrk 496	0.00	0.52 ± 0.15	5.28	0.60	$12.4^{+7.5}_{-7.2}$	...	...
Mrk 357	0.04	0.26 ± 0.15	4.08	1.45	$8.3^{+11.3}_{-4.8}$	$20.0^{+0.0}_{-14.9}$	...
Tol 1924−416	0.07	0.05 ± 0.10	3.25	2.40	$4.8^{+3.8}_{-1.2}$	$5.7^{+8.9}_{-2.1}$	$7.0^{+19.8}_{-3.5}$

Calzetti & Kinney (1992)

Local Lyman α emitters: the IUE era

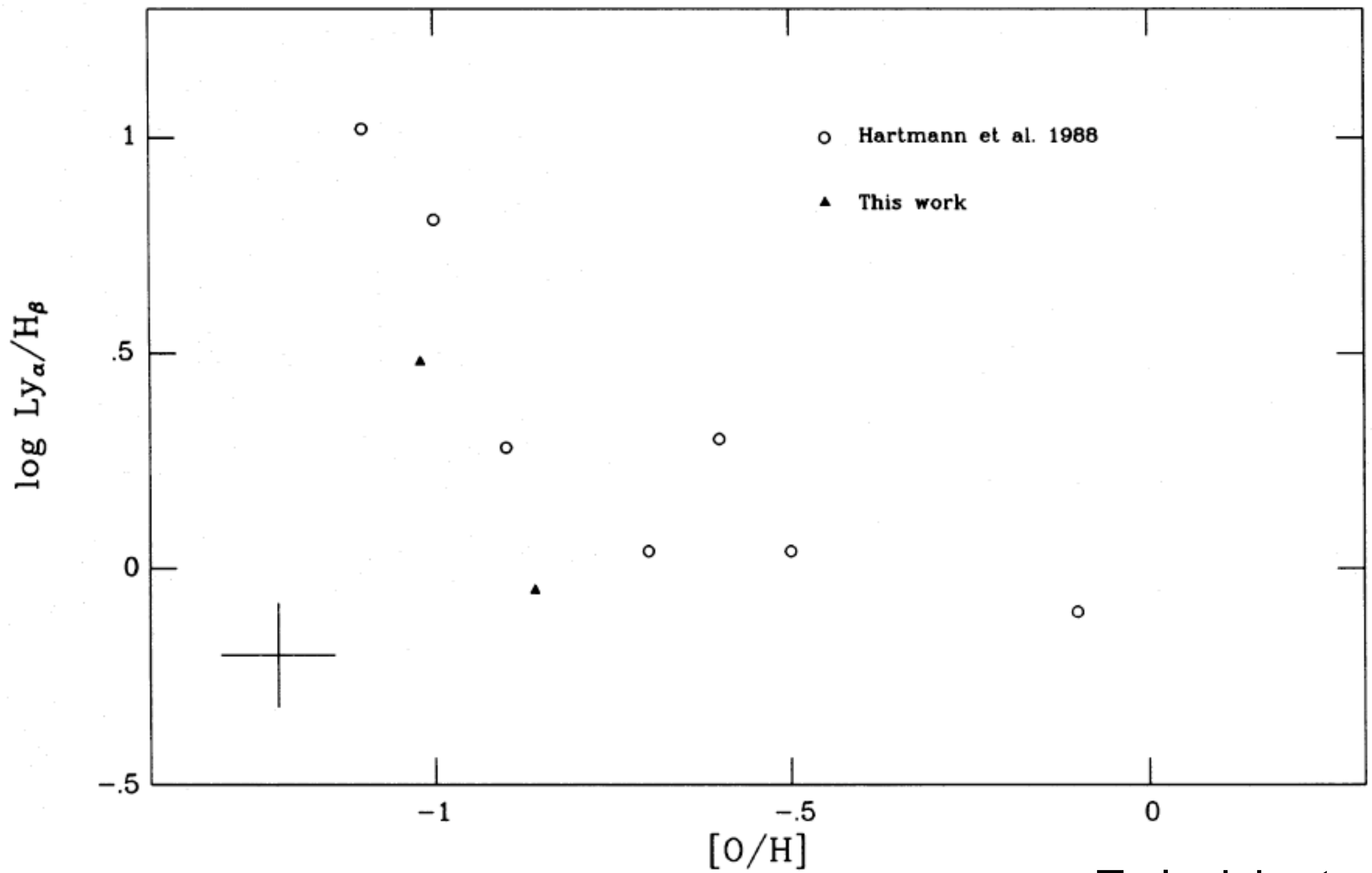
- On the other hand, the results by Hartmann et al. (1988) seemed to be confirmed later on by Terlevich et al. (1993), observing new Lyman α emitting HII galaxies at low metallicity.

Local Lyman α emitters: the IUE era



Terlevich et al. (1993)

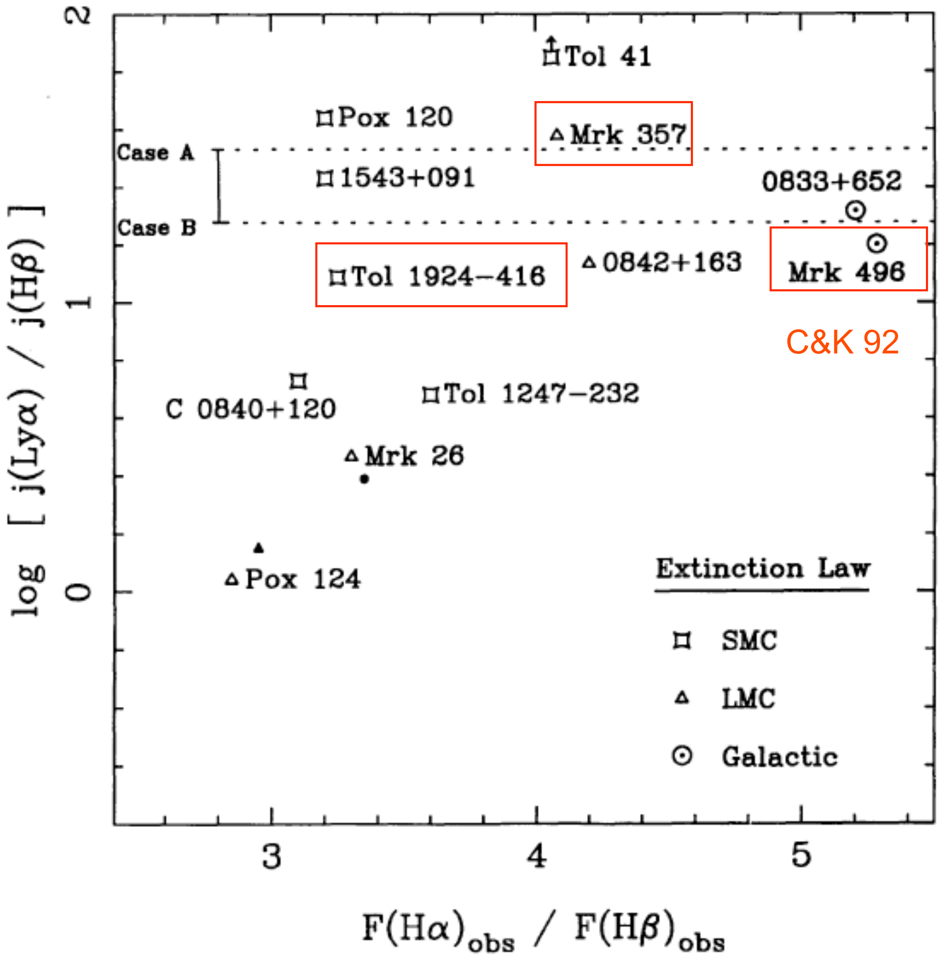
Local Lyman α emitters: the IUE era



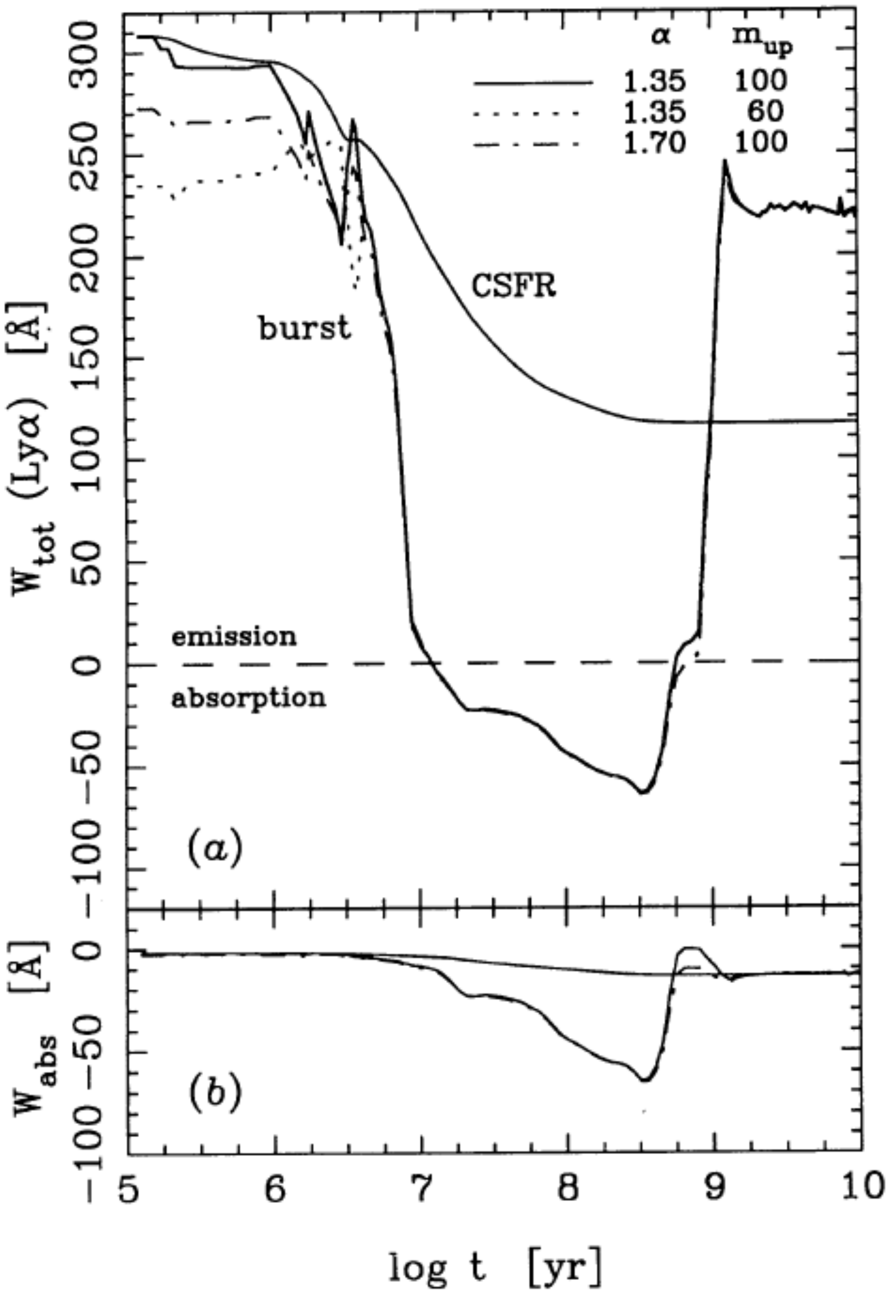
Terlevich et al. (1993)

Local Lyman α emitters: the IUE era

- Valls-Gabaud (1993) reanalyzed all the IUE observations applying consistent extinction laws:
  - *For several Galaxies the Lyα/Hβ ratio was rather consistent with Case A-B conditions.*
- He proposed that those objects with low Lyman α emission could be in a post-starburst phase, affected by stellar Lyman α absorption.



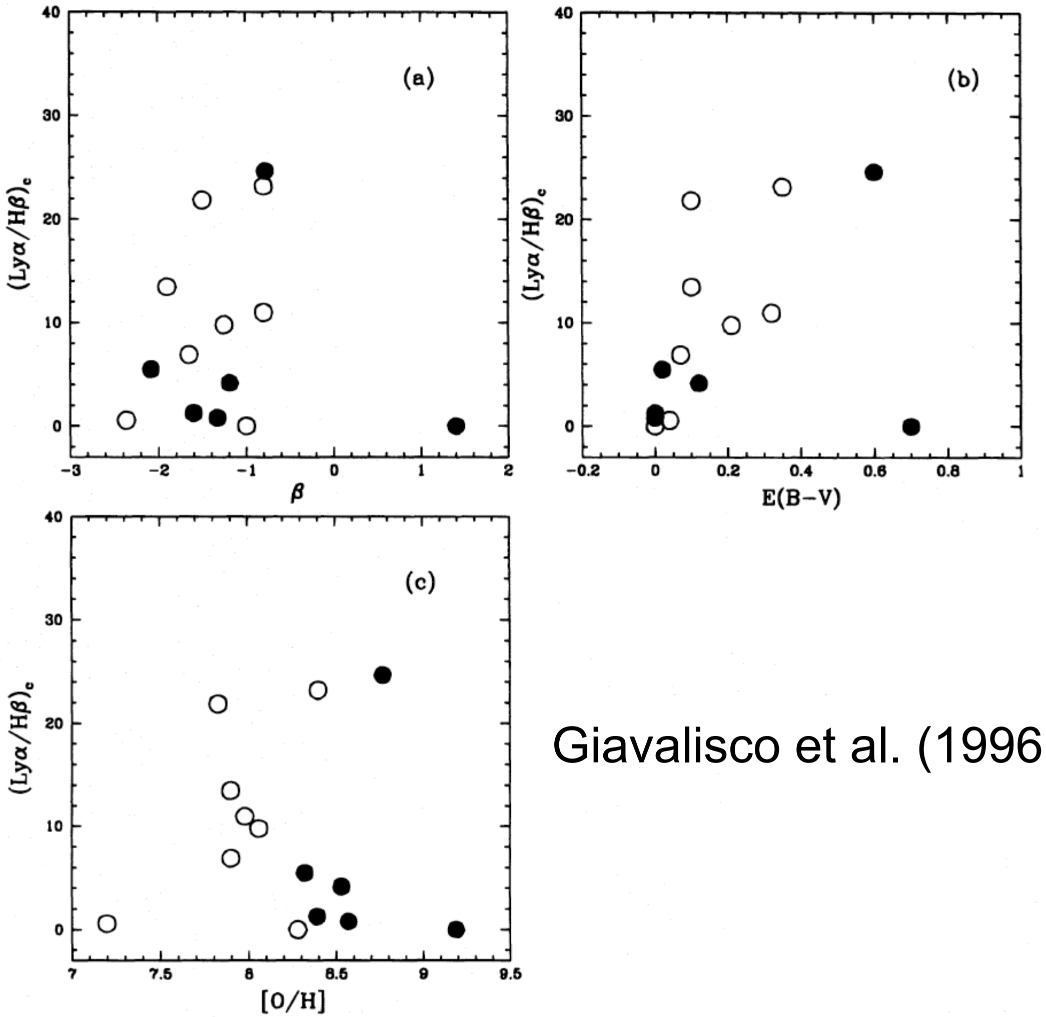
Valls-Gabaud (1993)



Valls-Gabaud (1993)

Local Lyman α emitters: the IUE era

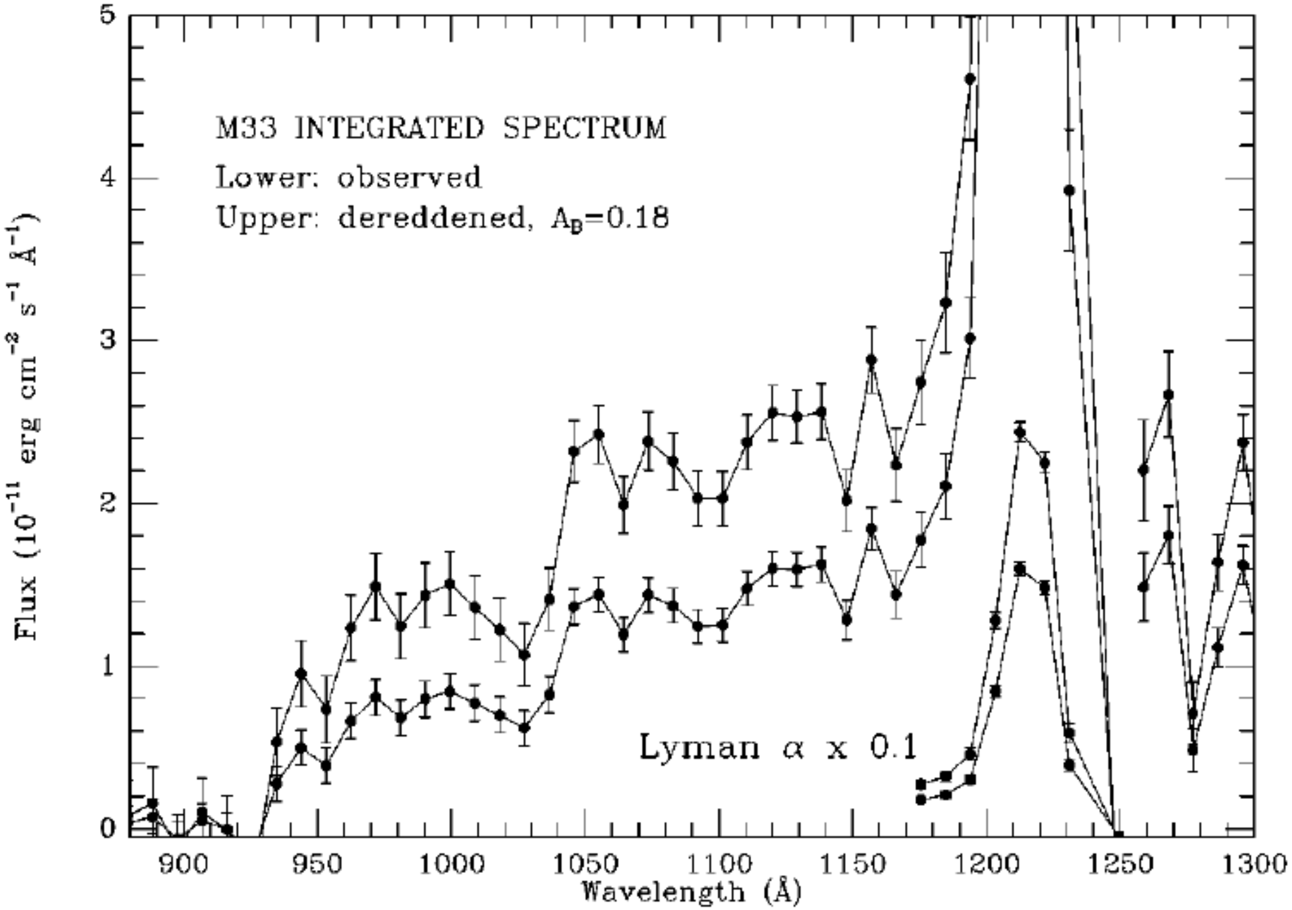
- Finally, a more complete and careful re-analysis of the IUE spectra by Giavalisco et al. (1996) concluded that there were not clear correlations between Lyman α emission and dust or metallicity indicators
  - *Geometry of the ISM was proposed to be the driving factor for the visibility of Lyman α, instead of mostly dust effects.*



Giavalisco et al. (1996)

Local Lyman α emitters: the IUE era

- Keel (1998) published integrated Lyman α fluxes of M33 obtained with *Voyager* around 1978, finding Lyα/Hα>3.



Local Lyman α emitters: the IUE era

- Summarizing, the following hypotheses were under consideration in the early ’90s to explain the visibility of the line:
  - *Dust + abundance (Meier & Terlevich 1981; Hartmann et al. 1988; Charlot & Fall 1993).*
  - *Extinction law: with an « appropriate » (metallicity-dependent) law the problem could be solved (Calzetti & Kinney 1992).*
  - *Proper extinction law and the underlying stellar Lyα absorption could explain the observed intensity of the line, considering the evolution of the burst (Valls-Gabaud 1993).*
  - *Inhomogeneous ISM geometry could be the primarily determining factor, not the dust (Giavalisco et al. 1996).*

→ *The answer was not clear at the end of the IUE era…*

Local Lyman α emitters: a deeper insight with HST/GHRS

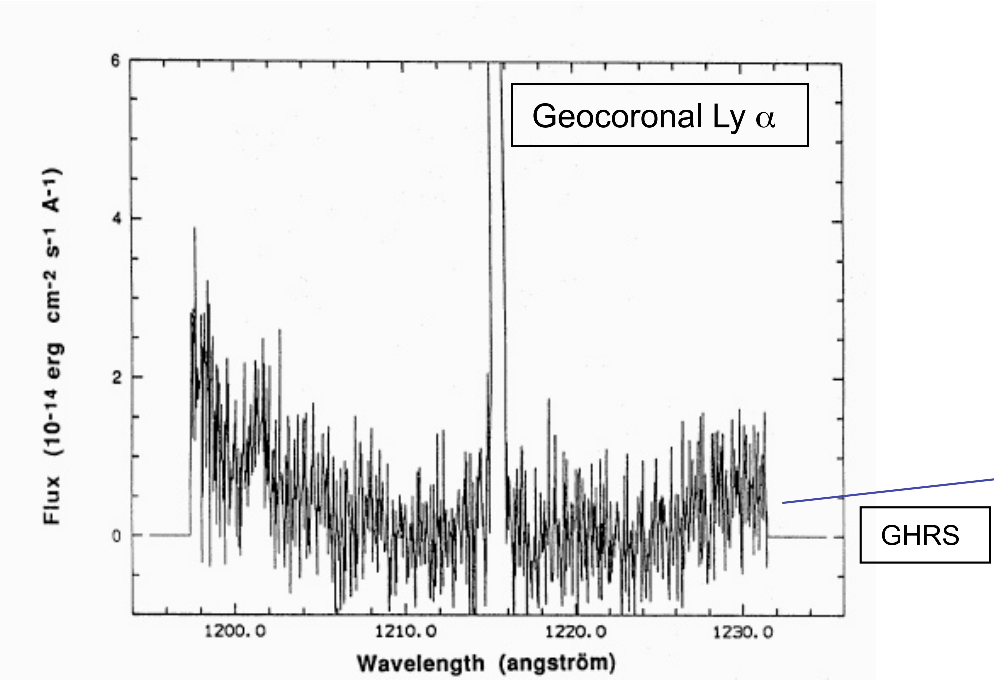
- High resolution spectroscopy with HST/GHRS allowed for the first time to observe local BCGs without blending with the Galactic absorption and geocoronal Ly α emission.

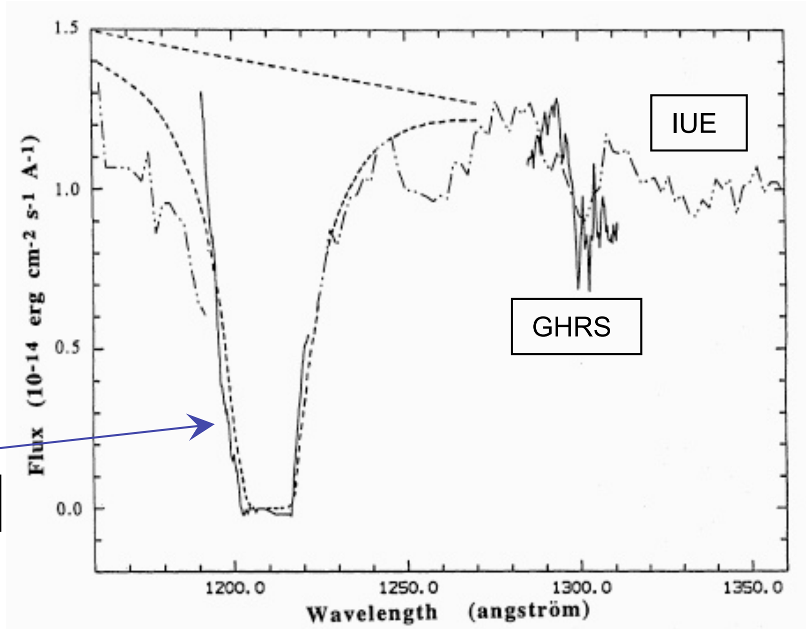
- First trial was made by Kunth et al. (1994) on IZw18.
  - *IZw18 is a low Z, low dust, unevolved BCG dominated by a young starburst. A strong Ly α emission was expected.*

- The results were surprising:
  - *Instead of a prominent emission, a strong, damped absorption was found !*

    This was against most theories considered at the time!

The Lyman α problem in BCG's: IZw18

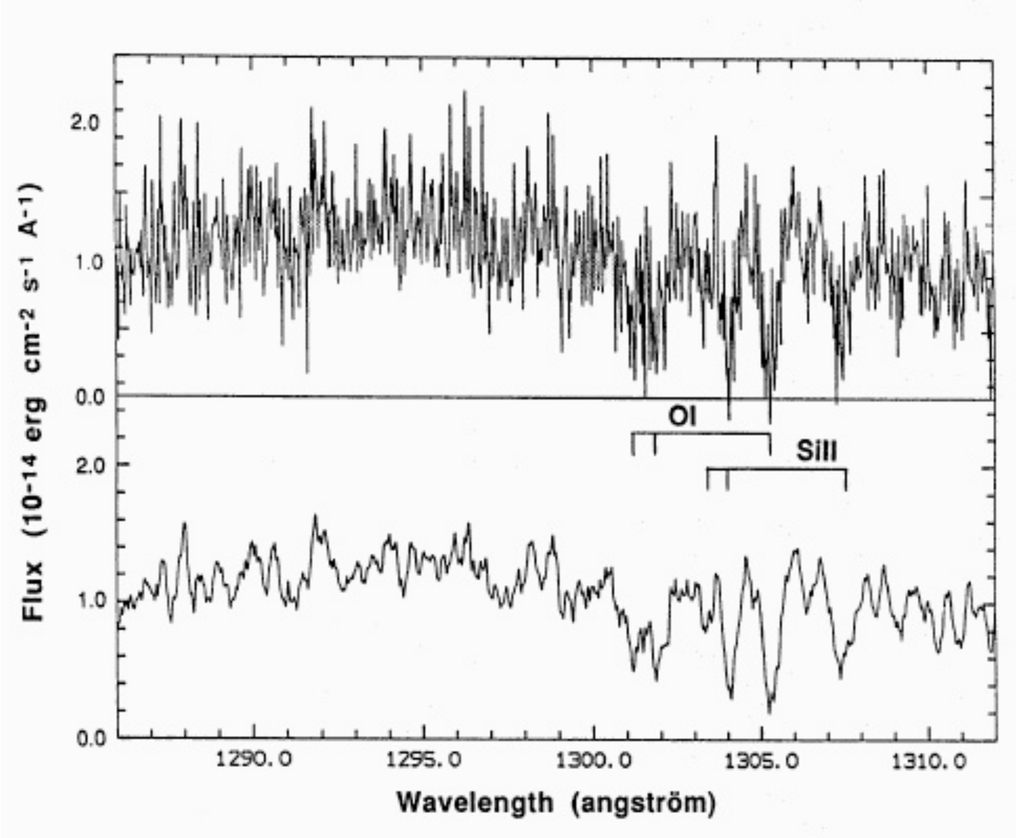




Kunth et al. (1994)

The Lyman α problem in BCG's: IZw18

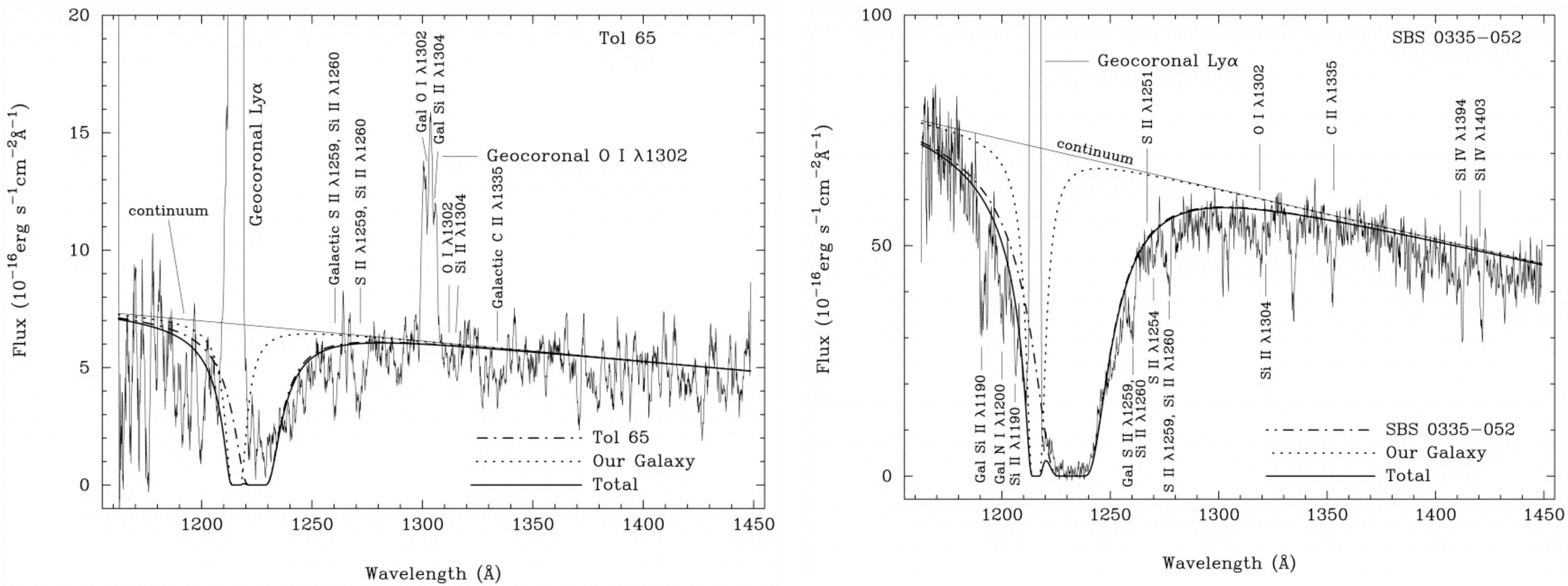
- Analysis of the metallic absorption lines showed that most of the surrounding gas was static w.r.t. the starburst.



Galactic and local OI and SiII lines
Kunth et al. (1994)

The Lyman α problem in BCG's: damped absorptions

- Similar results were found by Thuan and Izotov (1997) on other low metallicity BCGs, like Tol 65 and SBS 0335-052.



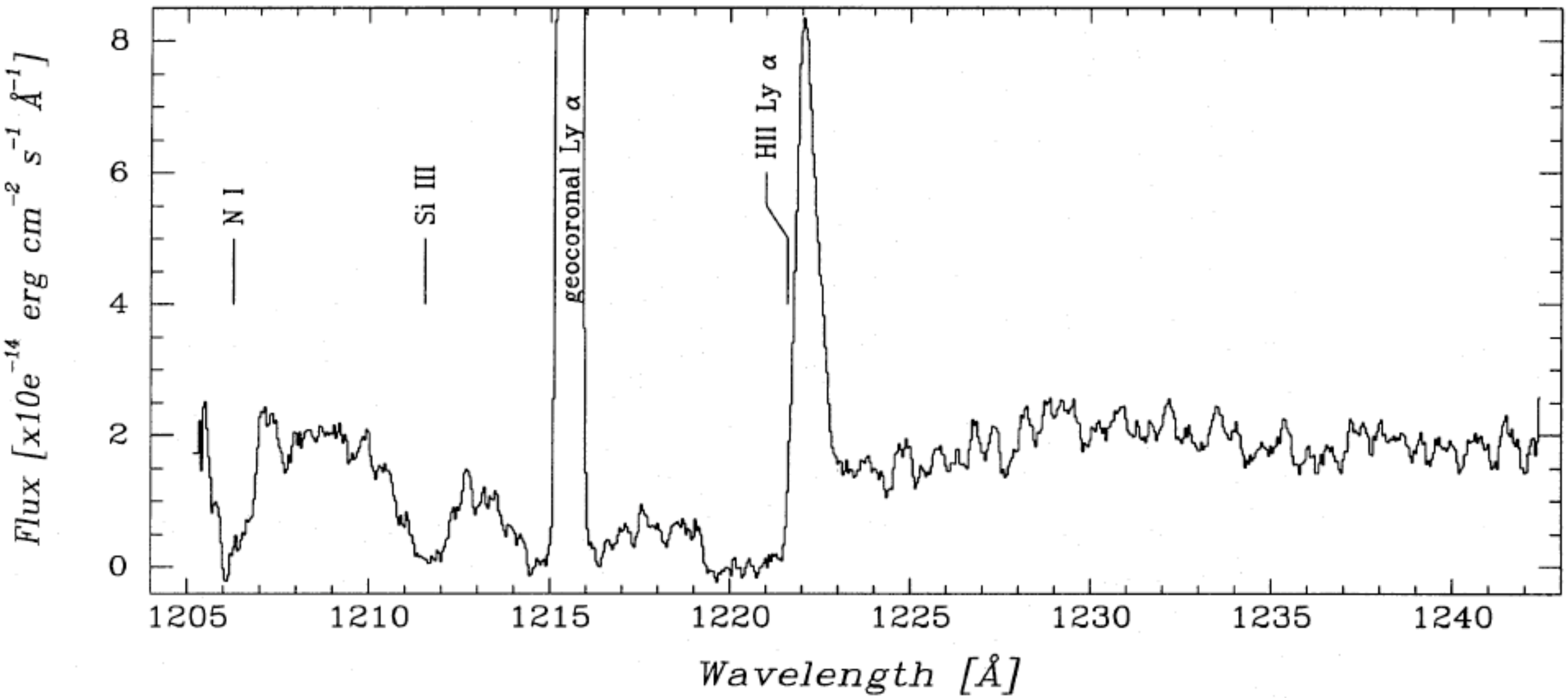
Thuan & Izotov (1997)

The Lyman α problem in BCG's: a larger GHRS sample

- We decided to observe with GHRS a sample of BCGs within a range of properties:
  - *Metallicity*
  - *Morphology*
  - *Compactness*

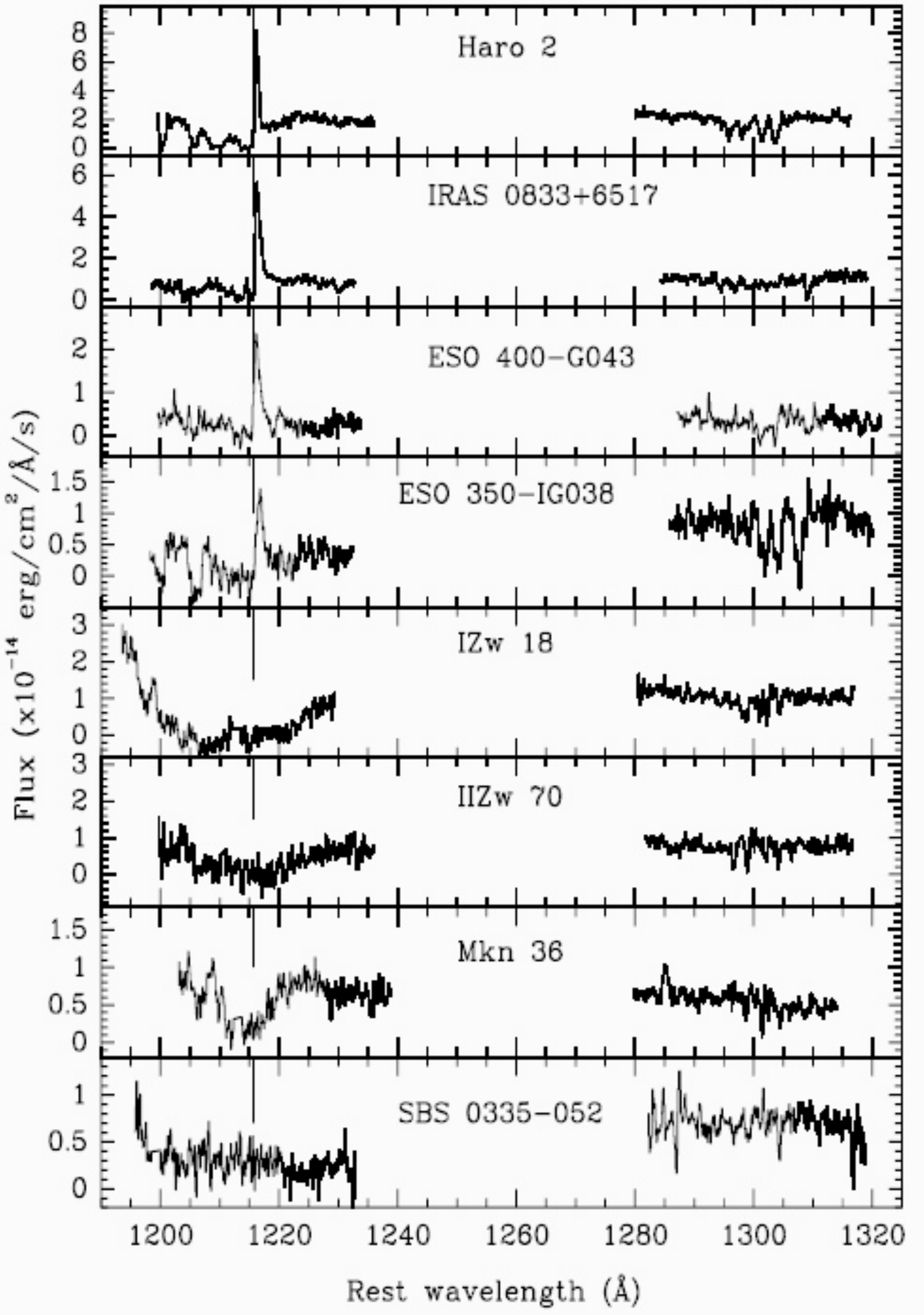
- We started with Haro 2, a Z=0.4 $Z_{\odot}$ BCG with an evolved, dusty starburst
  - *In principle, a candidate for non-detection.*
  - *But a prominent Ly α emission line was detected! (Lequeux et al. 1995).*

The Lyman α problem in BCG's: a larger GHRS sample



Lequeux et al. (1995)

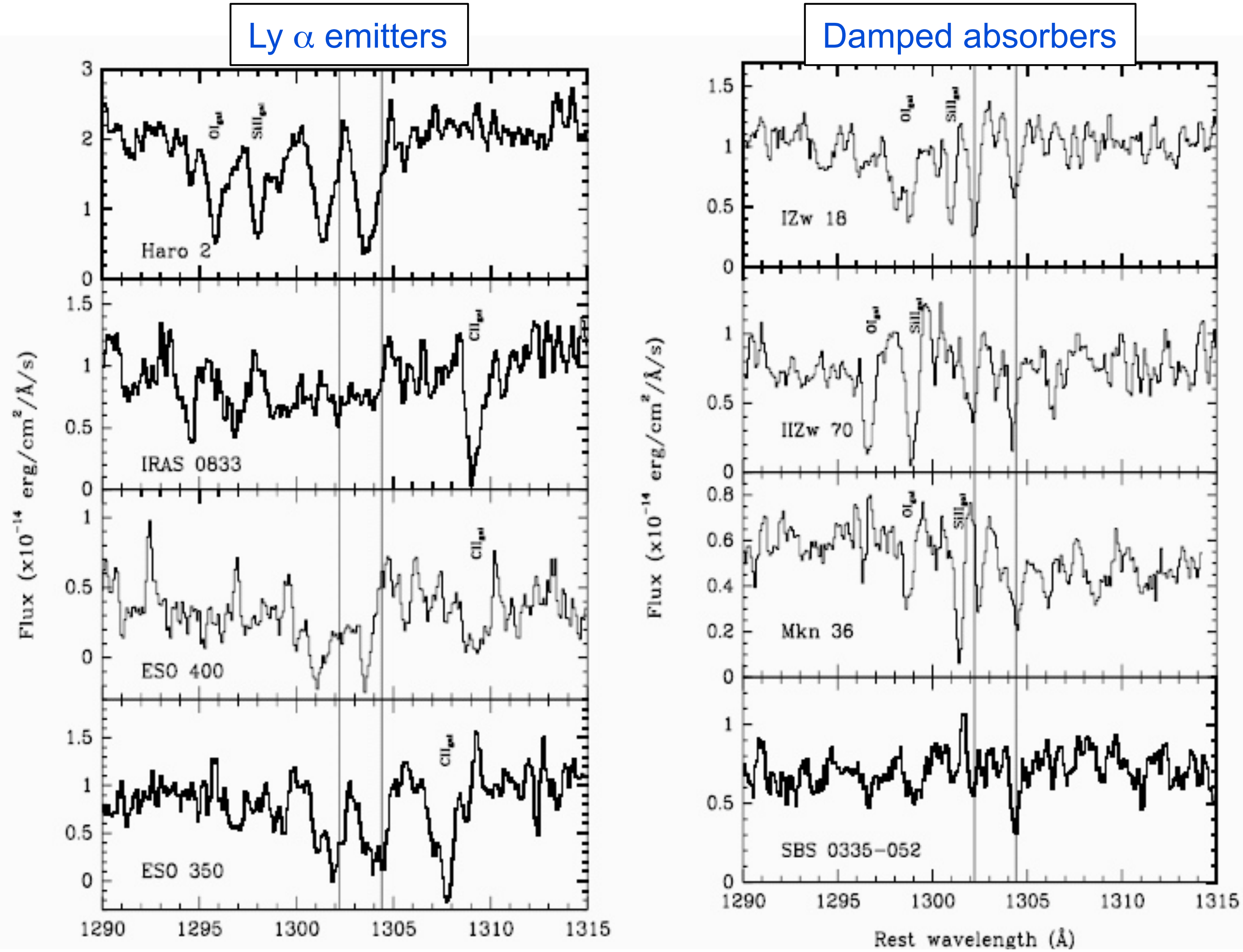
- We identified with GHRS:
  - *4 BCGs with Ly α emission*
  - *4 BCGs with damped absorption profiles*



Kunth et al. (1998)

The Lyman α problem in BCG's: the effect of kinematics

- In all Ly α emitters the neutral, metallic absorption lines were blueshifted by 100-400 km/s.
- In most cases, no absorption was even detected at systemic velocities.
- In the damped systems, the neutral absorptions were at, and only at, the systemic velocities.



Kunth et al. (1998)

The Lyman α problem in BCG's: the effect of kinematics

- All Lyman α emission lines showed a clear P Cyg profile, indicating the presence of an expanding shell of neutral gas.
- The profiles could be well fitted assuming the expansion velocity measured on the metallic absorption lines.
- A secondary emission peak was detected in IRAS 0833.

The Lyman α p
the effect c

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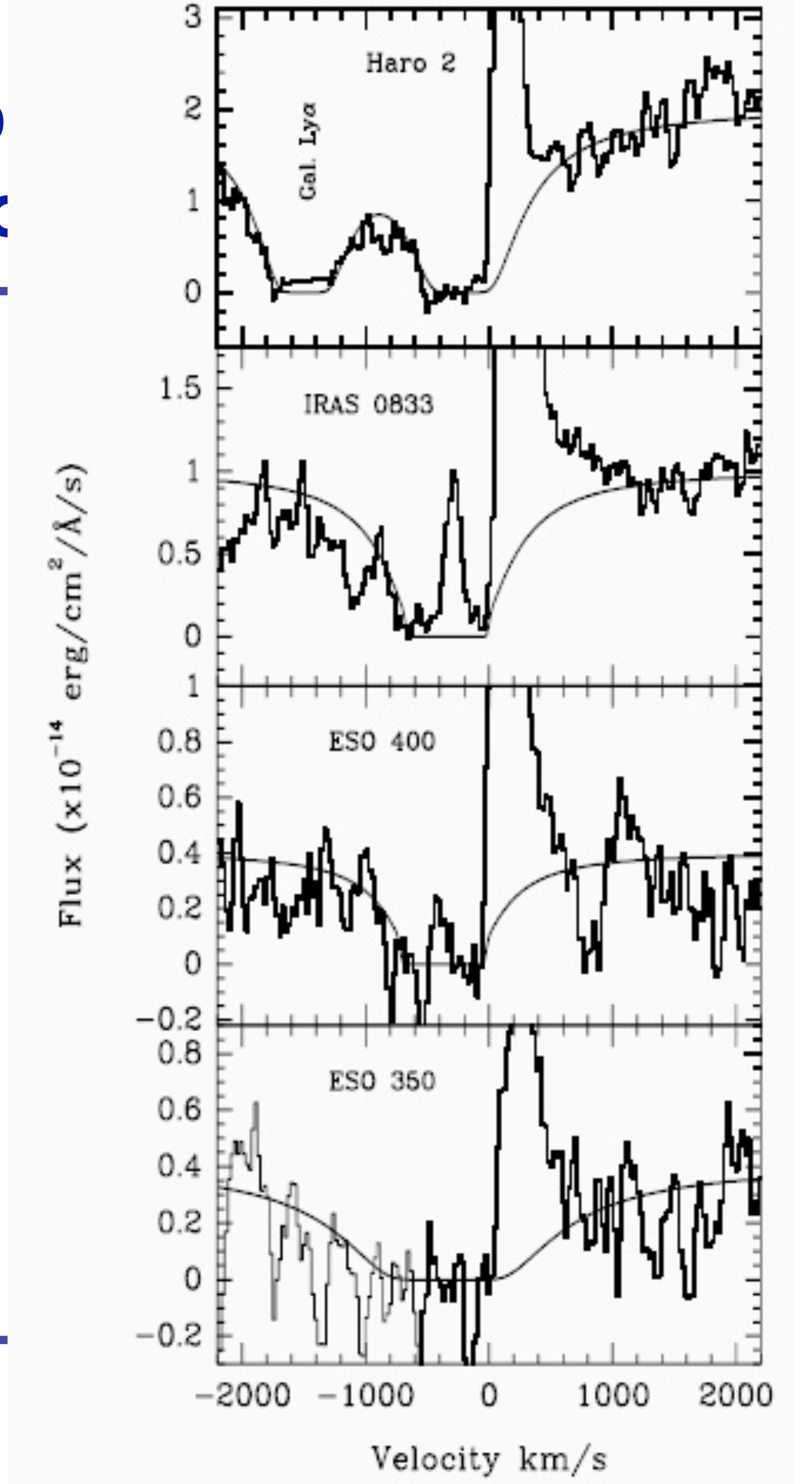
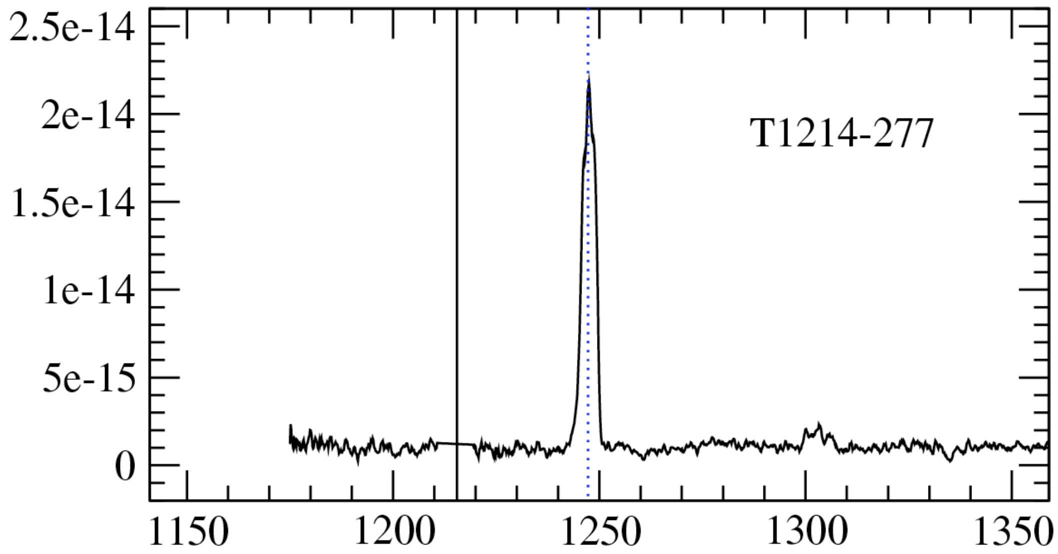


The Lyman α problem in BCG's: the effect of kinematics

- The casuistics was enlarged by Thuan and Izotov (1997), who found a strong and symmetric emission line in Tol 1214-277.

- But a detailed analysis of the profile showed a complex structure, with 2 blue- and redshifted components at ±300 km/s
  - *Indication of a fully ionized expanding shell!*



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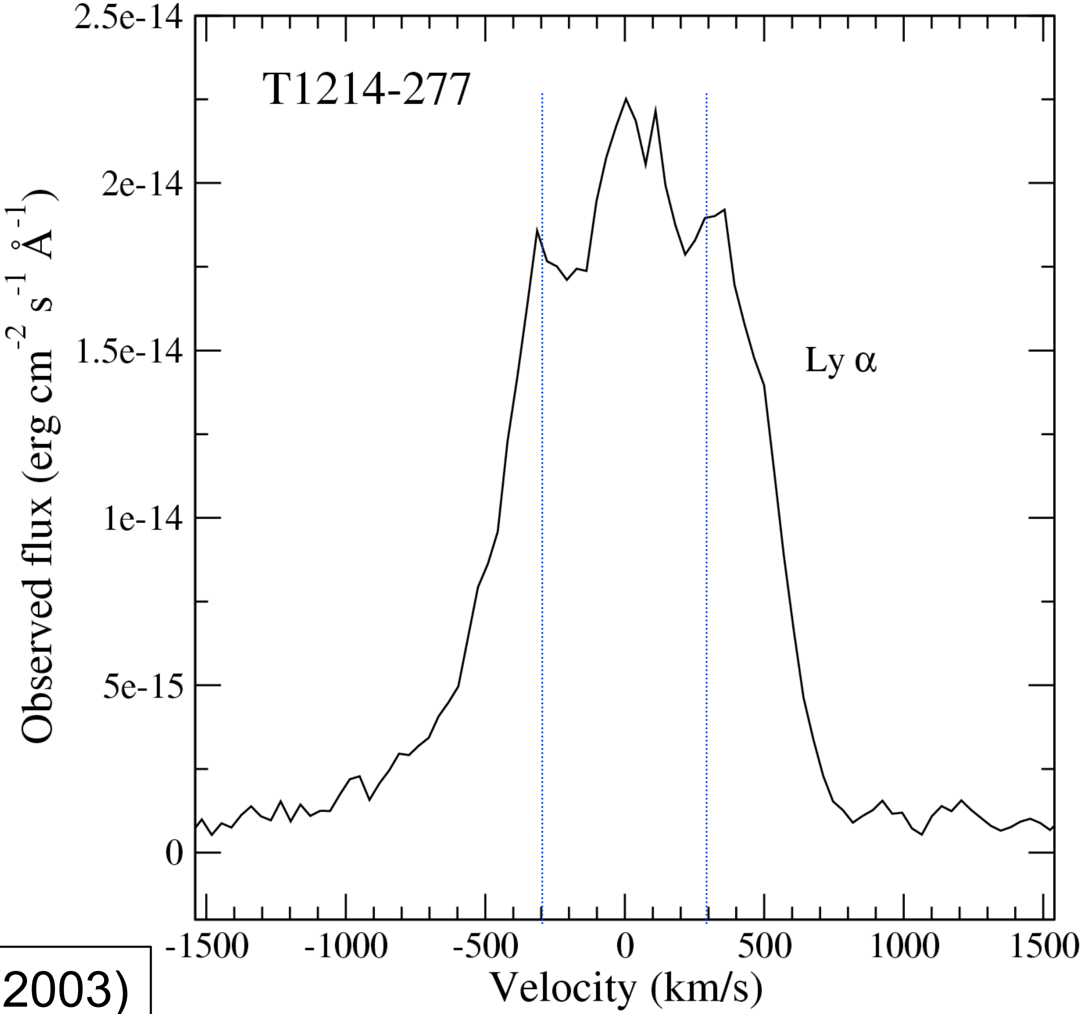
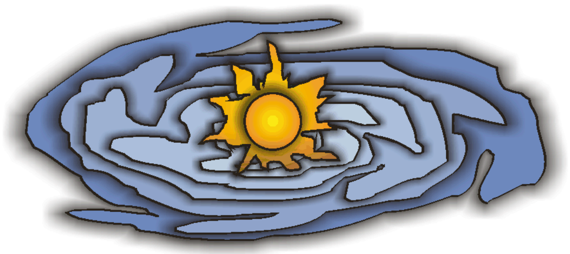
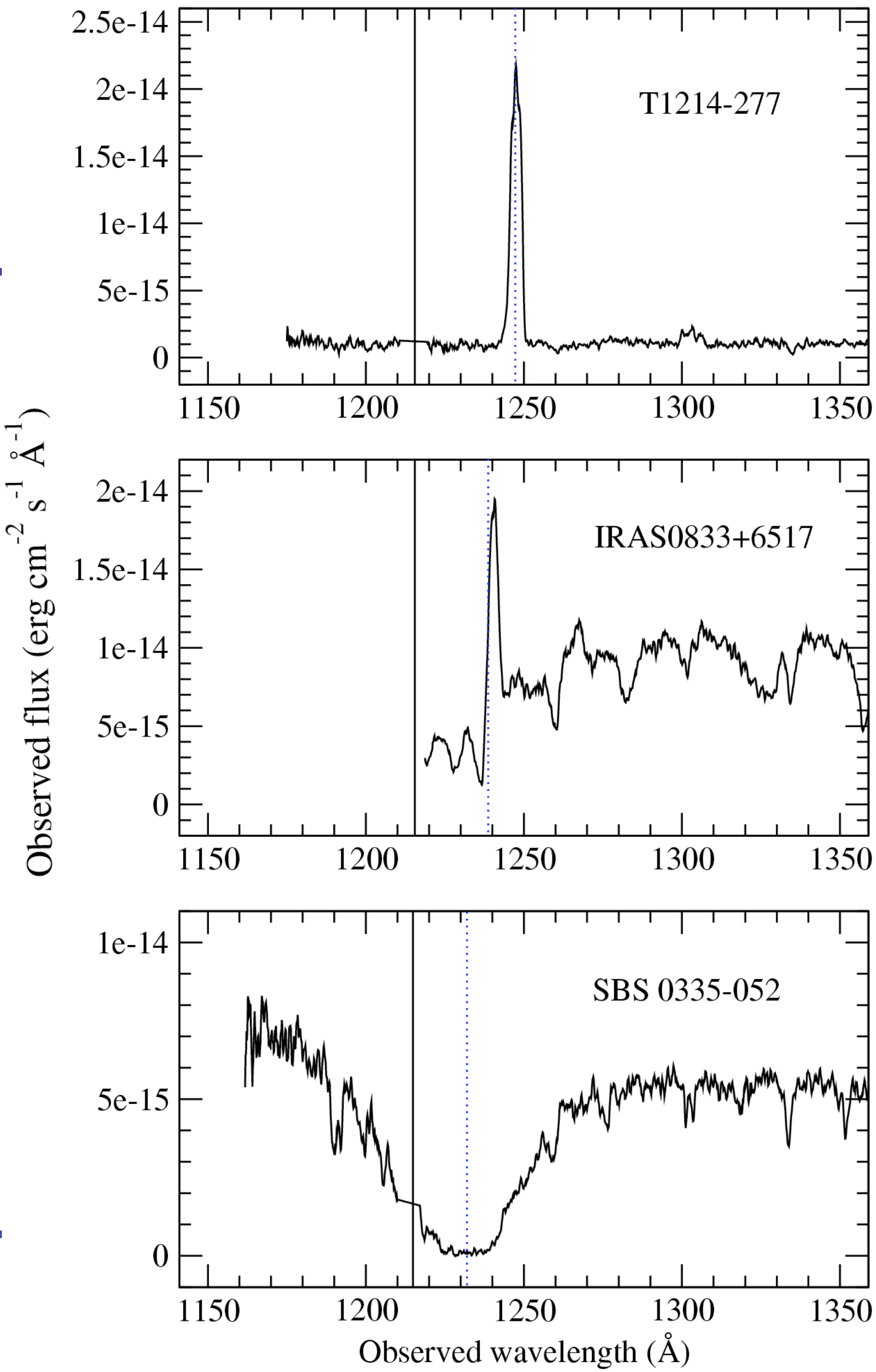


Mas-Hesse et al. (2003)



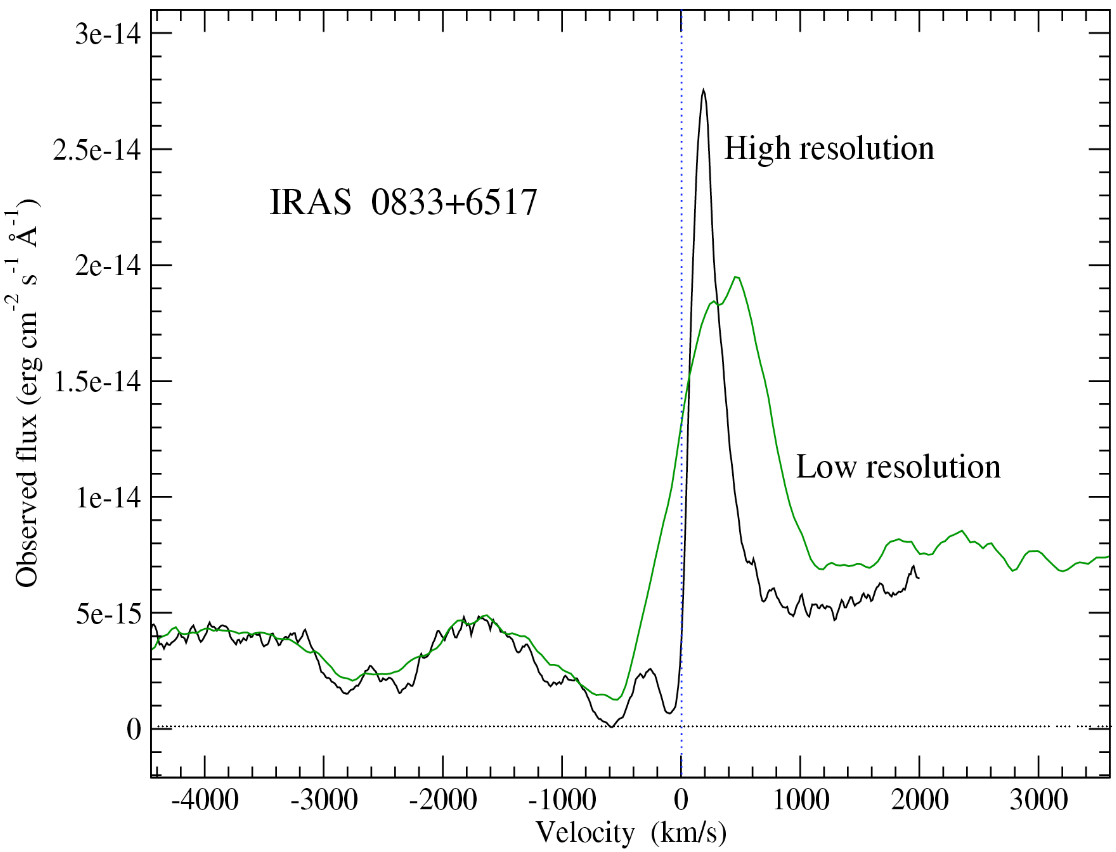
- GHRS summary: 3 well identified classes:
  - *Symmetric, broad emitter.*
  - *Asymmetric, P Cyg like emission line.*
  - *Broad, damped absorption profile.*

No clear correlation with metallicity, morphology, age,….



The Lyman α problem in BCG's: the effect of kinematics

- An important lesson from GHRS studies:
  - *Since kinematics plays an important role, resolution of ~50 km/s is needed to understand the properties of the line.*
- Lower resolution data can even become misleading
  - *Caution for studies at high redshift!*



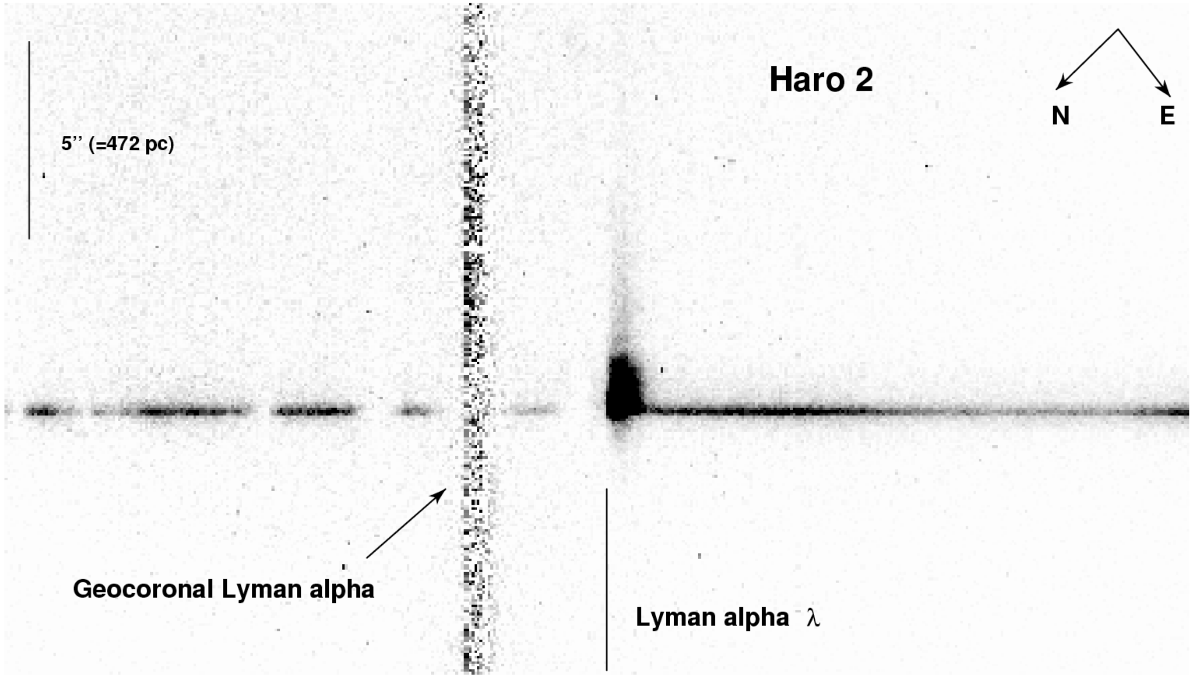
The Lyman α problem in BCG's: spatial analysis with HST/STIS

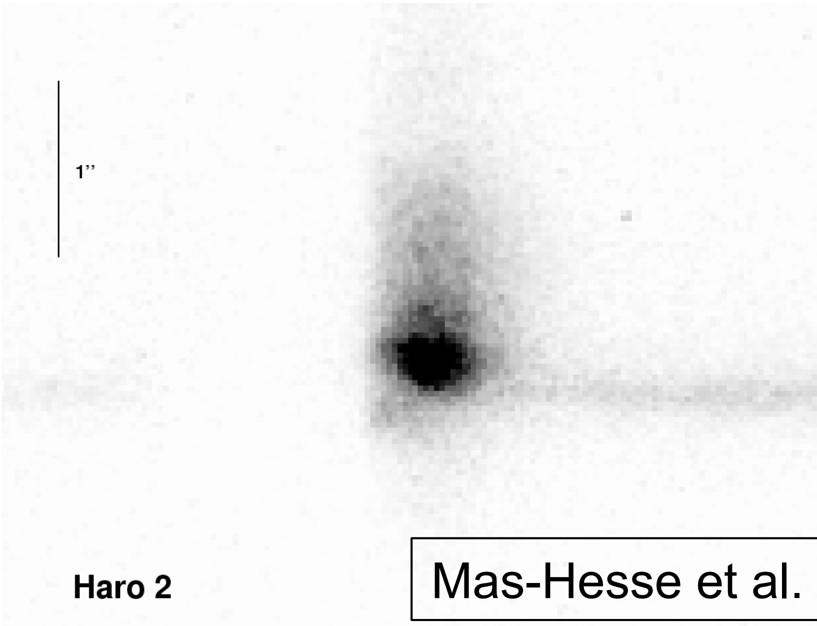
- The next step was to get long slit high-resolution spectroscopy with STIS, aiming:
  - *To map the distribution of the neutral gas and its kinematics.*
  - *To detect Lyman α photons leaking after multiple scattering by the neutral gas.*

- 3 cases were analyzed in high resolution (Mas-Hesse et al. 2003):
  - *Haro 2 and IRAS 0833, strong Ly α emitters.*
  - *IZw18, prototypical damped absorber.*

- Low resolution STIS data become available also for
  - *Haro 2 (Chandar et al.2004; Oti-Floranes et al. 2009, see poster)*
  - *ESO 338-IG04 (Chandar et al.2004; Hayes et al. 2005)*
  - *NGC 4303 (Colina et al. 2002)*

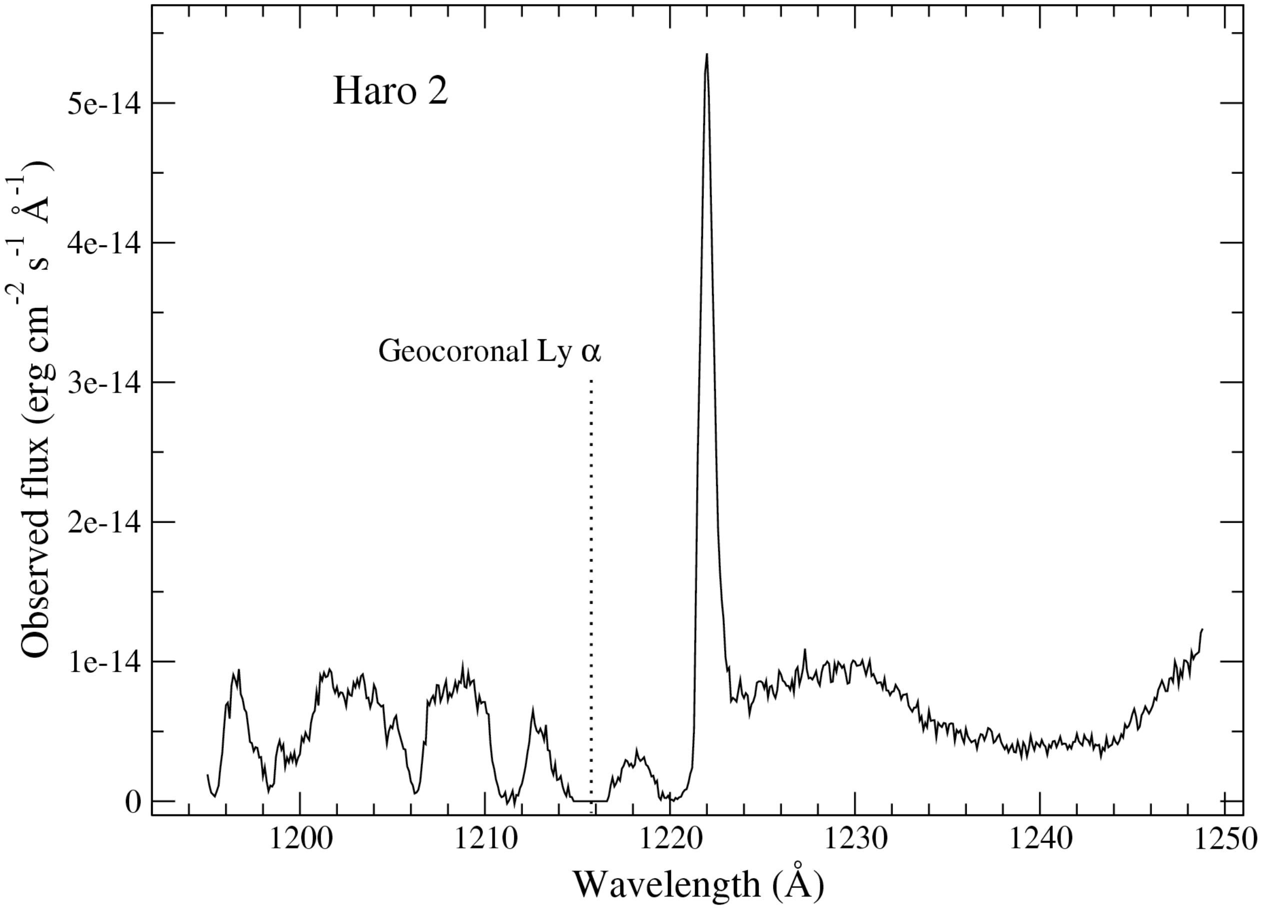
- Very compact massive cluster.
- Decoupled Ly α emission extended over more than 10” (~1 kpc).
- Absorption edge at the same velocity all over the slit:
  - *Large expanding shell powered by the central starburst.*
  - *Identified in Hα by Legrand et al. (1997).*





Mas-Hesse et al. (2003)

The Lyman α problem in BCG's: Haro 2



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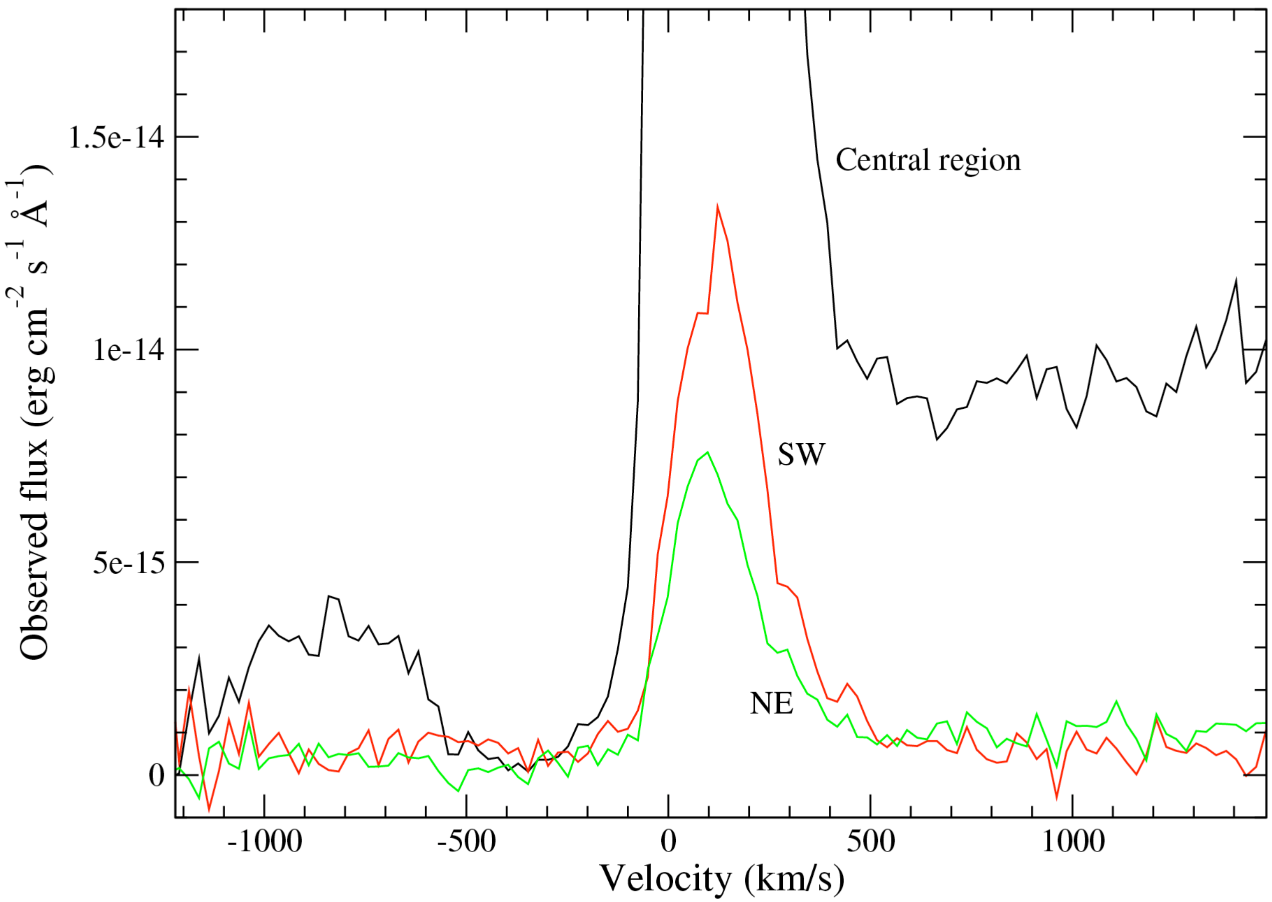
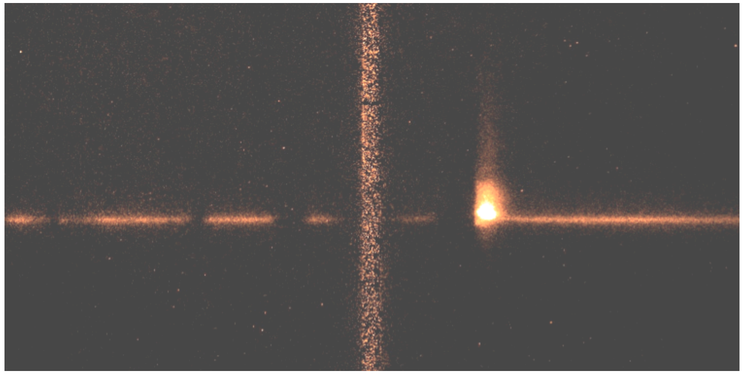
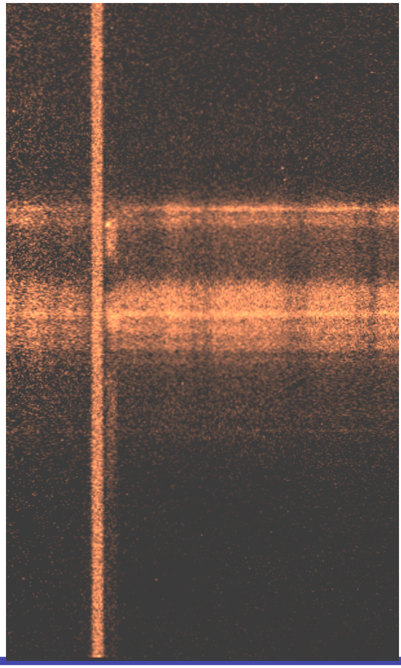


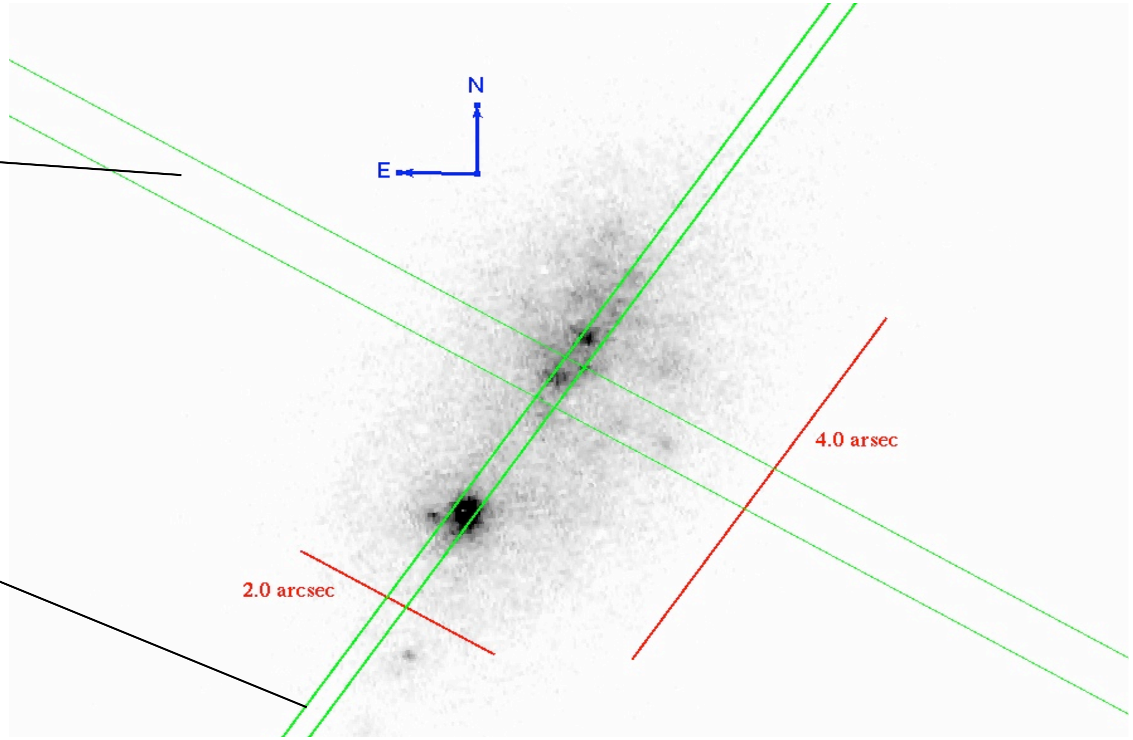
The Lyman α problem in BCG's: Haro 2

- Low resolution STIS spectra of Haro 2 show a complicated structure and distribution of Lyman α emission and absorption:
  - *The spatial distribution of the neutral HI and its kinematics is very complex.*

The Lyman α problem in BCG's: Haro 2

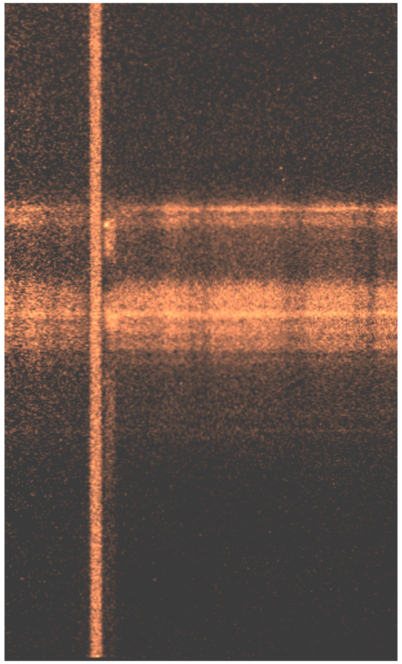


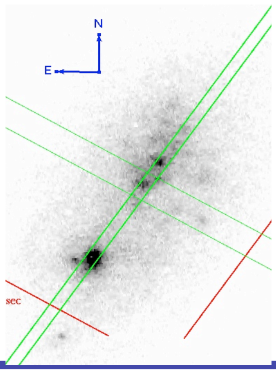


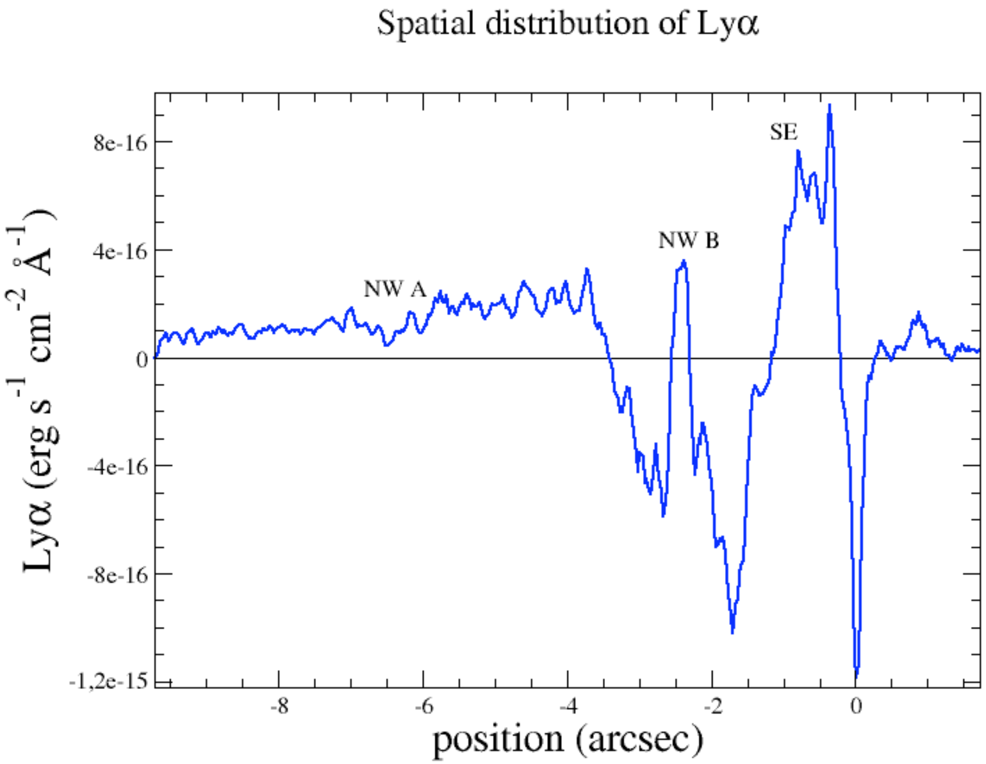


Otí-Floranes et al. (2009), *see poster #3*

The Lyman α problem in BCG's: Haro 2





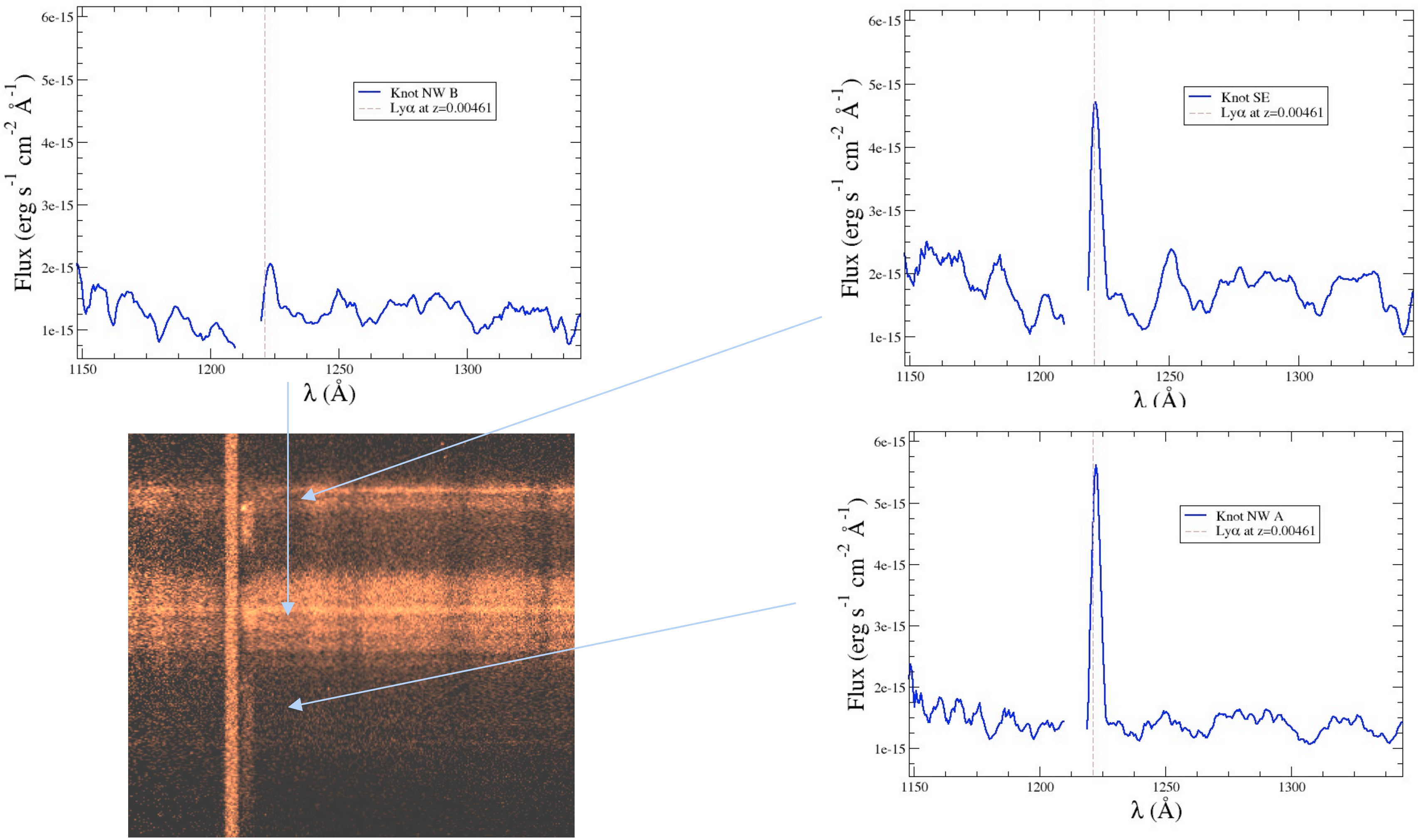


Otí-Floranes et al. (2009)

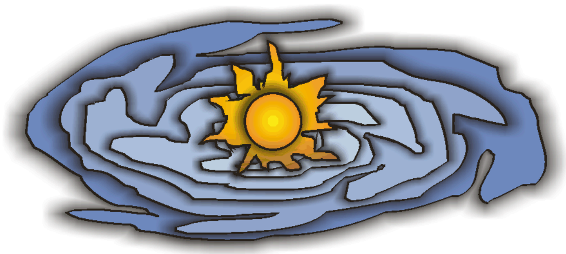
The Lyman α problem in BCG's: Haro 2

- Low resolution STIS spectra of Haro 2 show a complicated structure and distribution of Lyman α emission and absorption:
  - *The spatial distribution of the neutral HI and its kinematics is very complex.*
  - *The diffuse, extended Lyman α emission becomes one of the strongest components.*

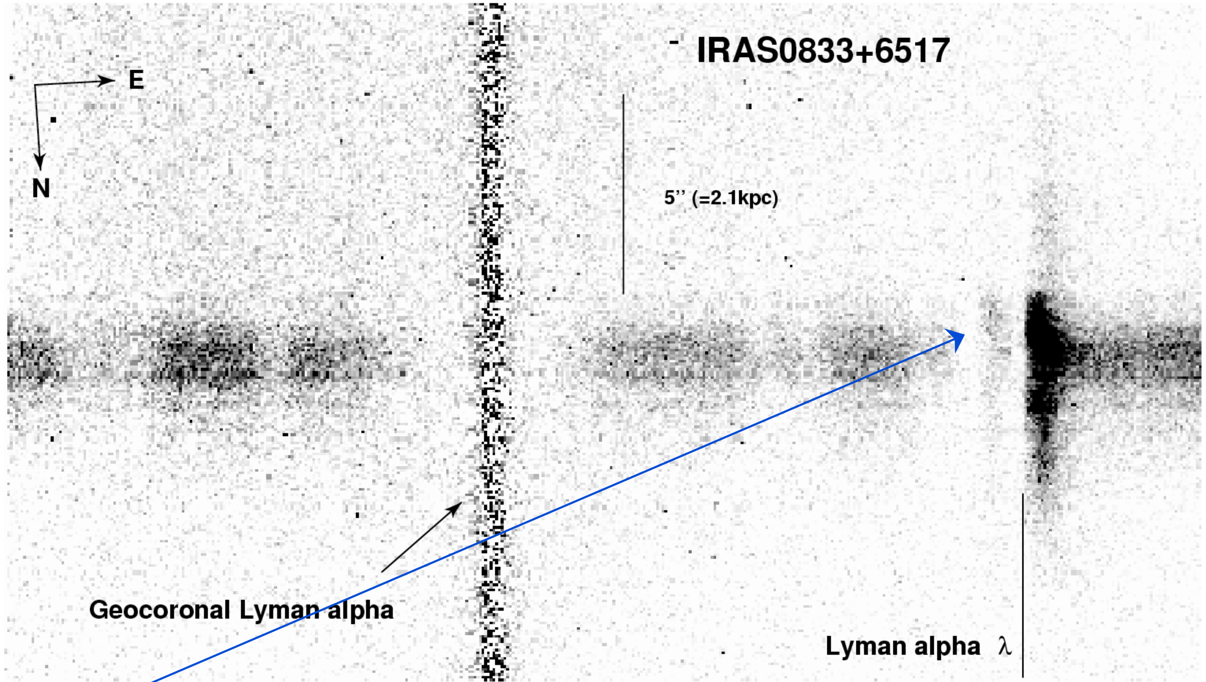
The Lyman α problem in BCG's: spatial analysis with HST/STIS

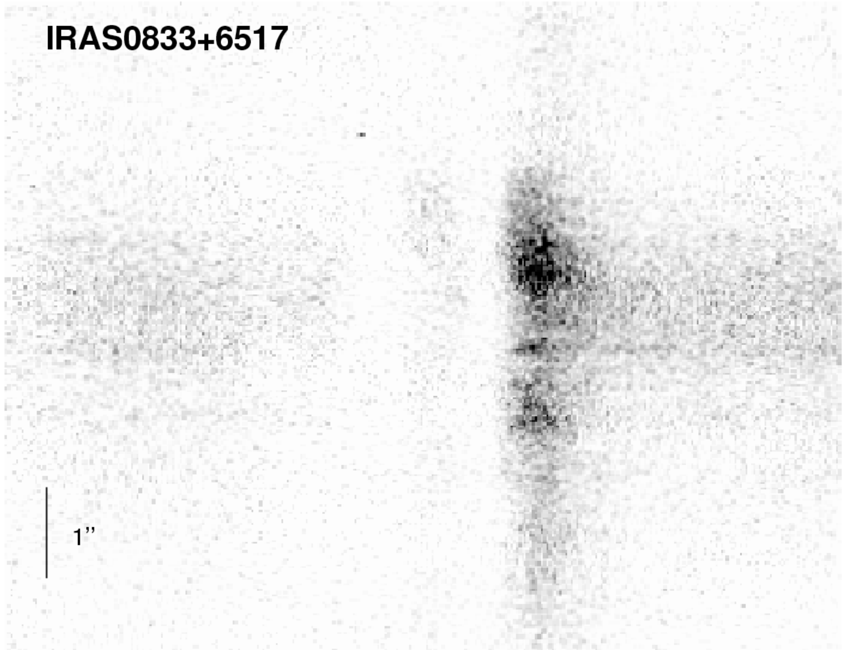


Otí-Floranes et al. (2009)

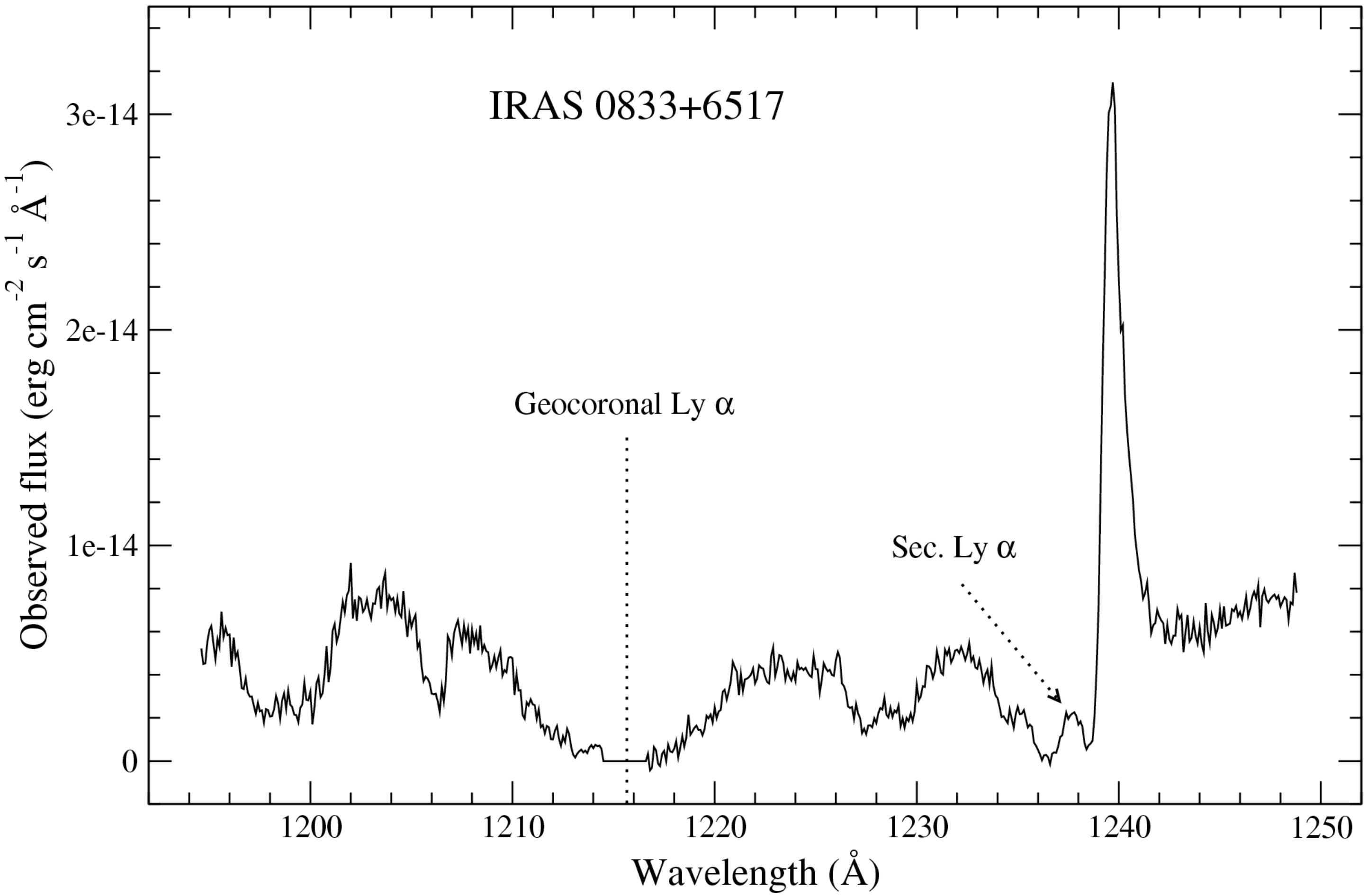


- Massive stars spread over ~1 kpc.
- Same velocity of the absorption edge over ~4 kpc.
  - *A secondary, broad and blueshifted emission blob located to the S.*

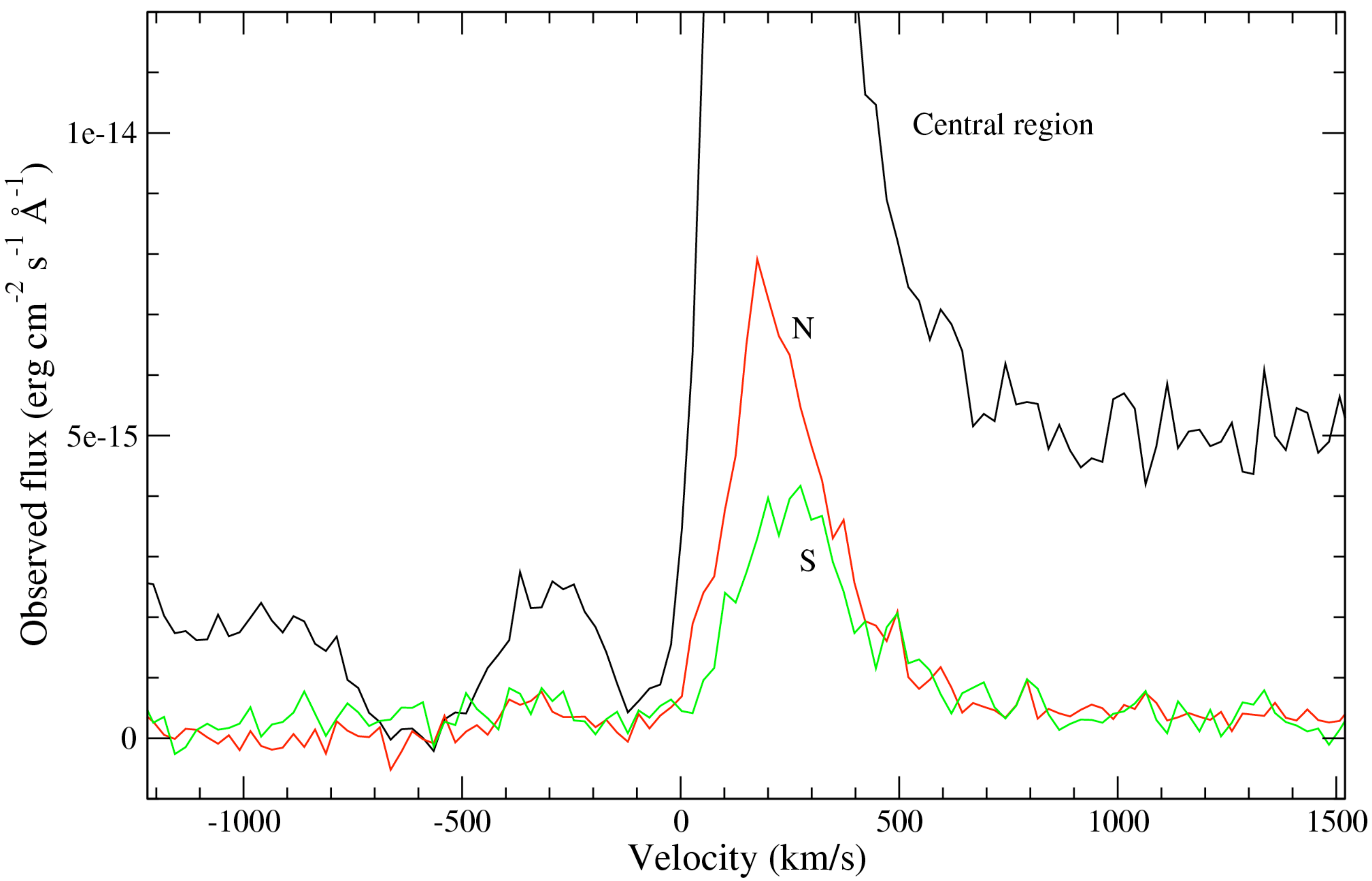




The Lyman α problem in BCG's: IRAS 0833+6517

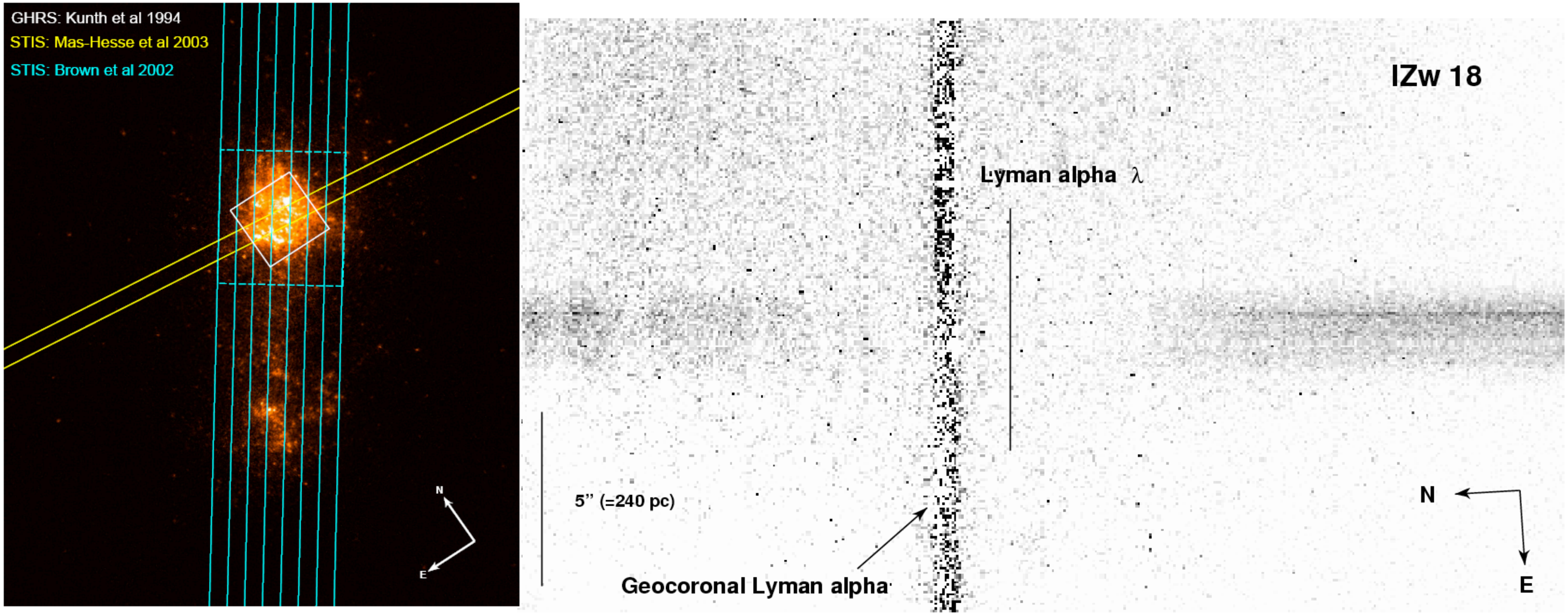


The Lyman α problem in BCG's: IRAS 0833+6517

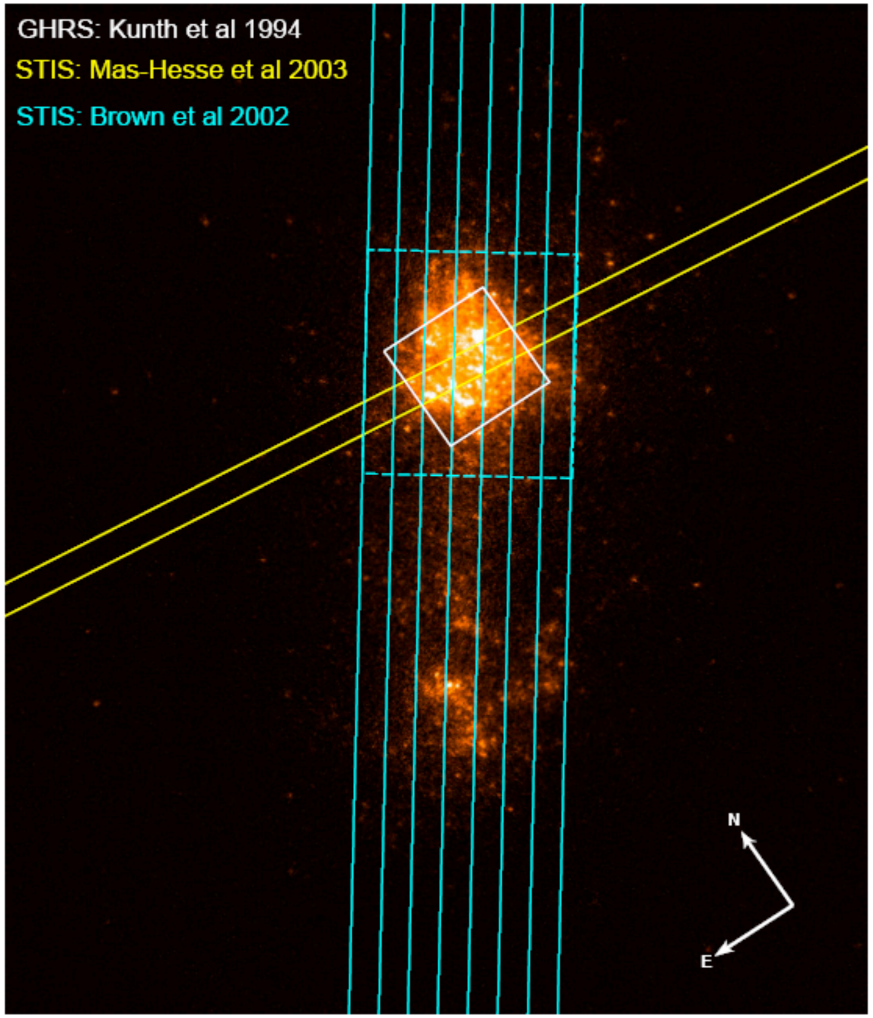


The Lyman α problem in BCG's: IZw 18

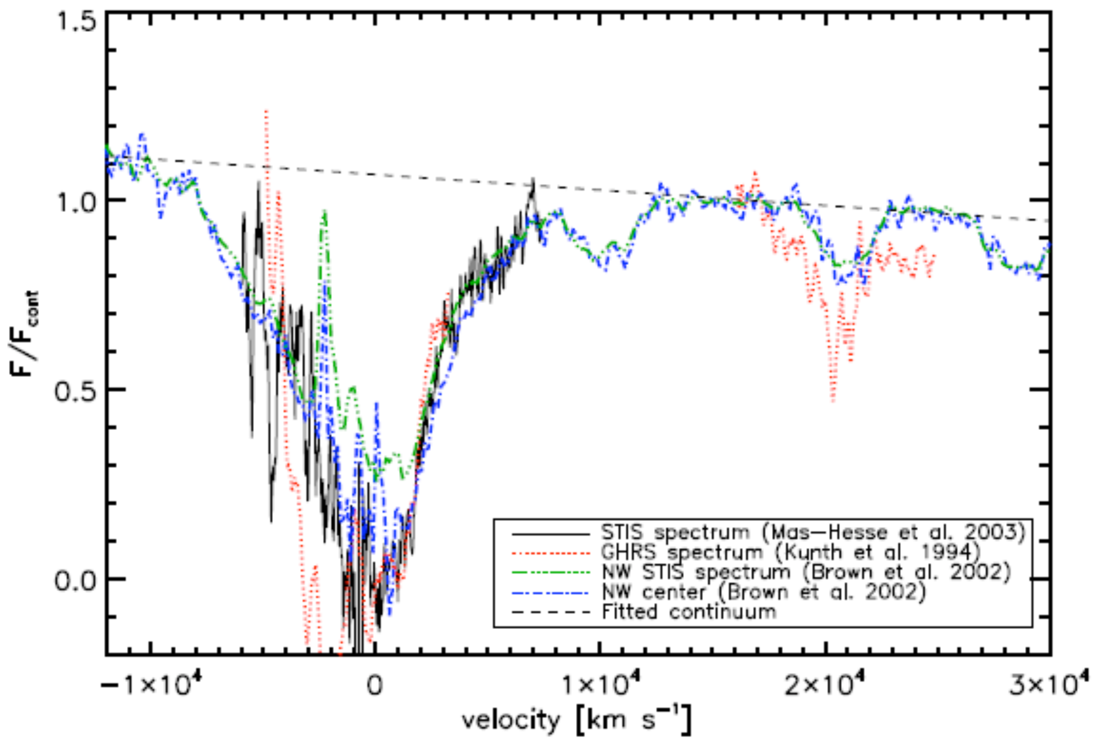
- No leaking or diffuse emission was detected over the slit.
  - *The scattered photons are completely destroyed within the neutral cloud*



The Lyman α problem in BCG's: IZw 18



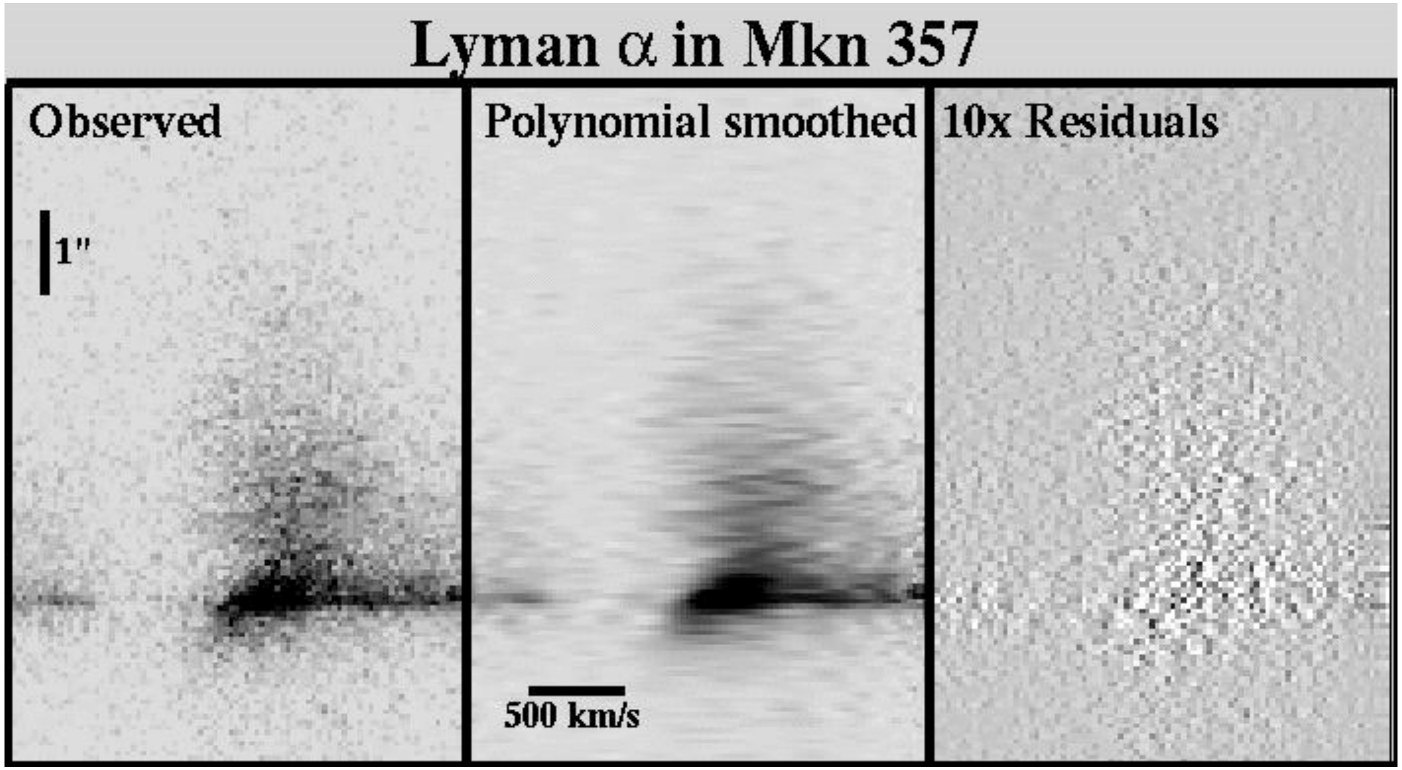
- No emission was detected either on other locations.



Atek et al. (2009)

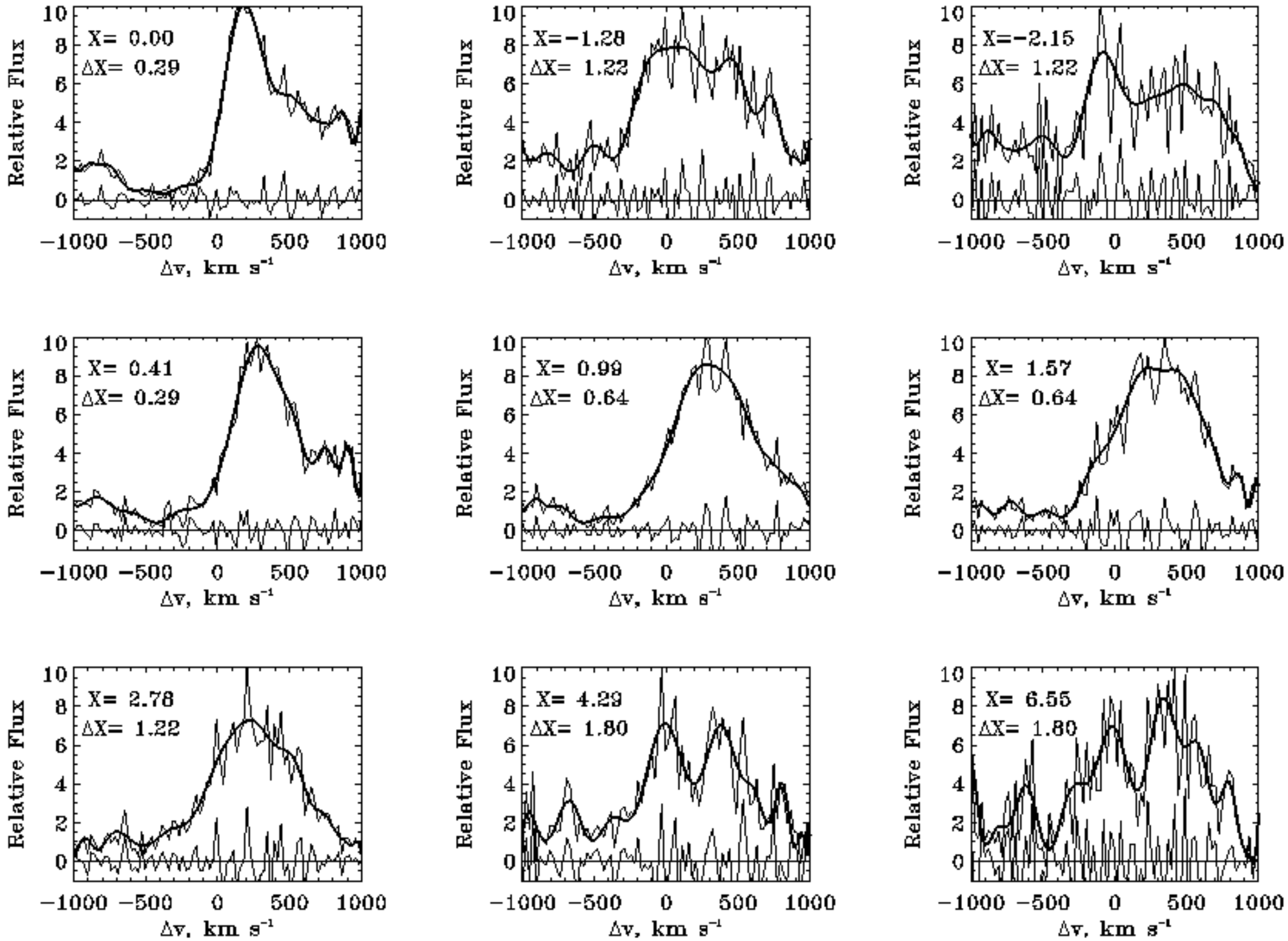
The Lyman α problem in BCG's: Mkn 357

- Keel (2005) observed with the same setup Mkn 357, getting very similar results.



Keel (2005)

The Lyman α problem in BCG's: Mkn 357

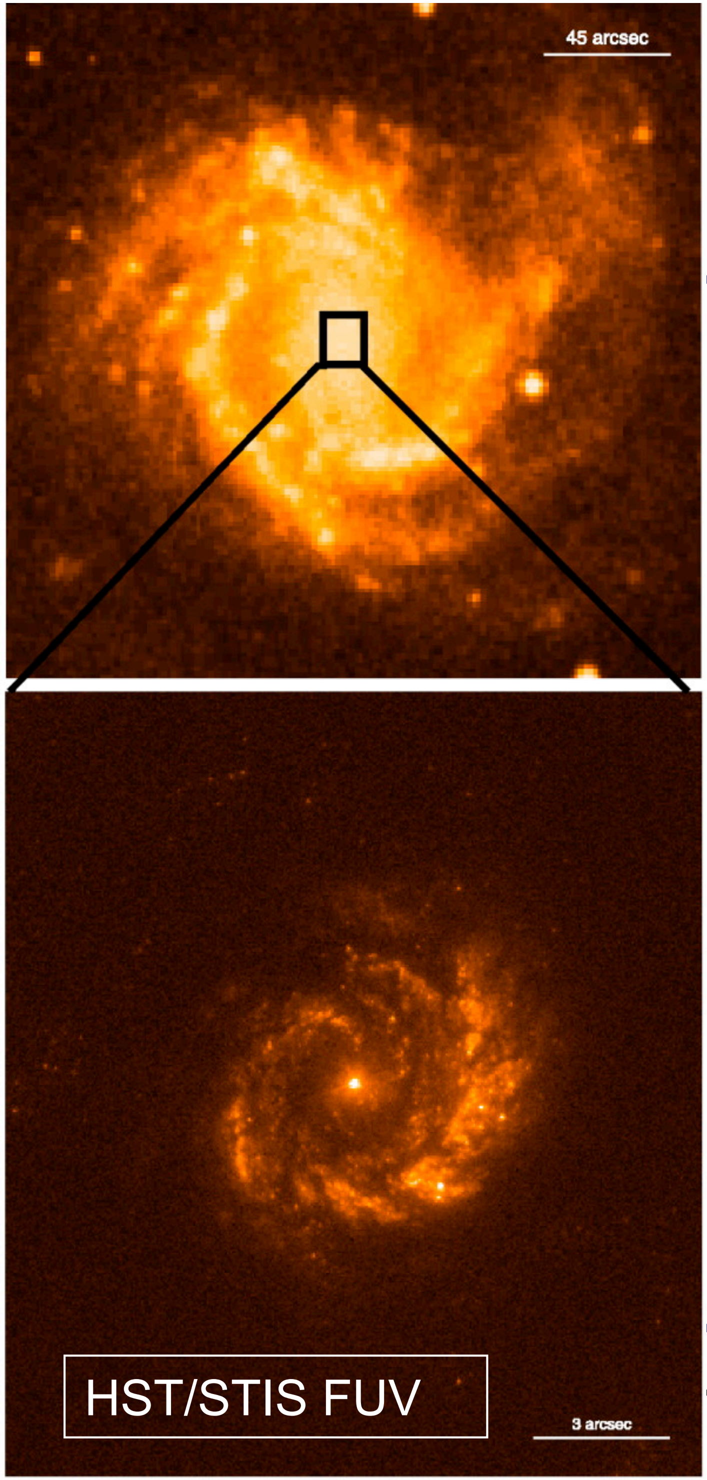


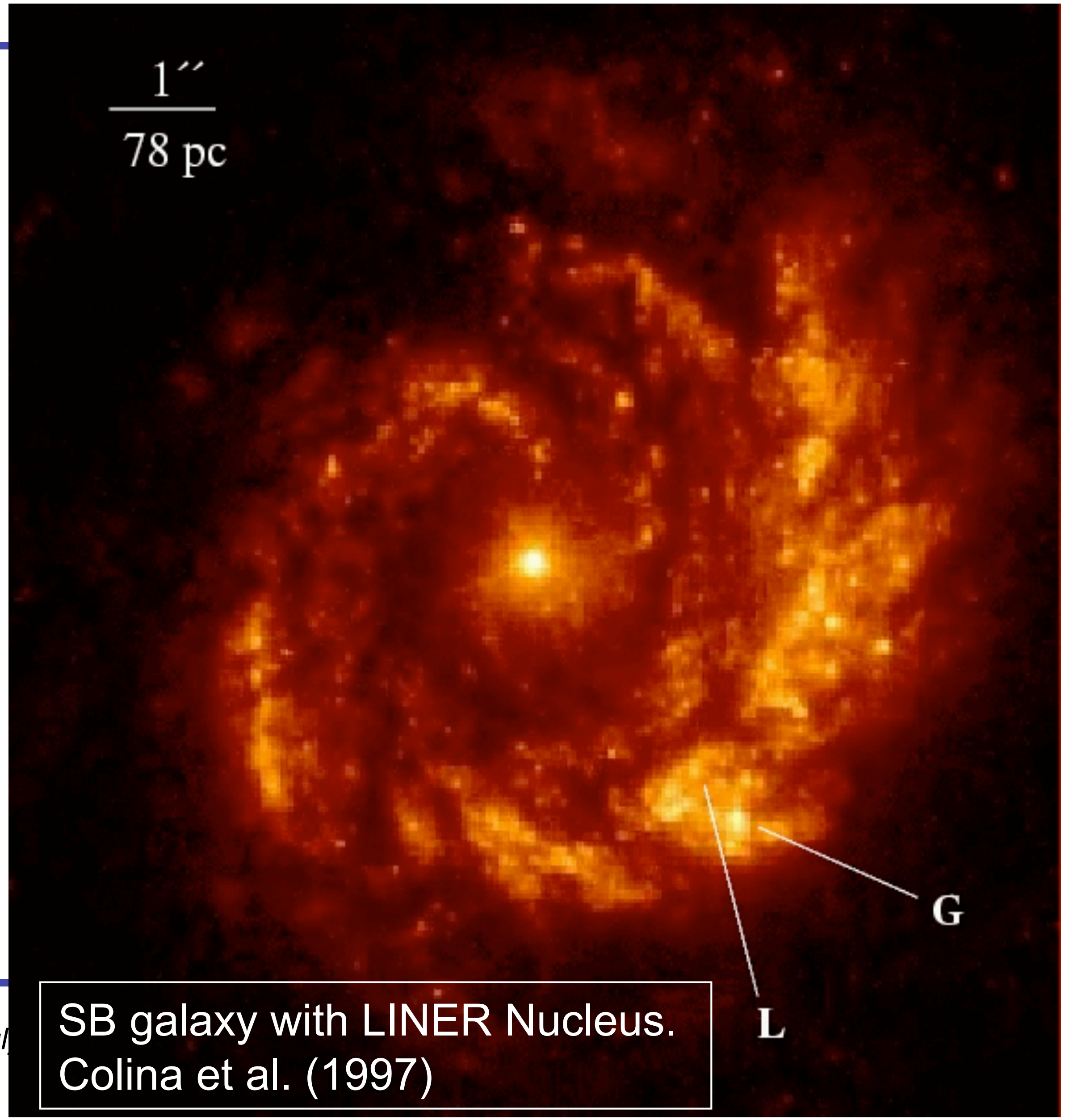
Keel (2005)

Local Lyman α emitters: NGC 4303

- While Lyman α emission is generally weak in local BCGs, it can become quite strong in other kind of galaxies.

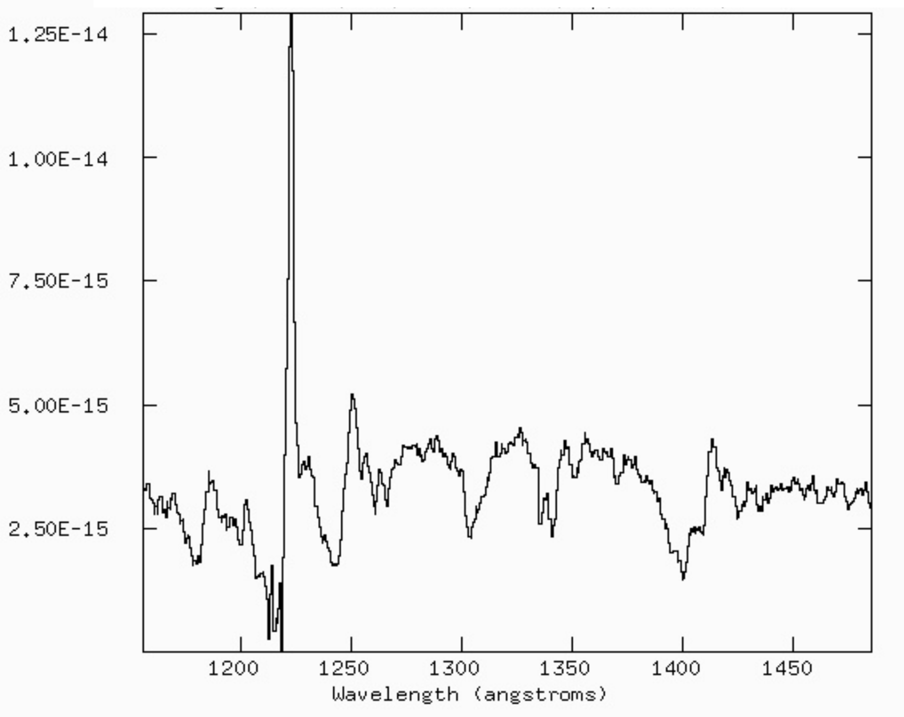
Local Lyman α emitters: NGC 4303



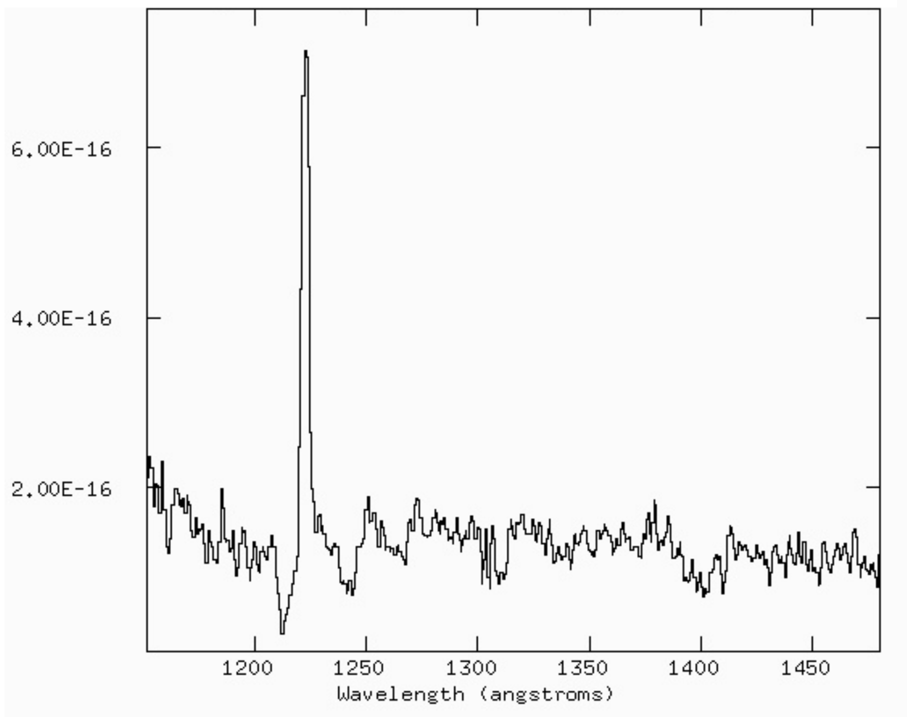


SB galaxy with LINER Nucleus.
Colina et al. (1997)

Local Lyman α emitters: NGC 4303

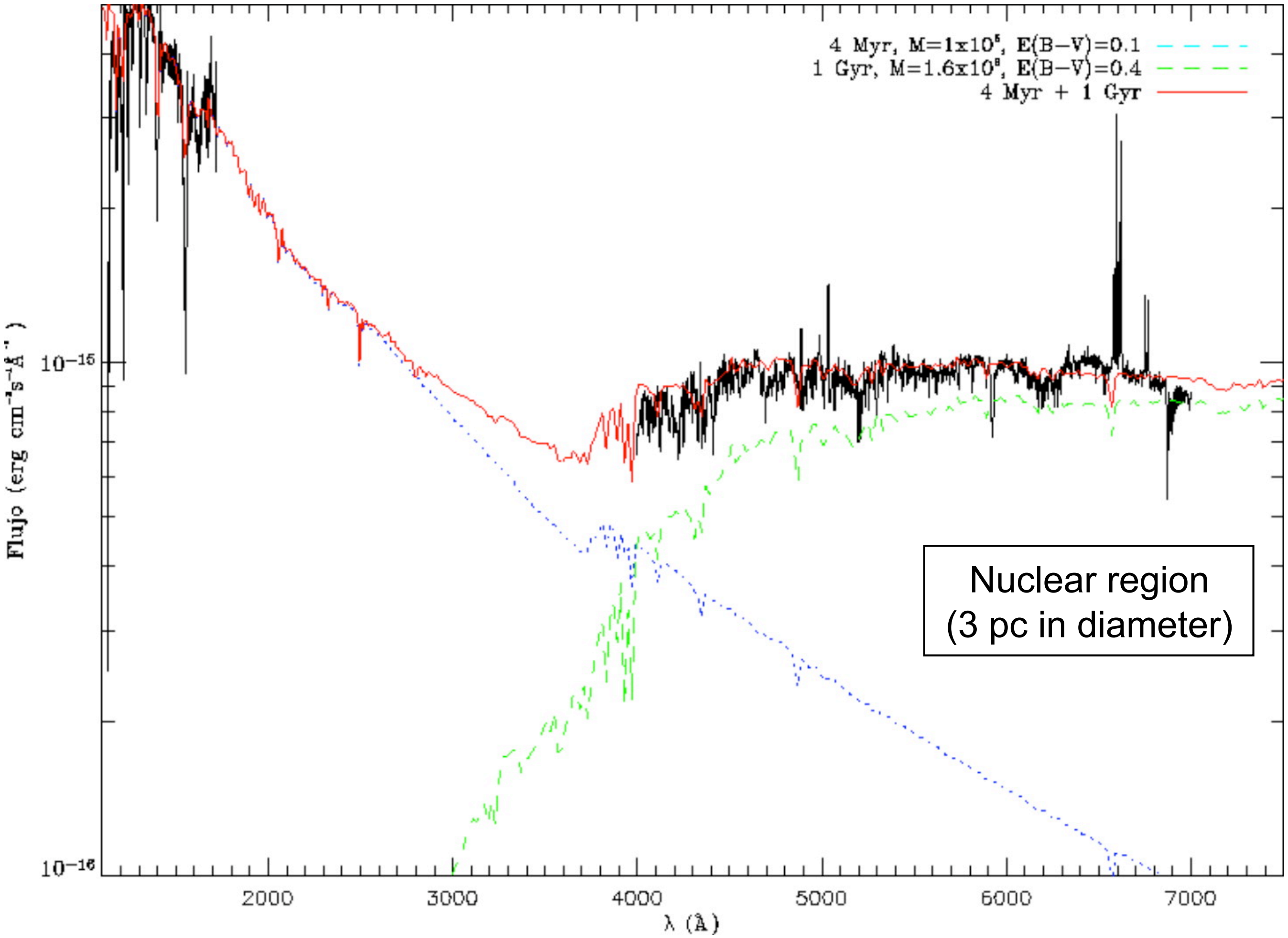


Nuclear region
(3 pc in diameter)



Intercluster diffuse emission

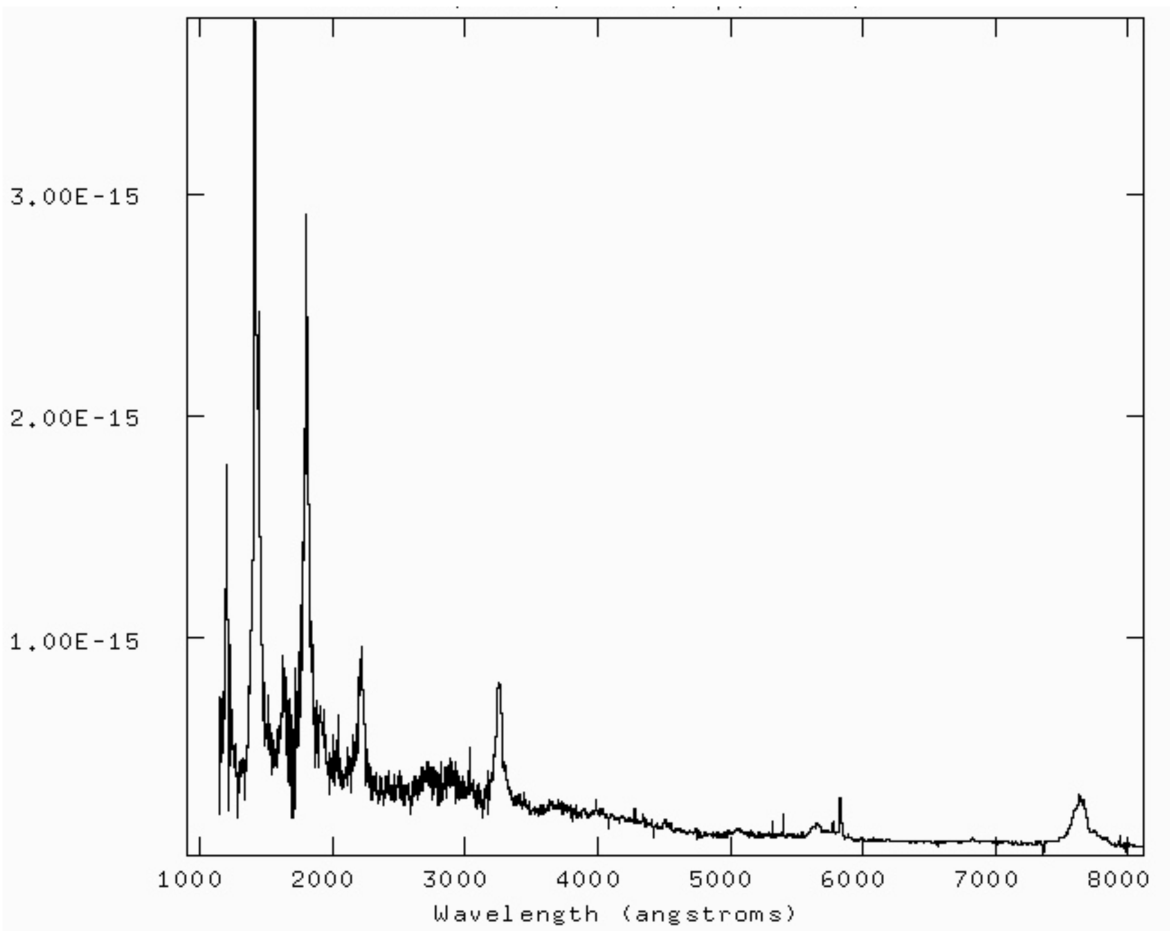
Local Lyman α emitters: NGC 4303



- Lack of neutral gas?
- Similar scenario in Seyfert 2.

Jiménez-Bailón et al. (2002)

Local Lyman α emitters: NGC 4303 and Seyfert 2



1701+610. Seyfert 2.

Local Lyman α emitters: status after IUE+GHRS+STIS

- Kinematical decoupling between the neutral gas surrounding a starburst and the ionized region seems to be the key factor driving the visibility and properties of the Lyman α line.
- When Lyman α photons become affected by resonant scattering, even small amounts of dust might destroy them.
- Distribution of the surrounding neutral and ionized gas is therefore critical:
  - *Porosity (low column density) or complete ionization of the gas along the line of sight can lead to strong emission lines.*

The emission of Lyman α photons is therefore a complex multiparametric process leading to a large variety of results.

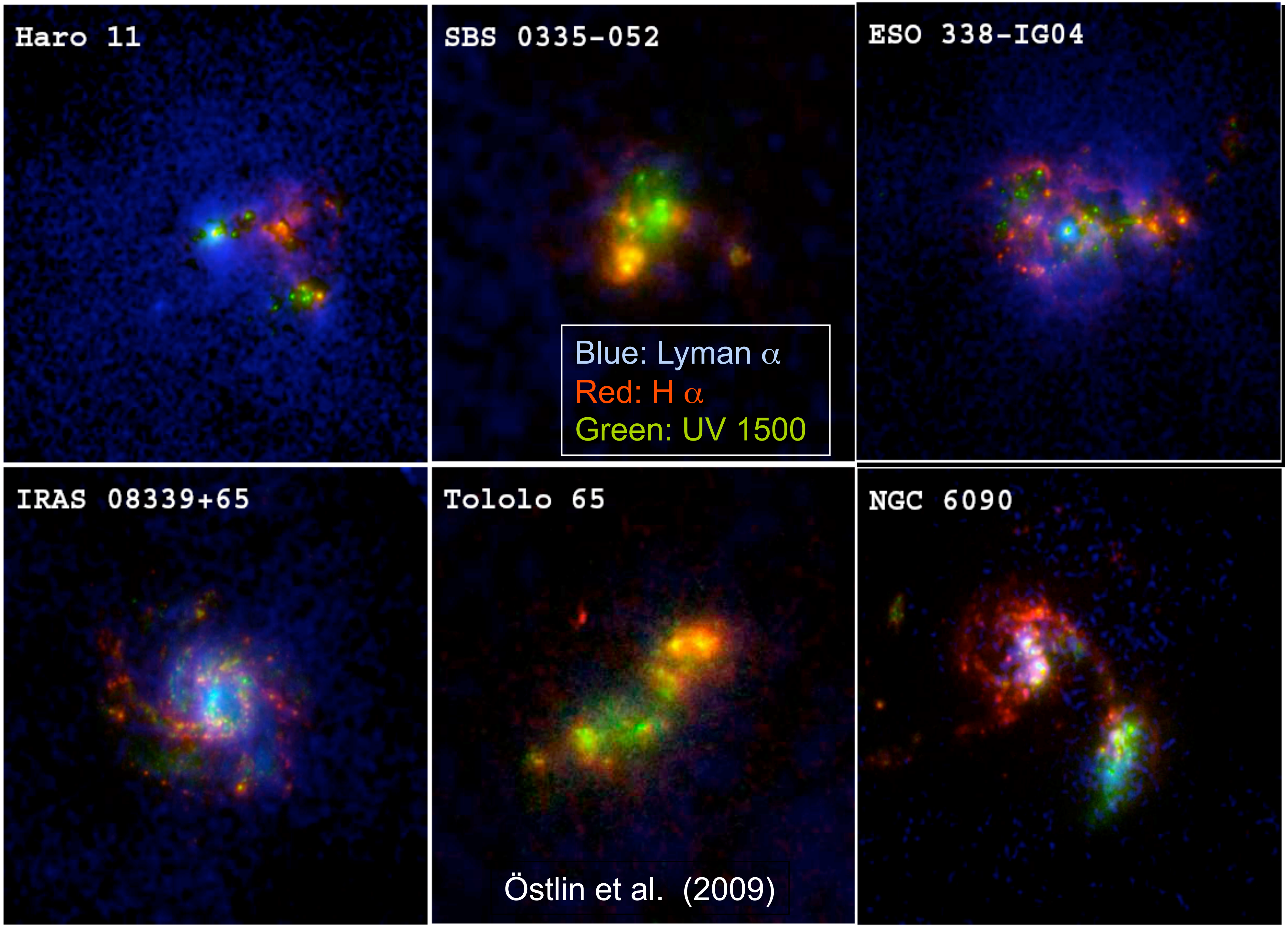
Local Lyman α emitters: imaging

- HST/ACS allowed us to get high resolution Lyman α images, aiming:
  - *To map the distribution of the neutral gas and its kinematics*
  - *To analyze the distribution of the diffuse component*
  - *To study the relation between Lyman α emission and young, massive stars in the different star-forming knots.*

- 6 objects covering a wide range of properties were observed:

Target name	Alternative name	RA(2000)	Dec(2000)	$E(B-V)_{\rm MW}$	$\log(n_{\rm HI})_{\rm MW}$	v_r (km/s)	12+ log(O/H)	M_B	Em/Abs[a]
Haro 11	ESO 350–38	00:36:52.5	−33:33:19	0.049	20.4	6175	7.9	−20	Em
SBS 0335−052	SBS 0335-052E	03:37:44.0	−05:02:40	0.047	20.6	4043	7.3	−17	Abs
IRAS 08339+6517	PGC 024283	08:38:23.2	+65:07:15	0.092	20.6	5730	8.7	−21	Em
Tol 65	ESO 380–27	12:25:46.9	−36:14:01	0.074	20.7	2698	7.6	−15	Abs
NGC 6090	Mrk 496	16:11:40.7	+52:27:24	0.020	20.2	8785	8.8	−21	Em
ESO 338–04	Tol 1924-416	19:27:58.2	−41:34:32	0.087	20.7	2832	7.9	−19	Em

Östlin et al. (2009)


Haro 11
SBS 0335-052
ESO 338-IG04
Blue: Lyman α
Red: H α
Green: UV 1500
IRAS 08339+65
Tololo 65
NGC 6090
Östlin et al. (2009)

Local Lyman α emitters: imaging

- The process of image subtraction between both ACS filters (F140LP and F122M) required the development of complex tools (see Hayes et al. 2009).
- One of the most important results has been the discovery of an extended, diffuse component, which contributes to a significant fraction of the total Lyman α emission.

More details on Lyman α imaging results will be provided in next talk by G. Östlin.

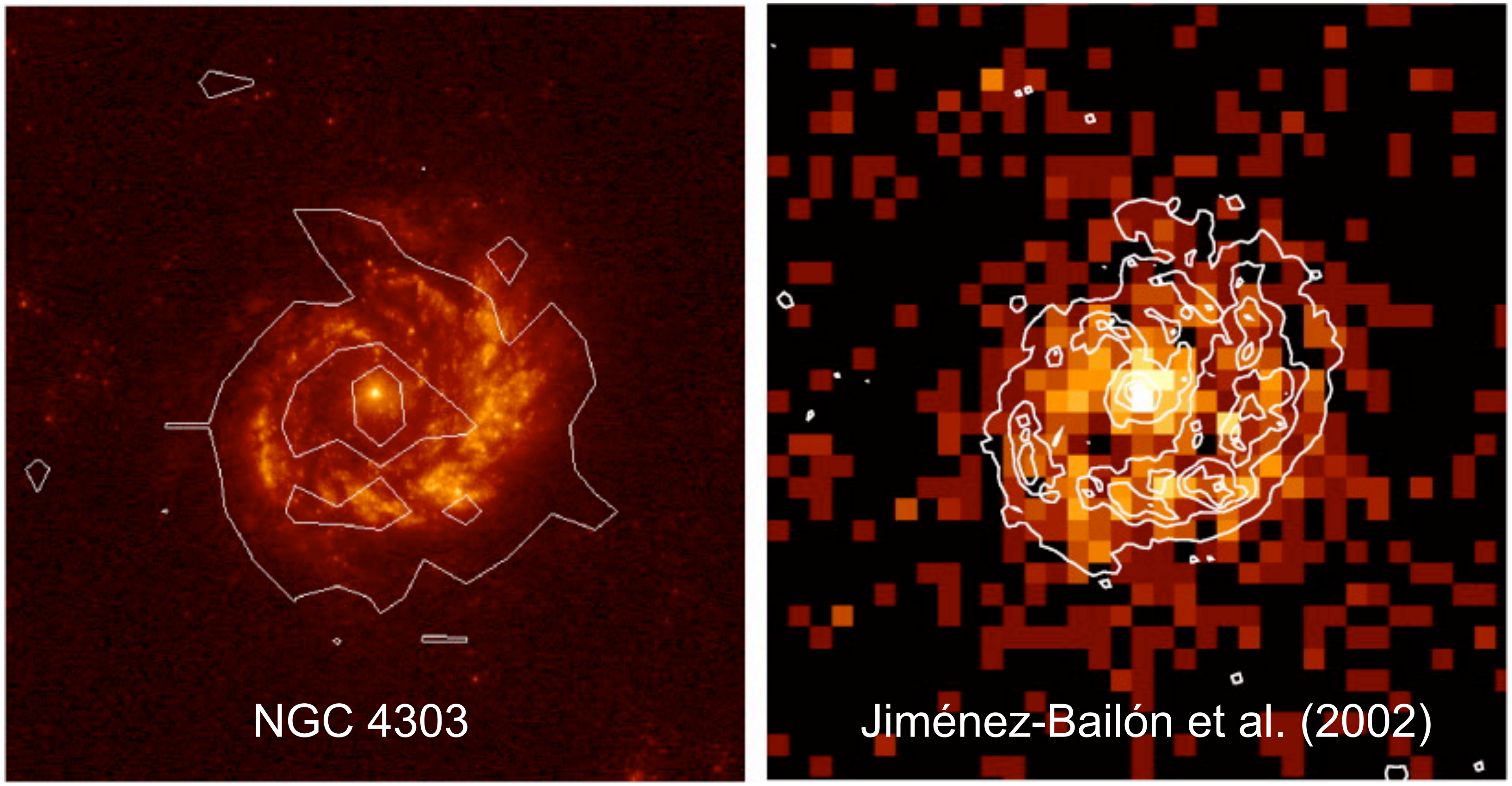
Local Lyman α emitters: high energy emission

- Since Lyman α emission is associated with the presence of massive outflows, it is expected that Lyman α emitters should be relatively strong X-ray sources.

- An ongoing study with Chandra and XMM-Newton shows that this is indeed the case.

Local Lyman α emitters: high energy emission

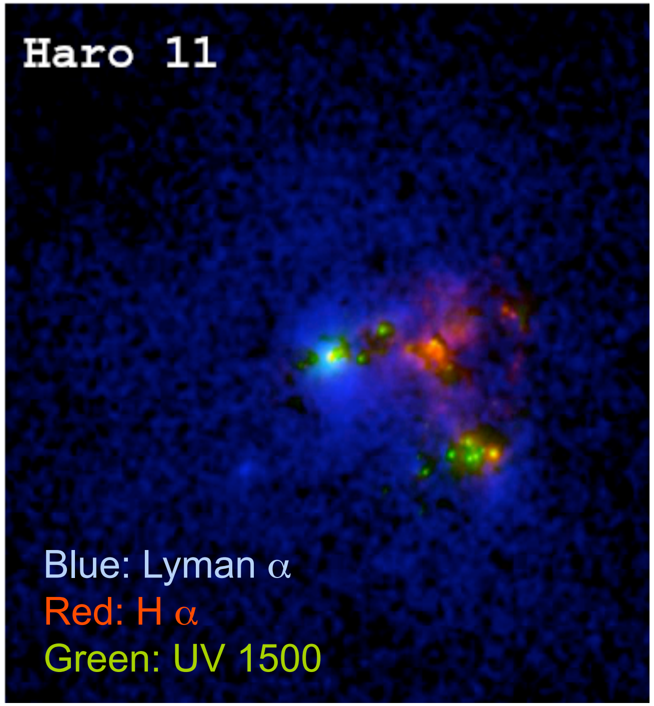
HST/STIS FUV + Chandra contours | Chandra + STIS FUV contours

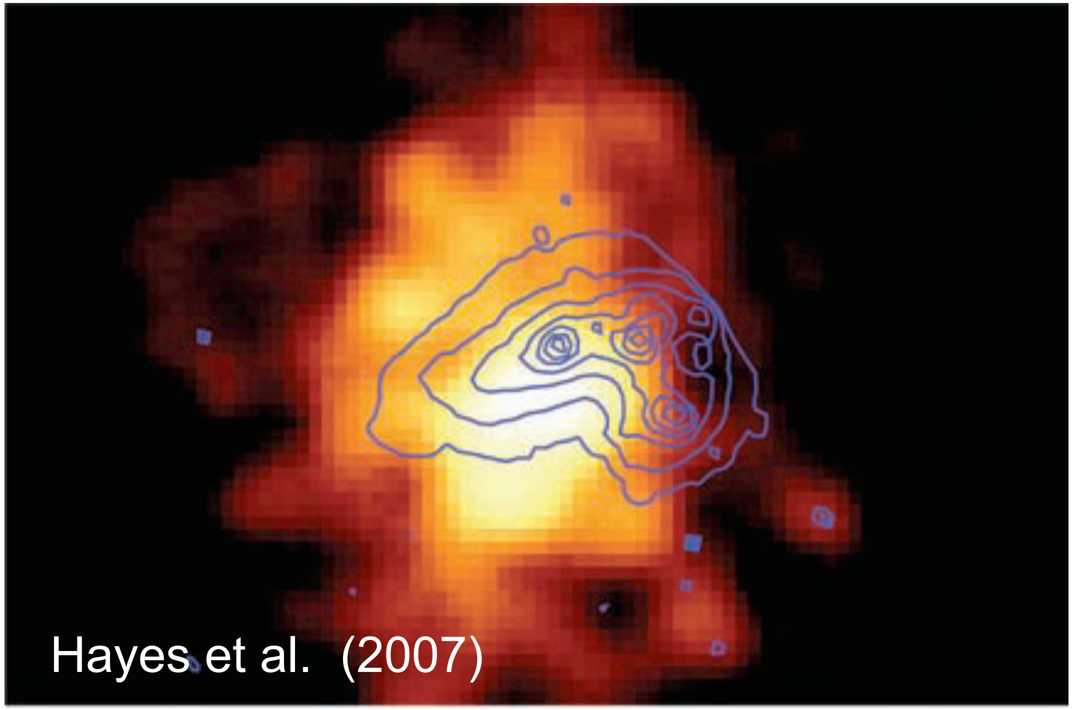


X-ray emission distribution follows the location of the star formation knots.

Local Lyman α emitters: high energy emission

Chandra 0.3-8 keV + ACS FUV contours

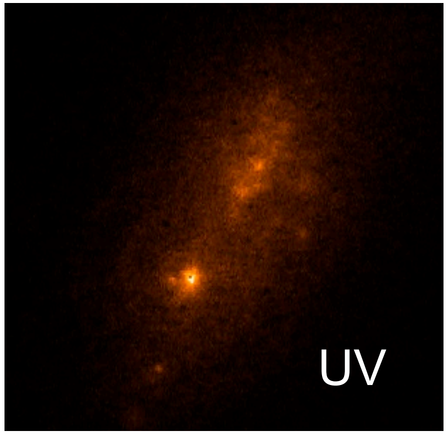


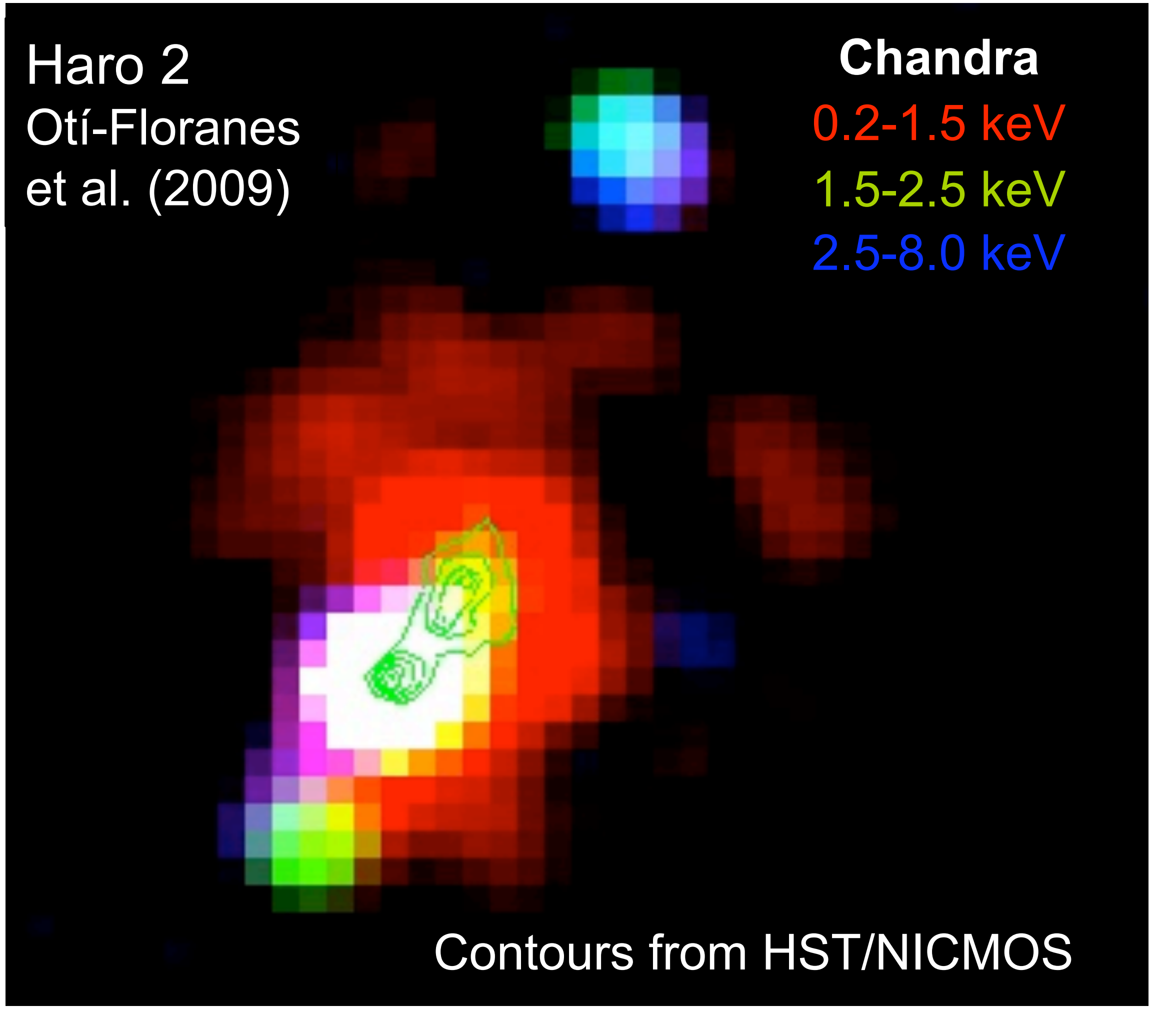


Extended X-ray emission, spreading from the knots of star formation.

Local Lyman α emitters: high energy emission

- In Haro 2, a thermal (red) component is centered on the older burst (NW B).
- There are evidences of young massive binaries and or Supernova remnants in knot SE.





Local Lyman α emitters: high energy emission

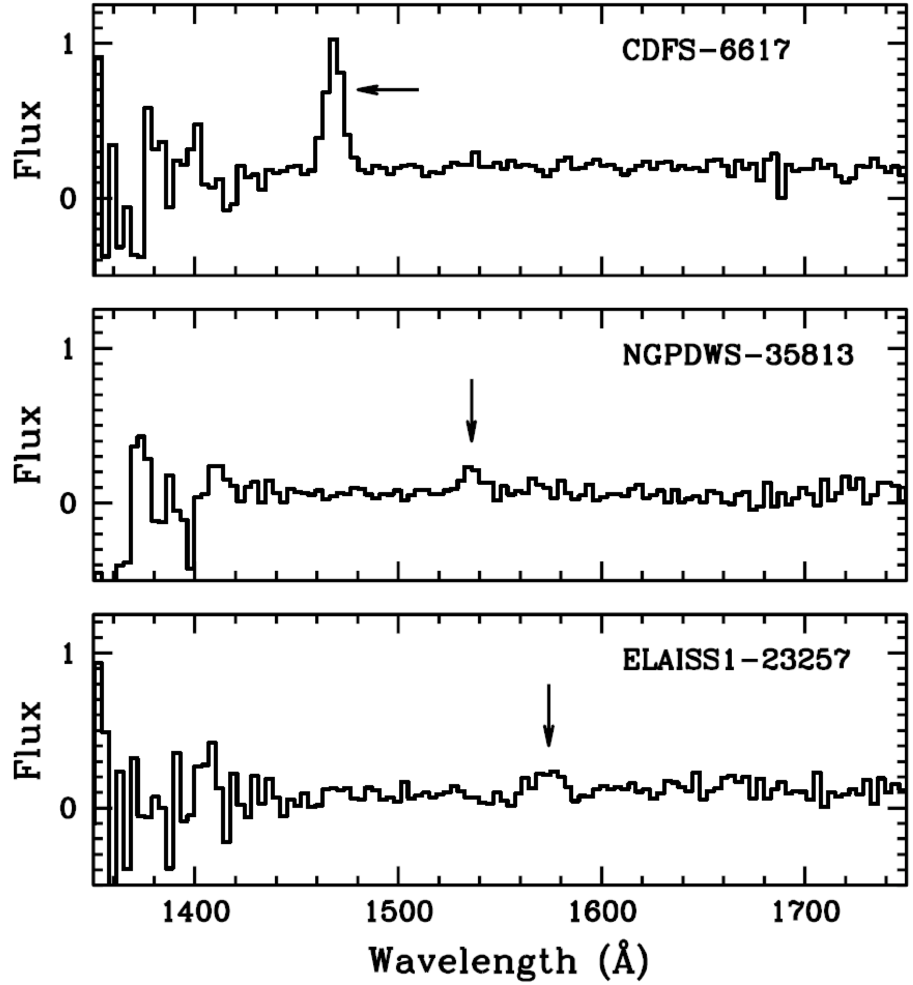
- The X-ray observations demonstrate the presence of a very turbulent interstellar medium in Lyman α emitters.
- There might be a trend showing diffuse Lyman α emission from the same locations where diffuse, soft (thermal) X-rays are produced.

Local Lyman α emitters: bridging the gap to high z

- Deharveng et al. (2008) have studied a sample of 66 Lyman α emitting star-forming galaxies in the redshift range z ~ 0.2 – 0.35.

Local Lyman α emitters: bridging the gap to high z

Examples of spectra of different quality.

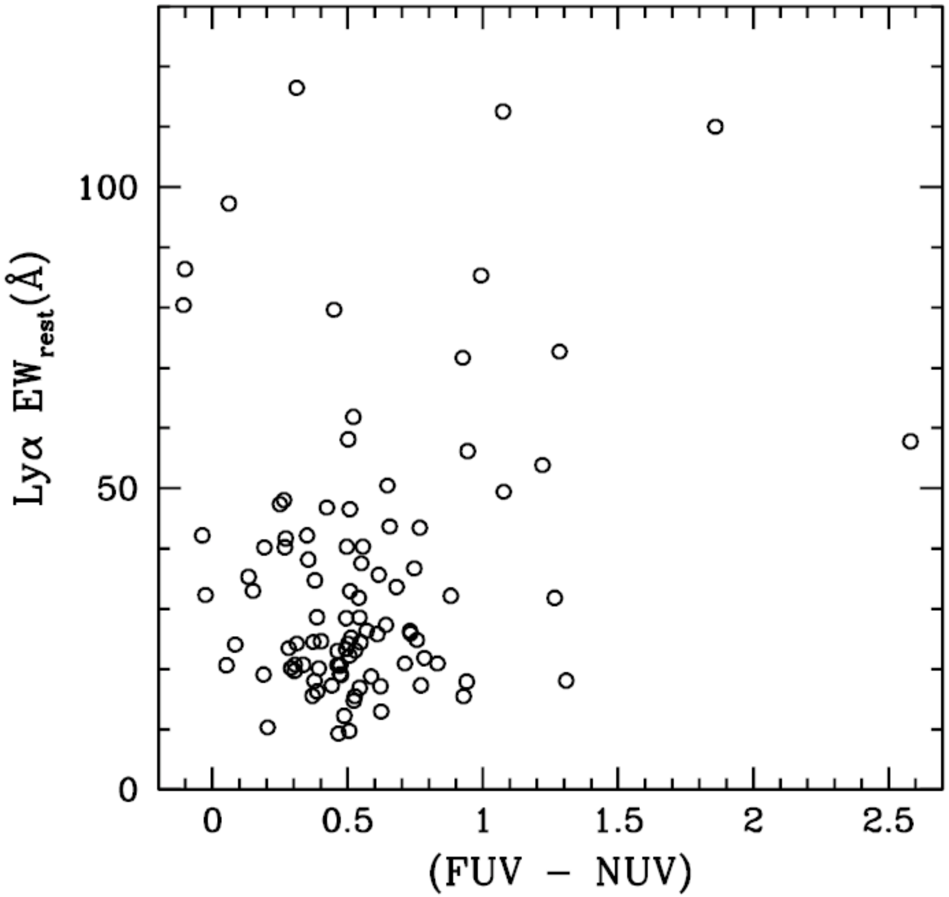


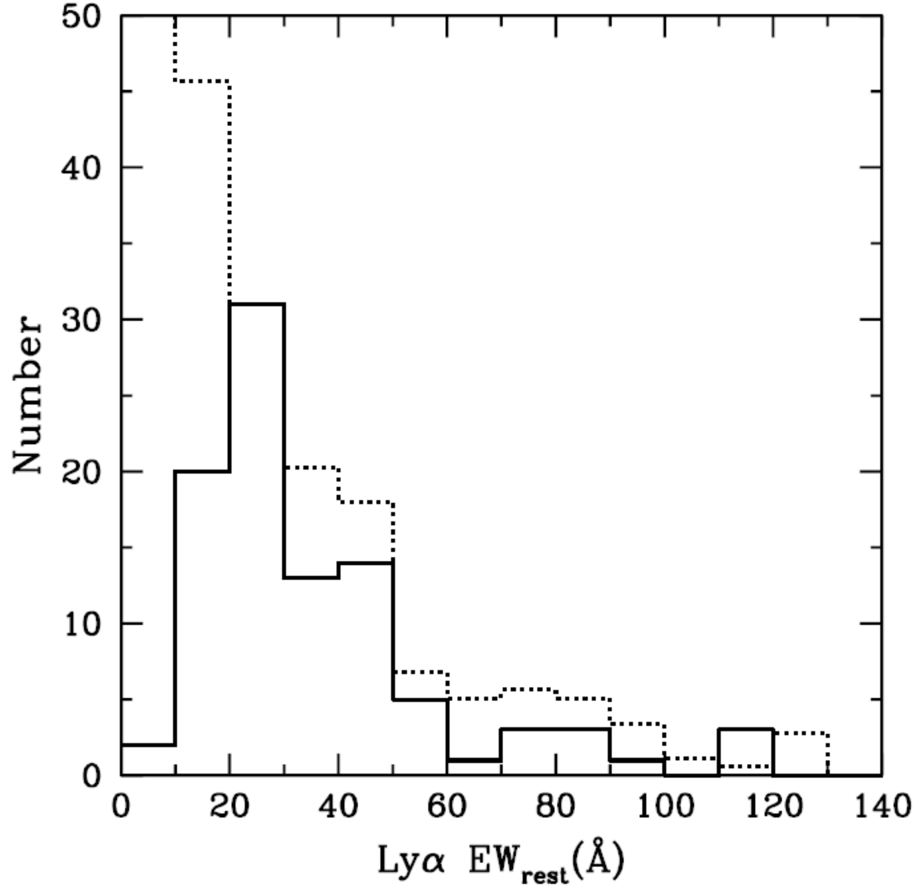
Deharveng et al. (2008)

Local Lyman α emitters: bridging the gap to high z

- Deharveng et al. (2008) have studied a sample of 66 Lyman α emitting star-forming galaxies in the redshift range z ~ 0.2 – 0.35.
- They found no trend between EW (Lyα) and the UV continuum reddening
  - *Decoupling of reddening affecting line and continuum photons.*
  - *EW (Lyα) peaks at around 30 Å.*

Local Lyman α emitters: bridging the gap to high z





Deharveng et al. (2008)

Local Lyman α emitters: bridging the gap to high z

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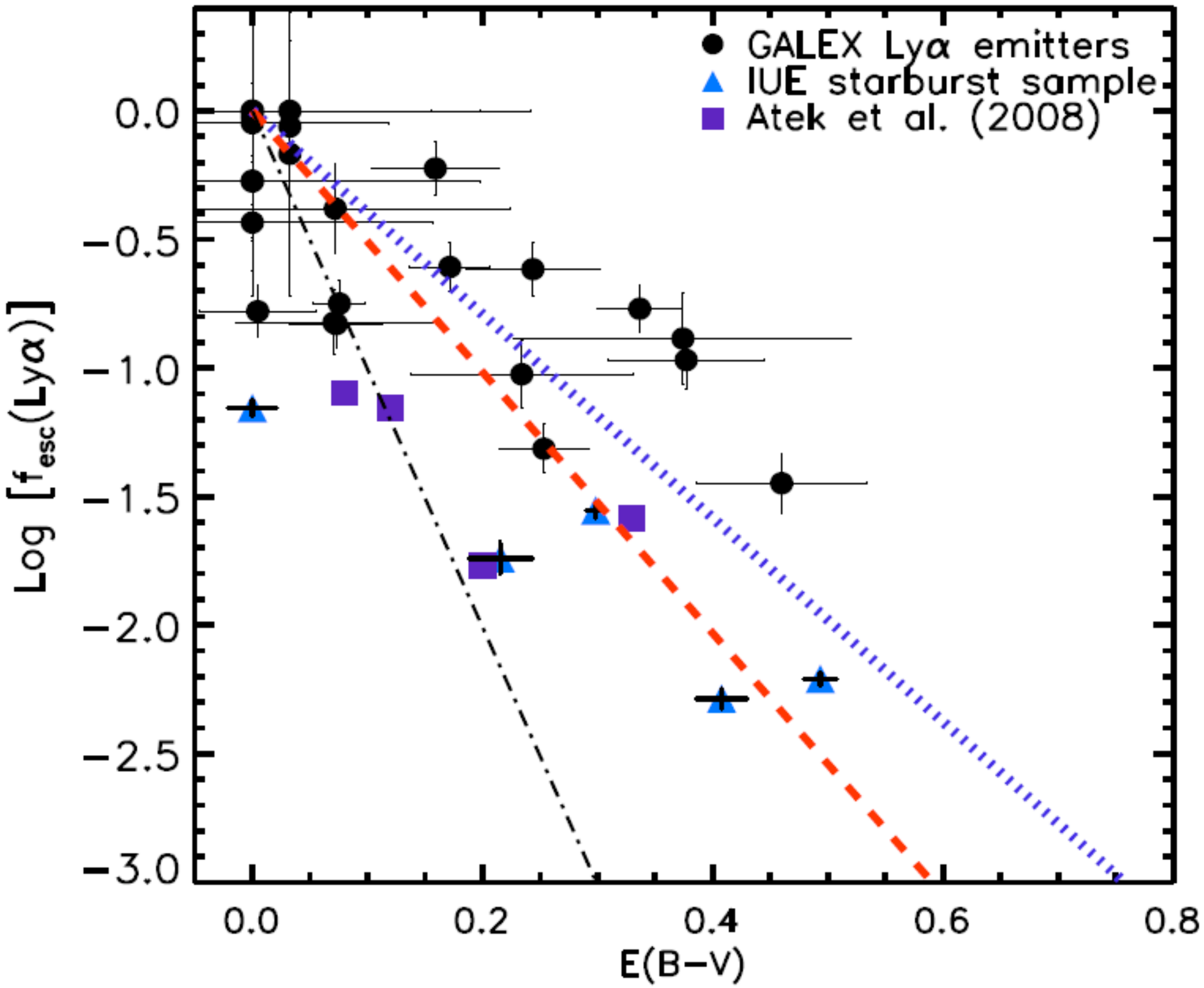
- They found no trend between EW (Lyα) and the UV continuum reddening
  - *Decoupling of reddening affecting line and continuum photons.*
  - *EW (Lyα) peaks at around 30 Å.*
- The Lyman α escape fraction spans a large range of values (~0 to ~100%).
  - *In the Local Universe the escape fraction is always below 14% (Östlin et al 2009).*

Local Lyman α emitters: bridging the gap to high z



Atek et al. (2009, *astroph*)
See poster #1

Lyman α emitters in the Local Universe: Summary

- After 30 years of observations we have got Lyman α spectra for < 30 star-forming galaxies in the Local Universe, thanks mainly to IUE and HST, and Lyman α images of only 6
  - *> 60 have been added by Galex at intermediate redshift.*
- Kinematics of the surrounding neutral gas, porosity of the medium, ionization state of the gas, amount of dust,….. all them play a role in driving the visibility of the line.
  - *The kinematical decoupling of the neutral and ionized gas seems to be the key factor to avoid the destruction of Lyman α emission line photons by resonant trapping in the gas surrounding the starbursts.*

Lyman α emitters in the Local Universe: The future

- Observations of Lyman α emitters in the Local Universe will remain possible only as long as ACS, STIS and COS remain operational on the HST.

- The post-HST era will be a *dark age* for local Universe UV astronomy, unless some ongoing projects mature and become a reality (very specially the World Space Observatory-UV).

- But the window of UV astronomy at redshiftz z > 2 is flourishing!

This Conference is a good example and we'll learn a lot about Lyman α emission at high redshifts.