Local Lyman α emitters and their relevance to high-redshift star-forming galaxies

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on behalf of the Lyman α team:

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Objectives

- Our goal: to study star formation processes in the high-z universe.

- Lyα emission might be used to trace star formation up to very large redshifts.

  - *But for this we need first to understand under which conditions a galaxy shows Lyα in emission!*

- Is the Lyα emission detectable at large z?

  + Brightest H recombination line $W_{Ly\alpha}$ > 100Å (Max $W_{Ly\alpha}$ = 240Å ?).
  + Detectable with ground optical telescopes at z = 2.5 - 6. Cheap!

  $\Rightarrow$ *Lyα should be a very competitive tool (and already proved to be), but its interpretation is not straightforward at all.*

Lyman α: The observational problem

- The Lyα puzzle in nearby starbursts:
  - 1980-90ies: several searches for Lyα emission from z~2-3 primordial galaxies unsuccessful

→ *1 or 2 puzzles: small number of galaxies and/or lower than expected Lyα emission?*

Lyman α: The observational problem

- The Lyα puzzle in nearby starbursts:
  - IUE satellite: UV spectra of nearby starbursts (Lyα) + optical spectra (Hα,Hβ)

→ 1) extinction corrected I(Lyα)/I(Hβ) << case B, and W(Lyα) smaller than expected from synthesis models.

(Meier & Terlevich 1981, Hartmann et al. 1984, Deharveng et al. 1986,… Giavalisco et al. 1996)

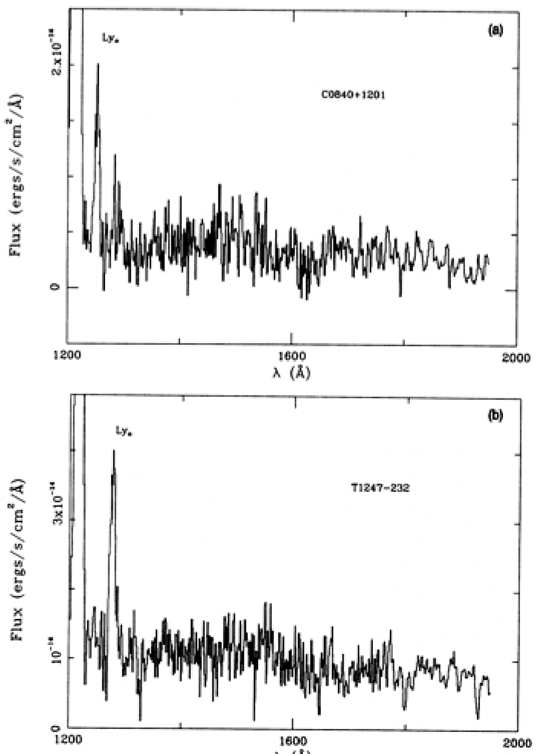
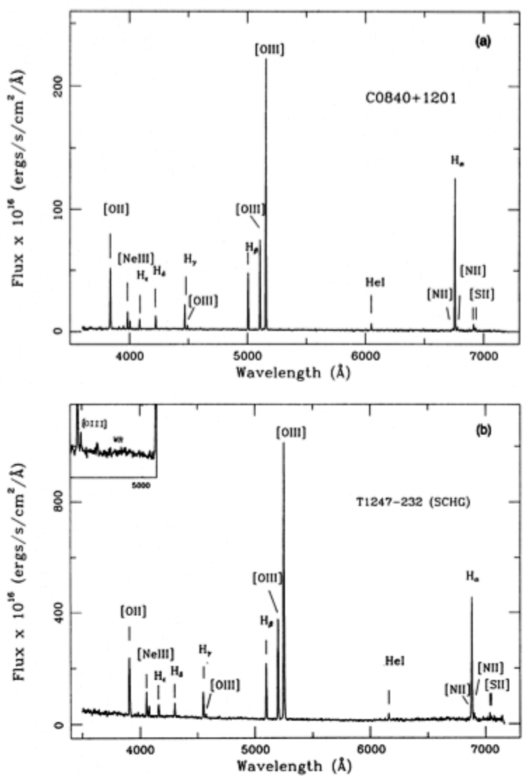
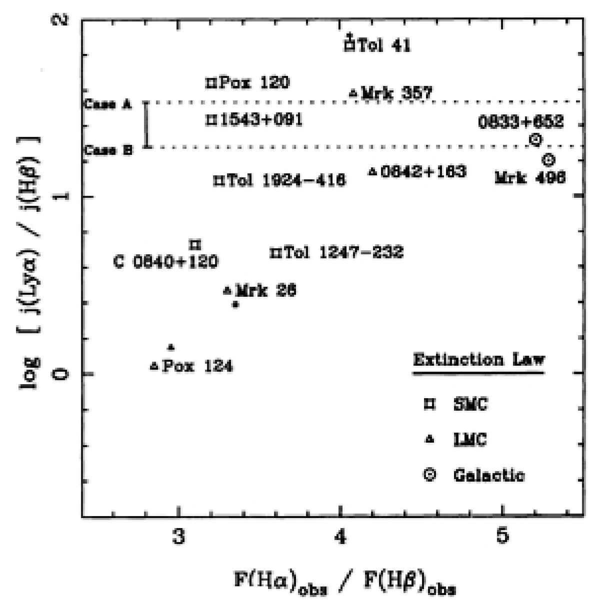


Figure 1. (a) UV spectrum SWP35814 of C0840 + 1201. (b) UV spectrum SWP35685 of T1247 − 232.





Terlevich et al. (1993)

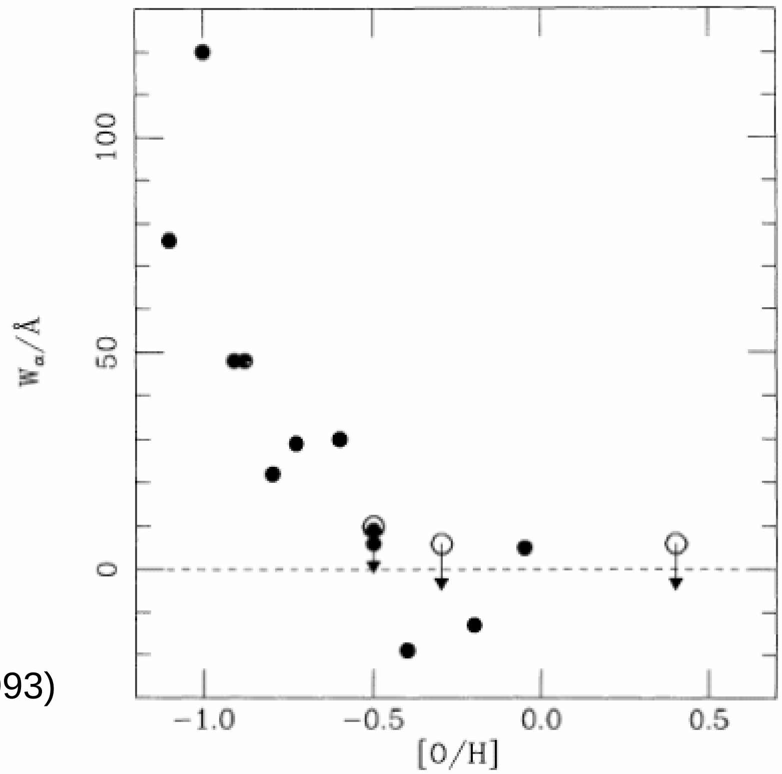
Valls-Gabaud (1993)

Lyman α: The observational problem

- The Lyα puzzle in nearby starbursts:
  - IUE satellite: UV spectra of nearby starbursts (Lyα) + optical spectra (Hα,Hβ)

→ 1) extinction corrected I(Lyα)/I(Hβ) << case B, and W(Lyα) smaller than expected (synthesis models).

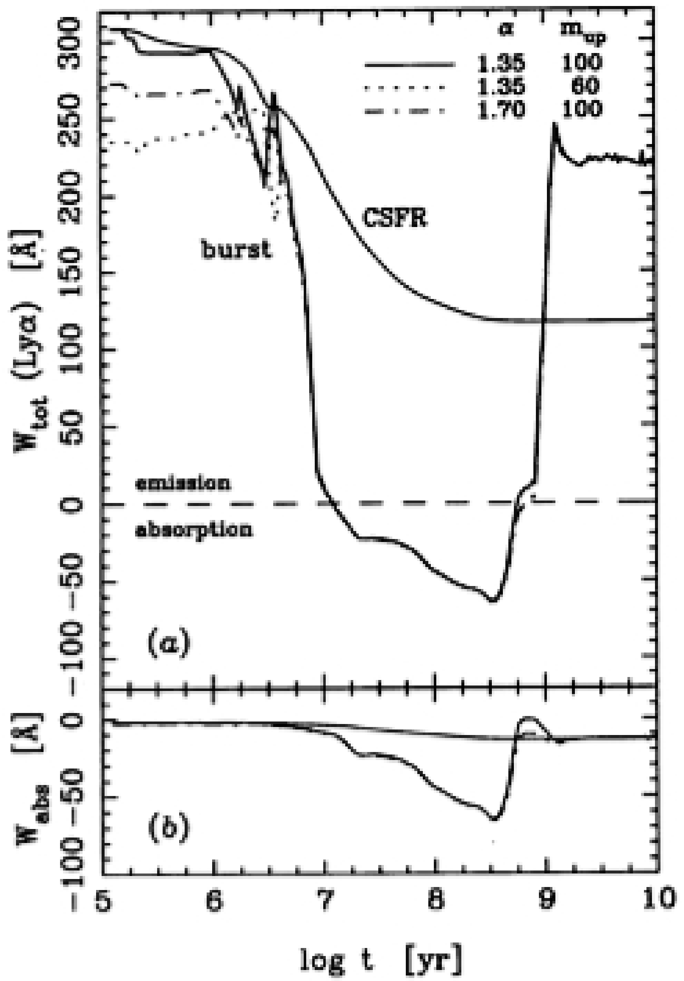
→ 2) Trends with metallicity (O/H)? Claimed by Charlot & Fall (1993), but not confirmed by other authors.



Charlot & Fall (1993)

Lyman α: The observational problem

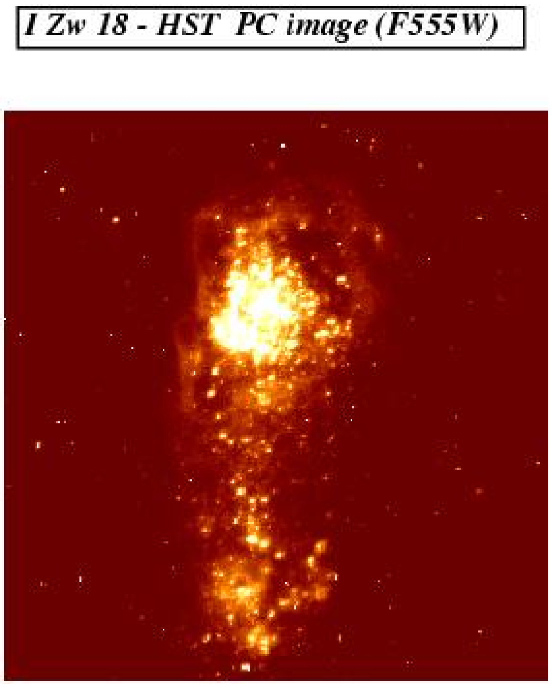
- The Lyα puzzle in nearby starbursts. Possible explanations:
  - Dust (Charlot & Fall 1993).
  - With « appropriate » (metallicity-dependent) extinction law “no problem”.
  - The underlying stellar Lyα absorption could be responsible for the low intensity of the line (Valls-Gabaud 1993).
  - Inhomogeneous ISM geometry could be the primarily determining factor, not the dust (Giavalisco et al. 1996).
  - Short « duty cycle » of SF might explain small number of Lyα emitters

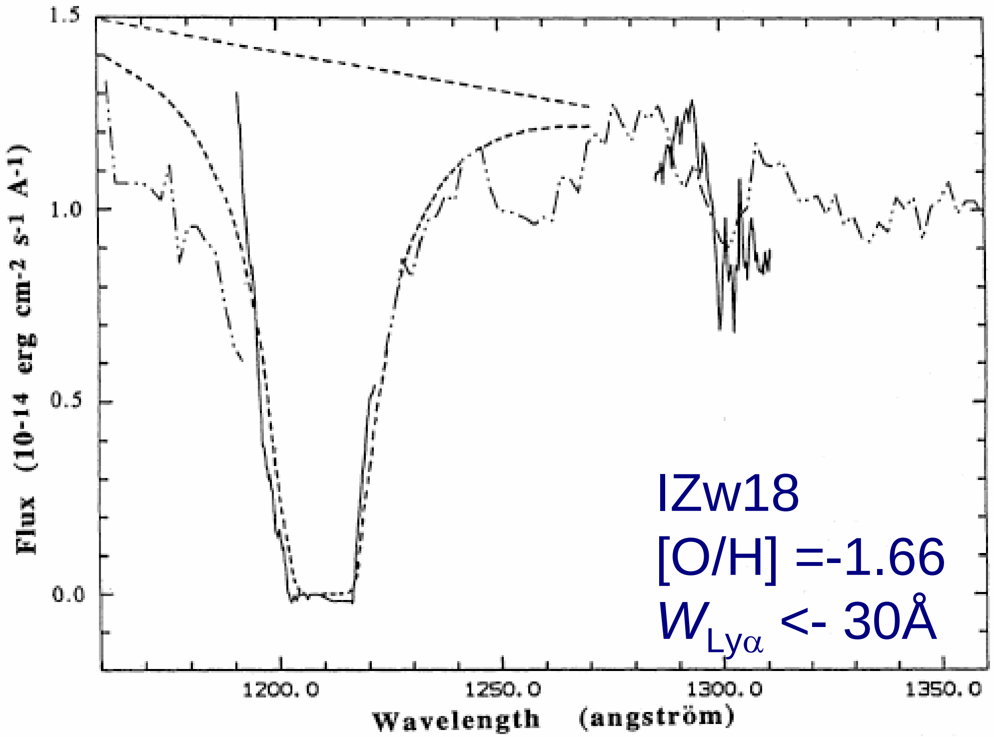


Lyman α: The observational problem

- The Lyα puzzle in nearby starbursts.
  - The HST era: high resolution spectra of the Lyα profiles.

  → 1) Very low metallicity / dust deficient galaxies, like IZw18, didn't show Lyα in emission, but a broad dumped absorption profile.



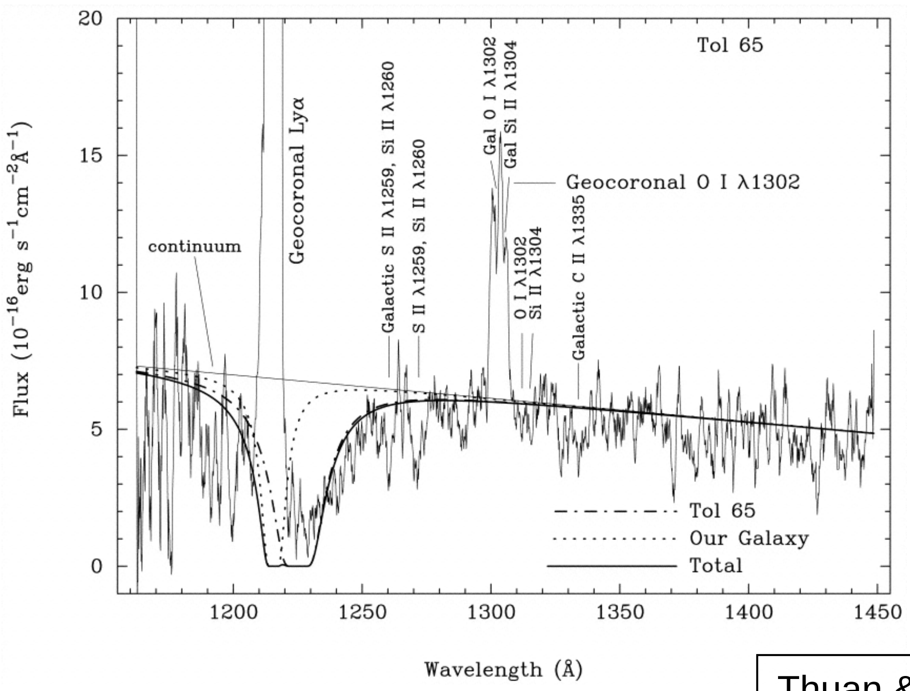


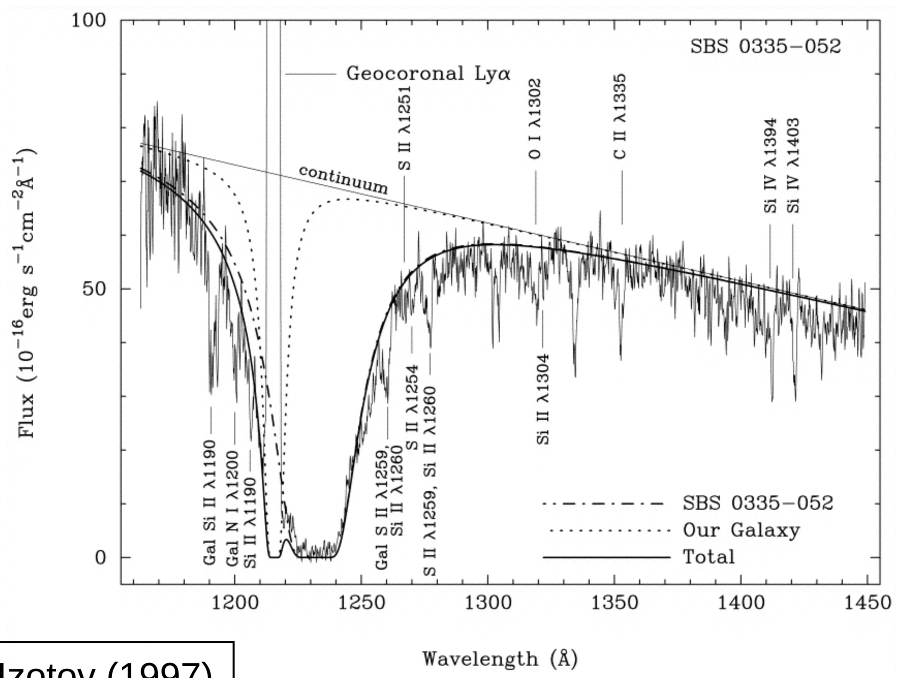
Kunth et al. (1994)

Lyman α: The observational problem

Tololo 65
[O/H] =-1.34
$W_{Ly\alpha}$ < -30Å

SBS 0335-052
[O/H] =-1.5
$W_{Ly\alpha}$ < -30Å





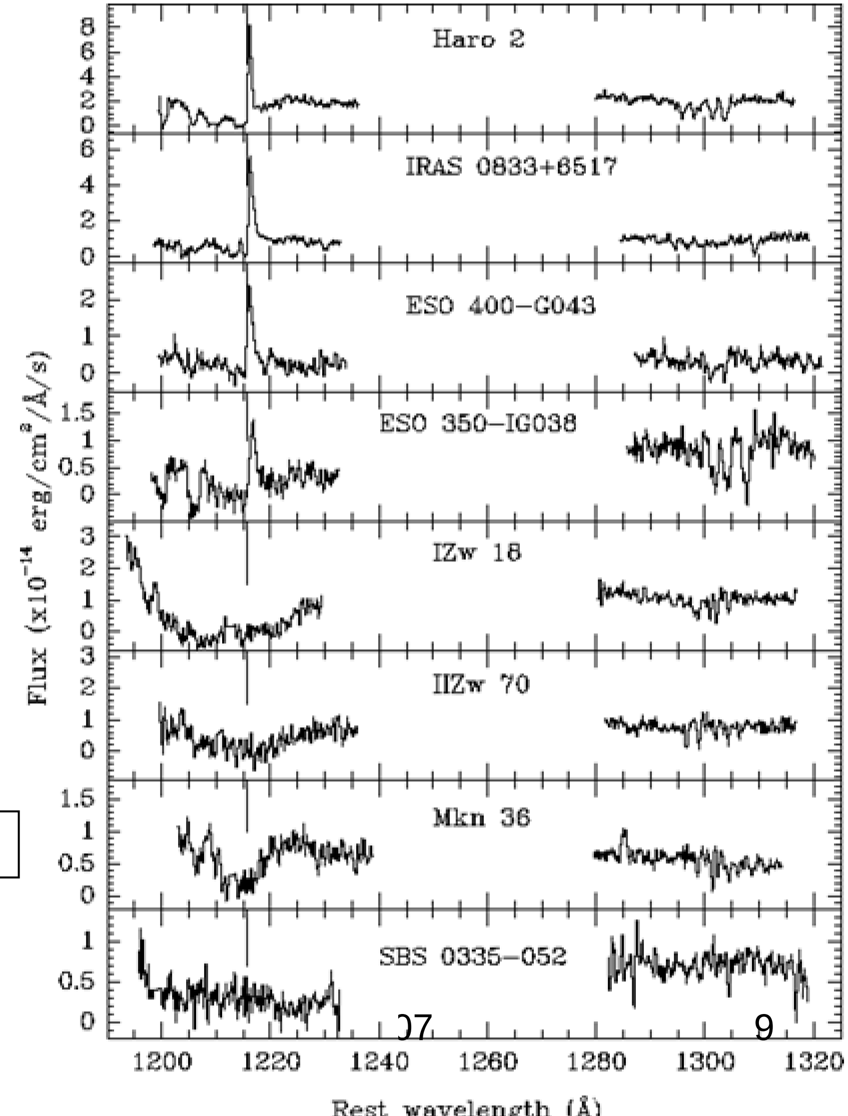
Thuan & Izotov (1997)

Lyman α: The observational problem

- The Lyα puzzle in nearby starbursts.
  - The HST era: high resolution spectra of the Lyα profiles.

→ 2) Lessons from GHRS-STIS studies:

+ Variety of profiles with no clear correlation to other previously assumed parameters:
  O/H, dust, mass,…….



Mas-Hesse et al. (2003)

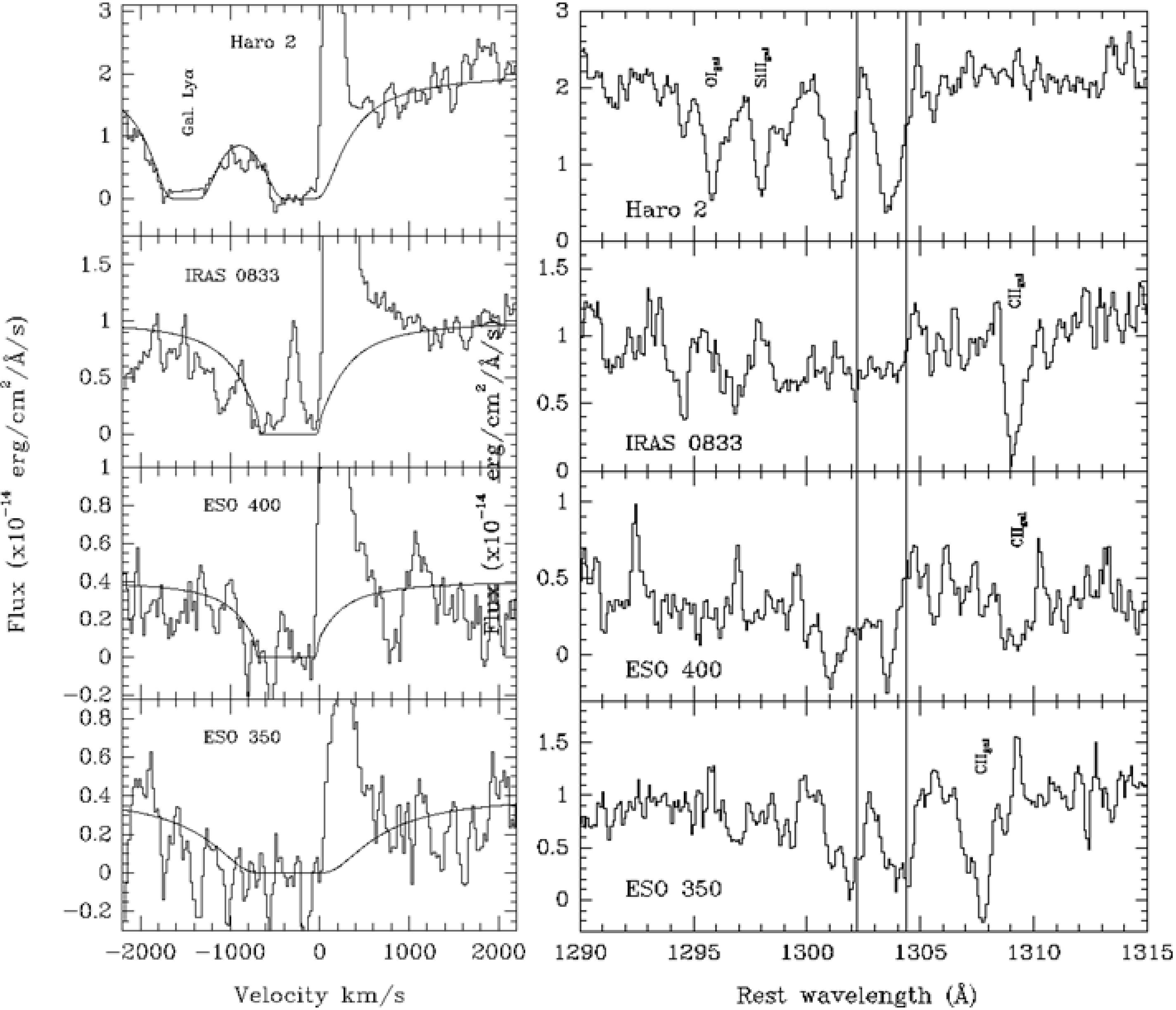
Lyman α: The observational problem

- The Lyα puzzle in nearby starbursts.
  - The HST era: high resolution spectra of the Lyα profiles.

→ 2) Lessons from GHRS-STIS studies:

+ Detection of neutral gas outflows with v ~ 200-300 km/s in 4 galaxies showing Lyα in emission.
+ Emission generally showing a clear P Cyg profile.

Lyman α: The observational problem



Haro 2
$Z \sim 0.4\ Z_0$
$W_{Ly\alpha} = 13$
v=200km/s

IRAS 08339
$Z \sim 0.55\ Z_0$
$W_{Ly\alpha} = 34$
v=200km/s

ESO 400
$Z \sim 0.15\ Z_0$
$W_{Ly\alpha} = 20$
v=220-250 km/s

Haro 11
$Z \sim 0.1\ Z_0$
$W_{Ly\alpha} = 37$
v=200-300 km/s

Lyman α: The observational problem

- The Lyα puzzle in nearby starbursts.
  - The HST era: high resolution spectra of the Lyα profiles.

→ 2) Lessons from GHRS-STIS studies:

+ Detection of neutral gas outflows with v ~ 200-300 km/s in 4 galaxies showing Lyα in emission.
+ Emission generally showing a clear P Cyg profile.
+ Only 1 case found with a pure emission line.
+ The galaxies with no outflows showed dumped absorptions.

→ *Outflows and superwinds might be the main crucial/determining factor for Lyα escape!?*

Lyman α: The observational problem

- The Lyα puzzle in nearby starbursts.
  - The HST era: high resolution images of Lyα emission.

→ 3) Lessons from ACS/SBC studies:

+ We performed a pilot study of 6 nearby starburst galaxies of different morphologies, properties and Ly α profiles.

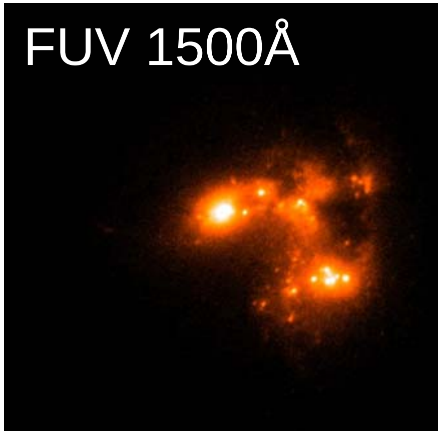
+ Combining ACS/HST imaging in Lyα + narrow continuum filter with WFPC2/HST images in 5 other filters we were able to remove the effects of stellar population, UV slope …

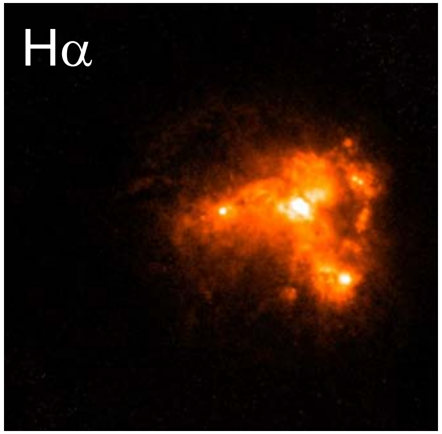
→ Diffuse Lyα emission detected and mapped!

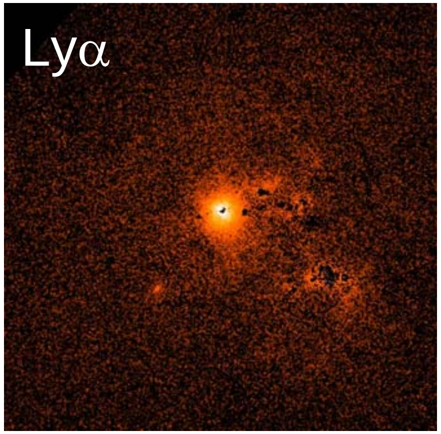
Diffuse emission can account in some cases for 2/3 of total flux in large apertures (IUE…)

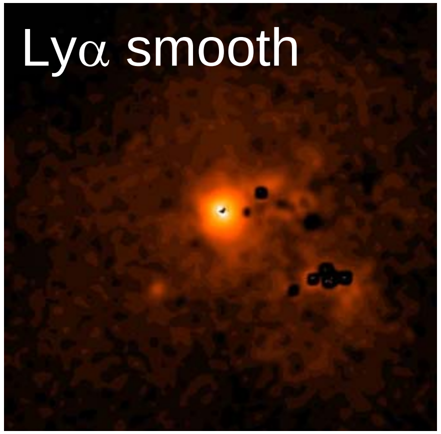
→ Confirmation of Lyα resonant scattering halo!

Results: Haro 11



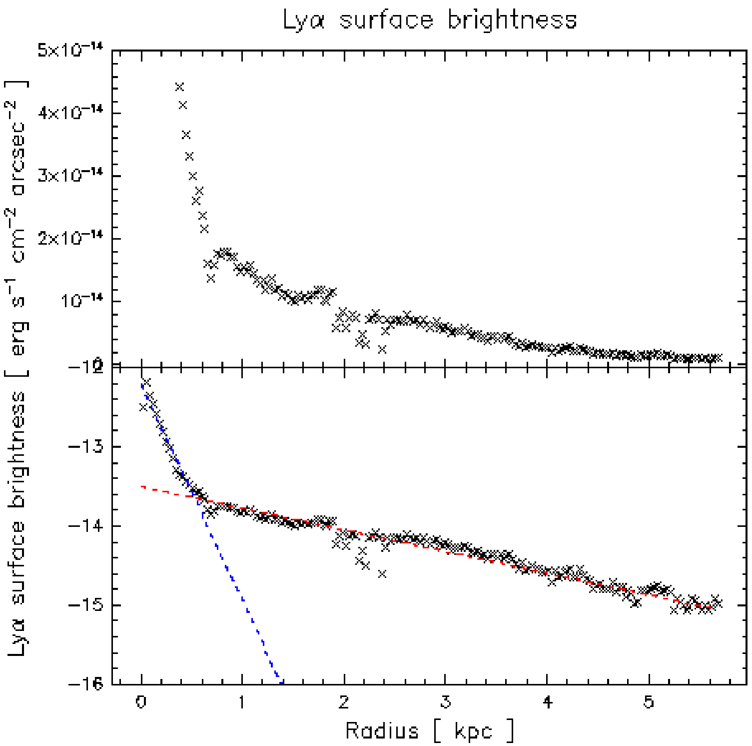




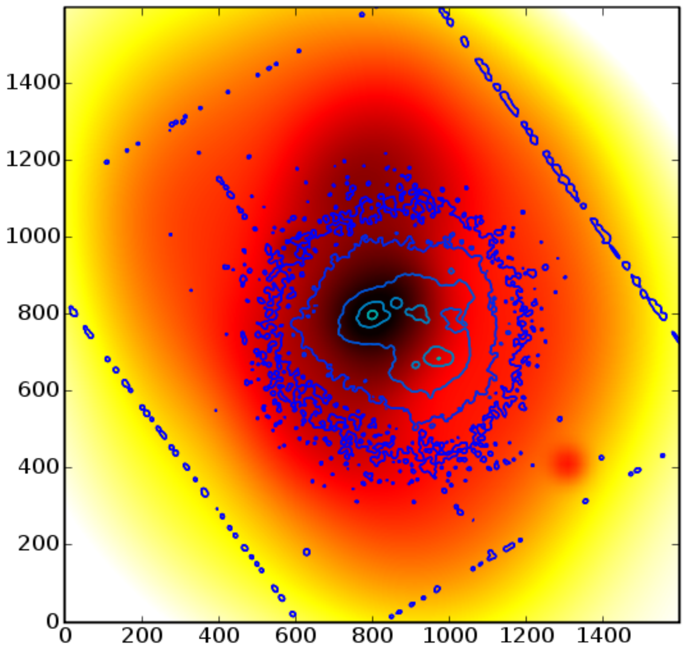


Luminous blue compact galaxy
SFR ~$20 M_0$/yr

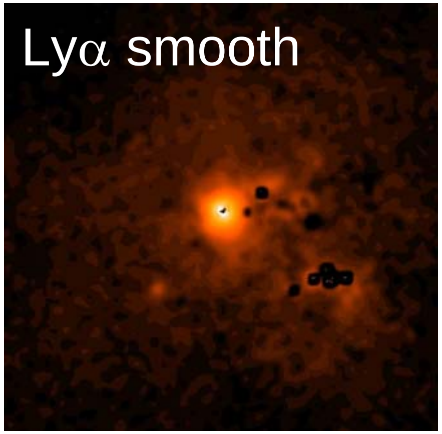
- Brightest UV knot NOT brightest in Hα
- Lyα largely uncorrelated with Hα and UV
- Lyα driven by singe star-forming knot
- Large diffuse, symmetric Lyα halo
- 80% in diffuse component
- Total escape fraction ~8% assuming case B
- LyC escape fraction also 8%



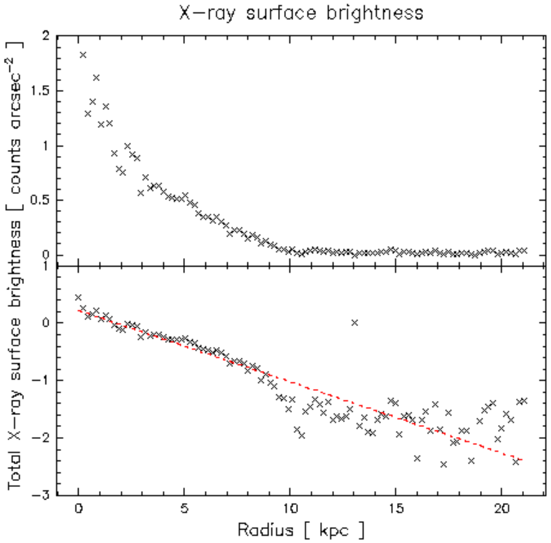
Results: Haro 11

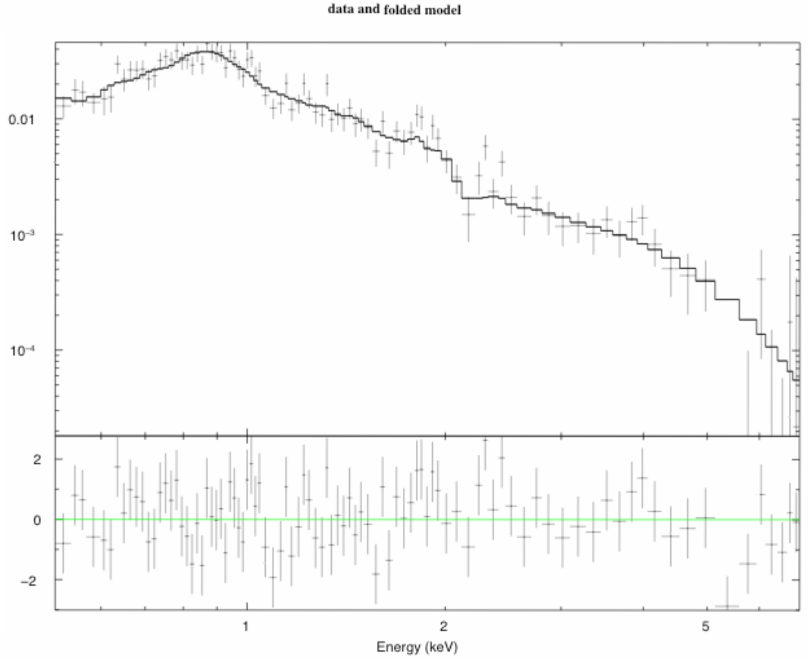


- 1500 Å contours on Chandra 0.2-10 keV.
- Emission associated to the knot emitting Lyα.
- Outflowing hot gas in diffuse X-ray ~30kpc (MEKAL kT~8 × 10^6K)
- Supports Lyα emission visibility associated to the presence of winds.

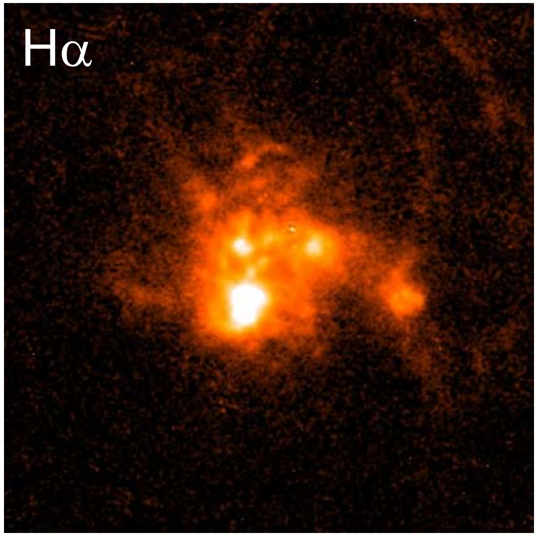


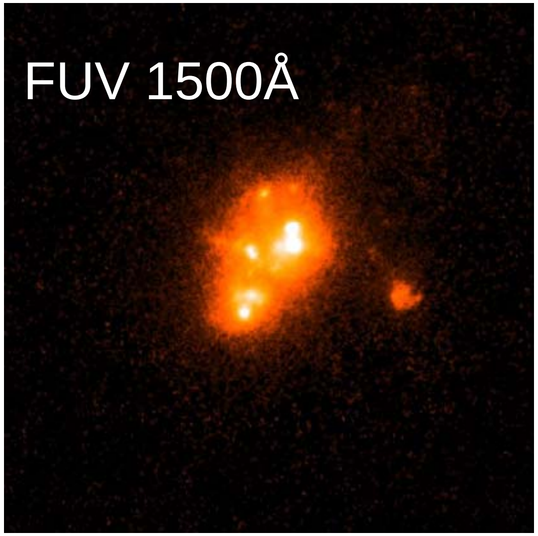
May 30th, 2007

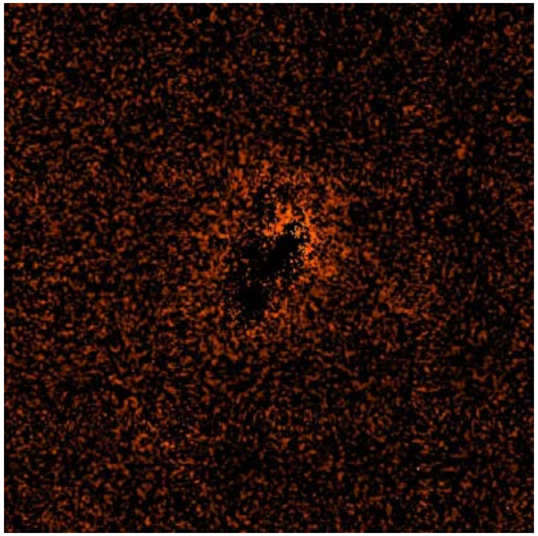




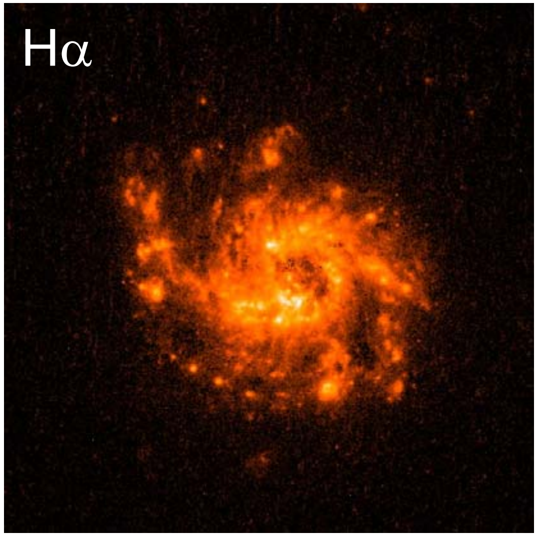
Results: SBS 0335-052

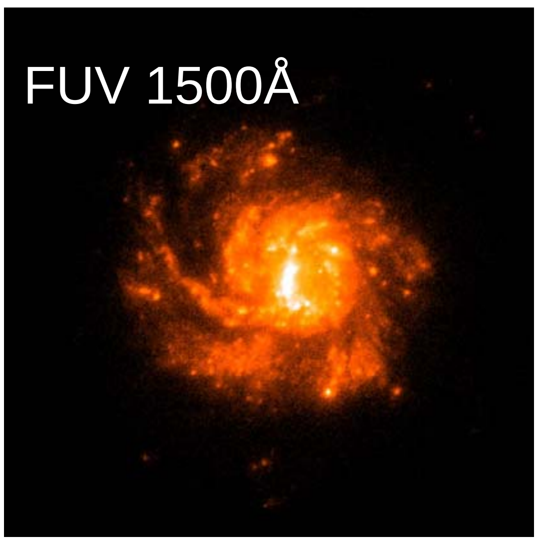


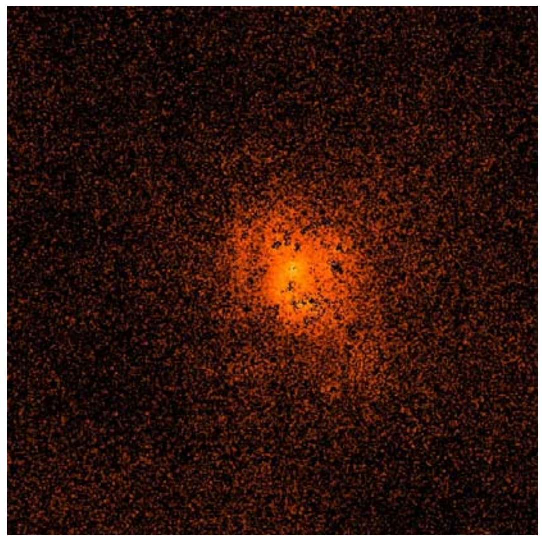


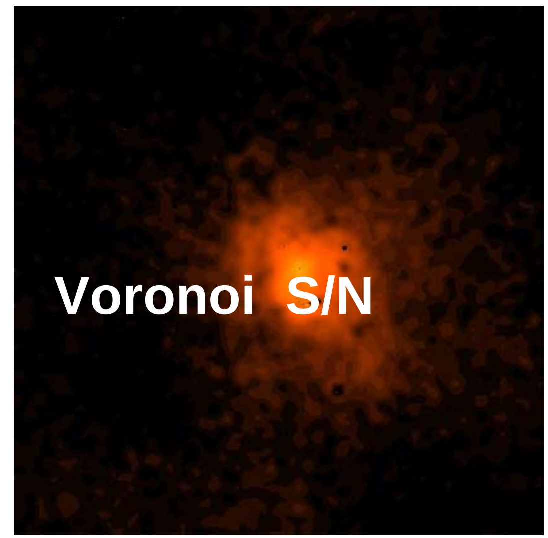


Results: IRAS 08339+65

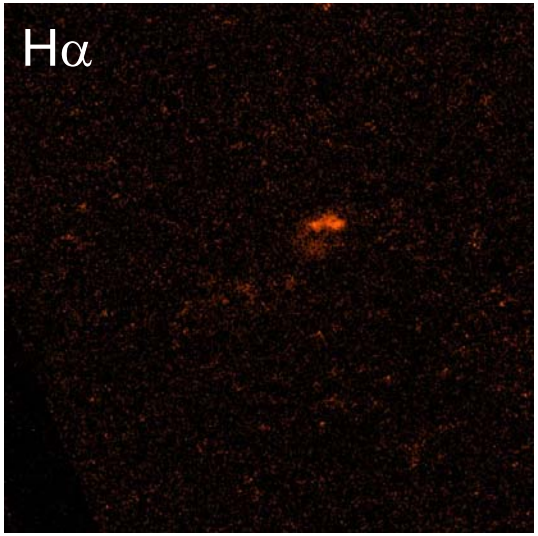


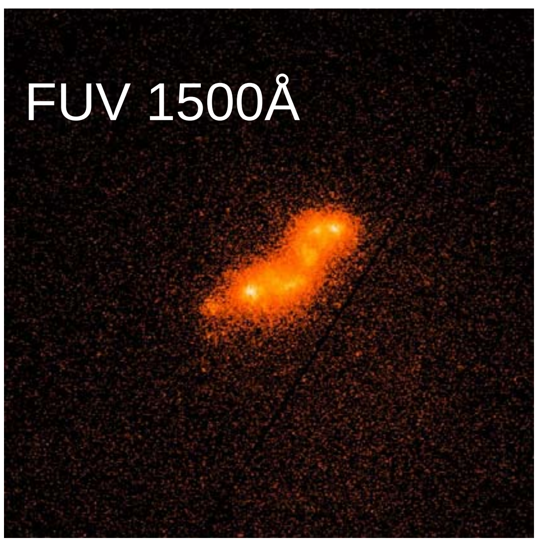


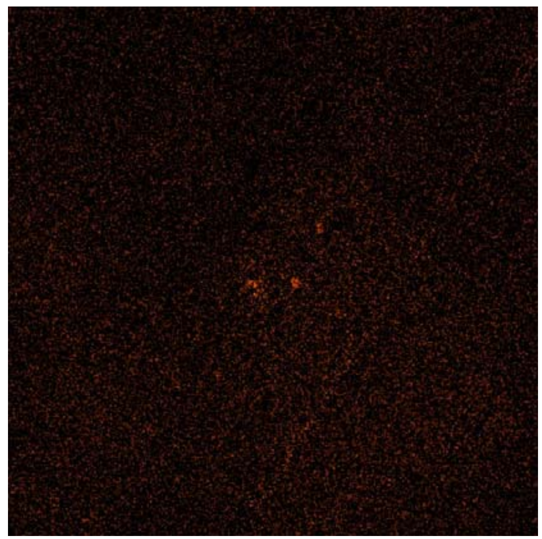




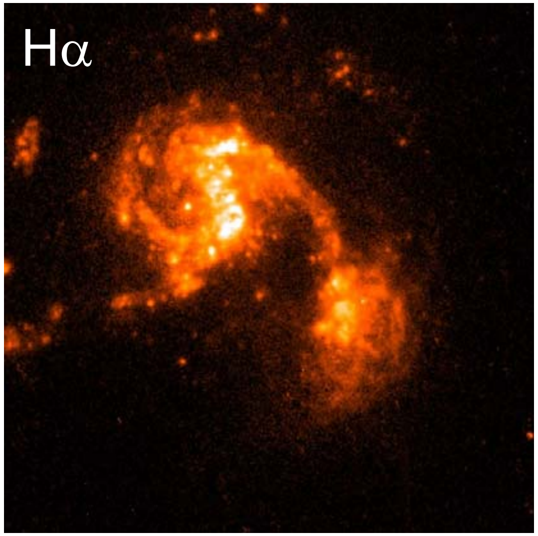
Results: Tololo 65

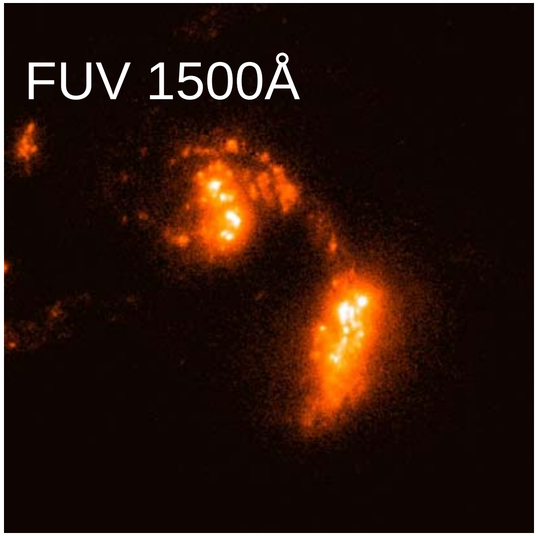


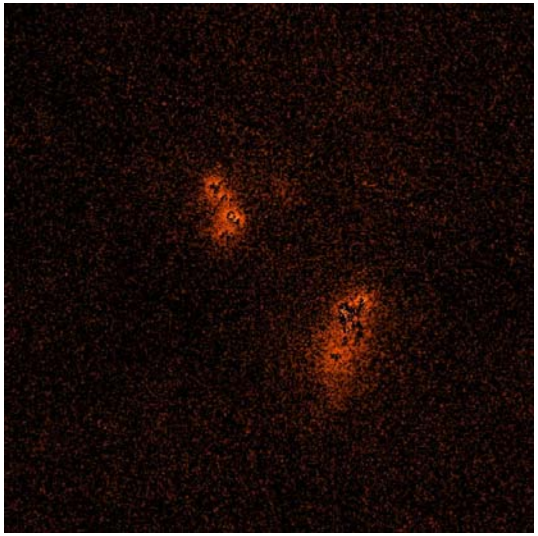




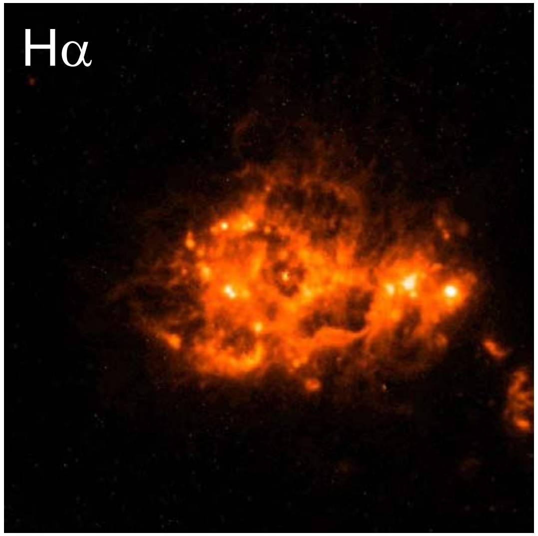
Results: NGC 6090

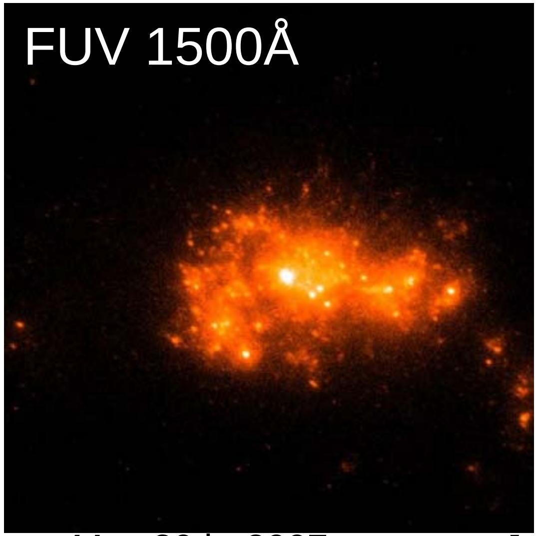


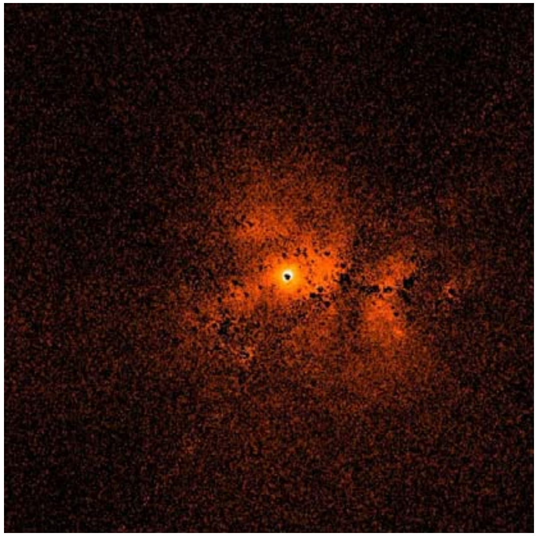




Results: ESO 338-IG04







Overview of local sample

- Hand-picked pilot study. Six galaxies only -- not statistically significant.
- Max escape fraction just ~6% !
- Least dusty and lowest *Z*: *only* net absorber

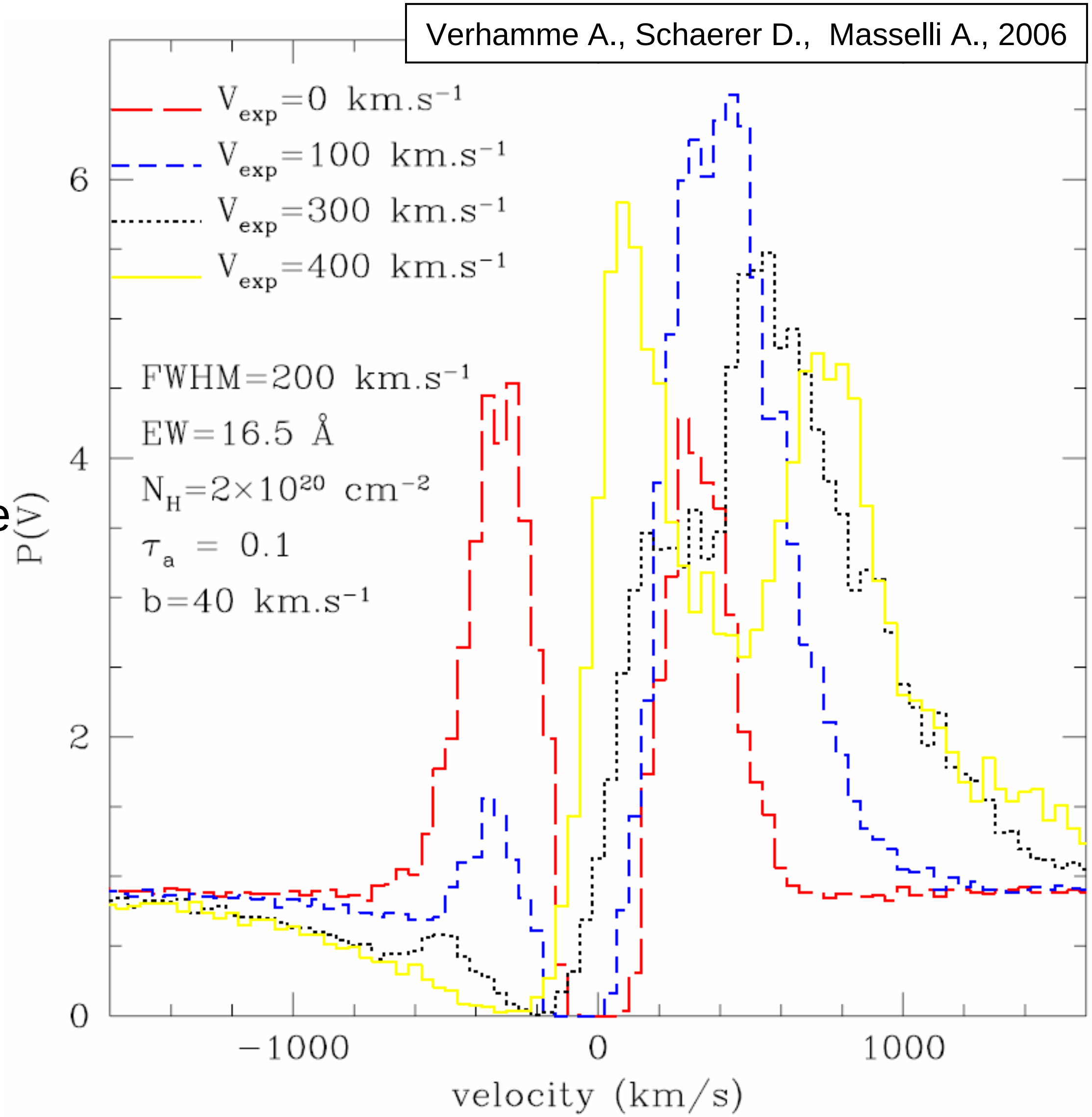
  Highest *EW(Lya)* in the dustiest, highest *Z* galaxy.

Name	M_B	O/H	Log FUV	*EW* (Hα)	*EW* (Lyα)	f_{Esc} (Lyα)
Haro 11	–20	7.9	10.2	663	18.8	0.035
SBS 0335-52	–17	7.3	9.1	1455	–11.3	<0
IRAS 08+65	–21	8.7	10.0	200	21	0.036
Tol 65	–15	7.6	8.3	74	2.4	0.005
NGC6090	–21	8.8	9.9	328	54	0.039
ESO338–04	–19	7.9	9.6	2383	23	0.057

Modelling the properties of the Lyman α profile

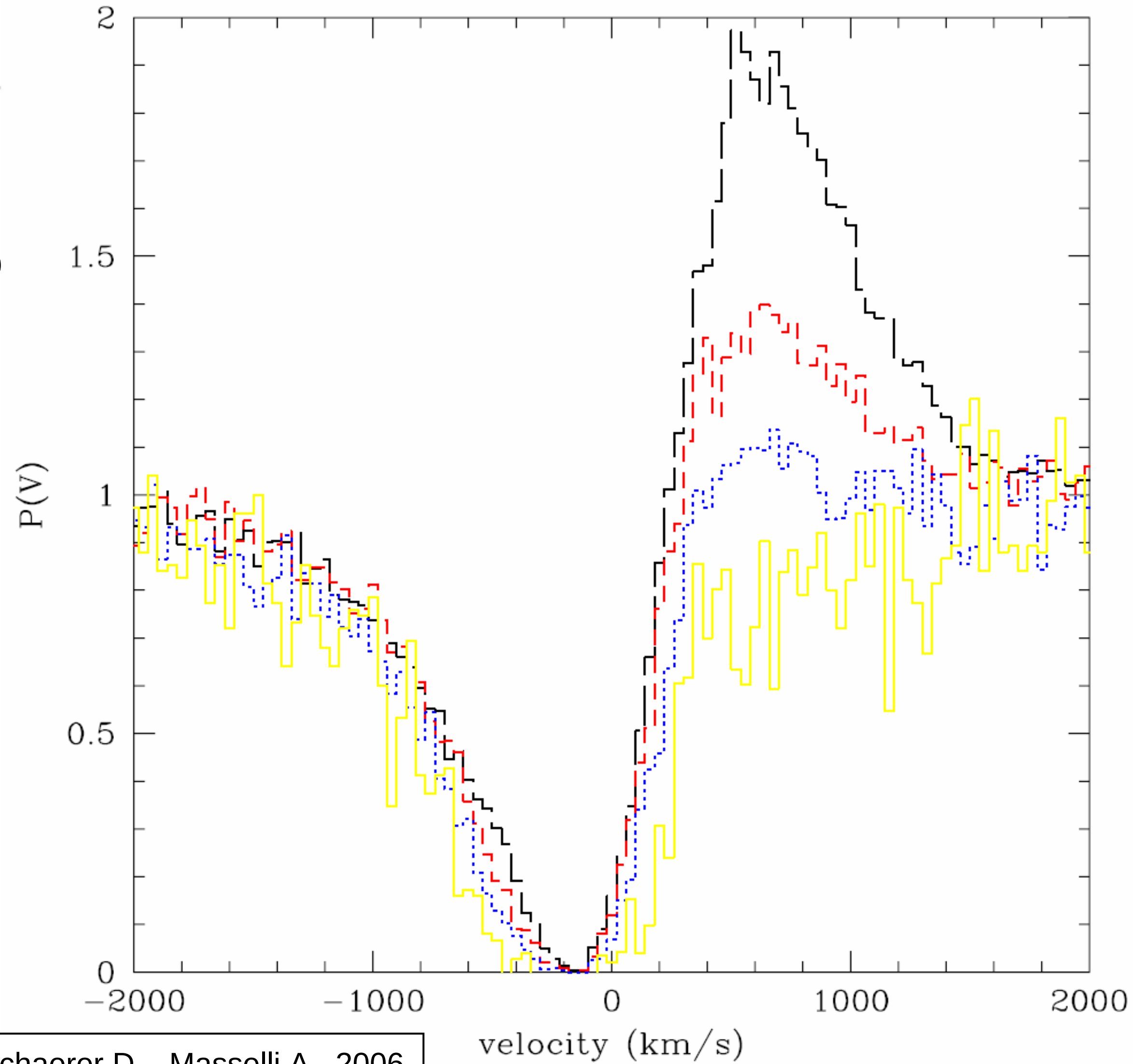
- Verhamme et al (2006) presented a grid of consistent models of the Lyα profiles produced by an expanding shell surrounding a star formation region, as a function of the physical properties of the expanding gas.
- Depending on the velocity of the shell, the emission profile might appear (with no dust):
  - Double peaked (Vexp = 0).
  - P Cyg with redshifted emission peak (Vexp = 100-300 km/s).
  - P Cyg with double, redshifted emission peaks (Vexp > 400 km/s).

Verhamme A., Schaerer D., Masselli A., 2006



Modelling the properties of the Lyman α profile

- But even small amounts of dus destroy the scatered photons and yield profiles ranging from estándar P Cyg ones (black) to pure, blueshifted absorbtion (yellow).



Verhamme A., Schaerer D., Masselli A., 2006

Lyman α: lessons from local starbursts

- W(Lyα) and Ly α/Hβ < case B prediction !
- No clear correlation of Ly α with metallicity, dust, other parameters found.
- Strong variation of Ly α profiles observed within a galaxy.
- Ly α scattering « halo » observed.
- Starbursts show complex structure (super star clusters + diffuse ISM); outflows ubiquitous.
- Ly α affected by:
  - ISM kinematics.
  - ISM (HI) geometry.
  - Dust.
  - Precise order of importance unclear!

High-z Lyman α emission

At (very) low metallicity: strong/dominant Lyα! since

- increased ionising flux from stellar populations.
- dominant cooling line (few metals).
- emissivity increased by collisional excitation.
- (higher nebular temperature, Te).

→ up to ~10% of L_{bol} emitted in Lyα!

→ *potentially detectable out to highest redshifts!!*

…but searches unsuccessful until 1990ies

Partridge & Peebles (1967)

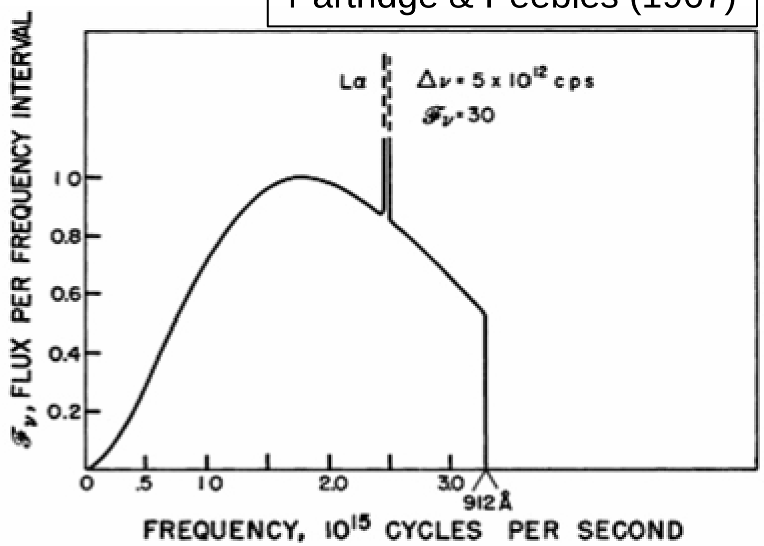
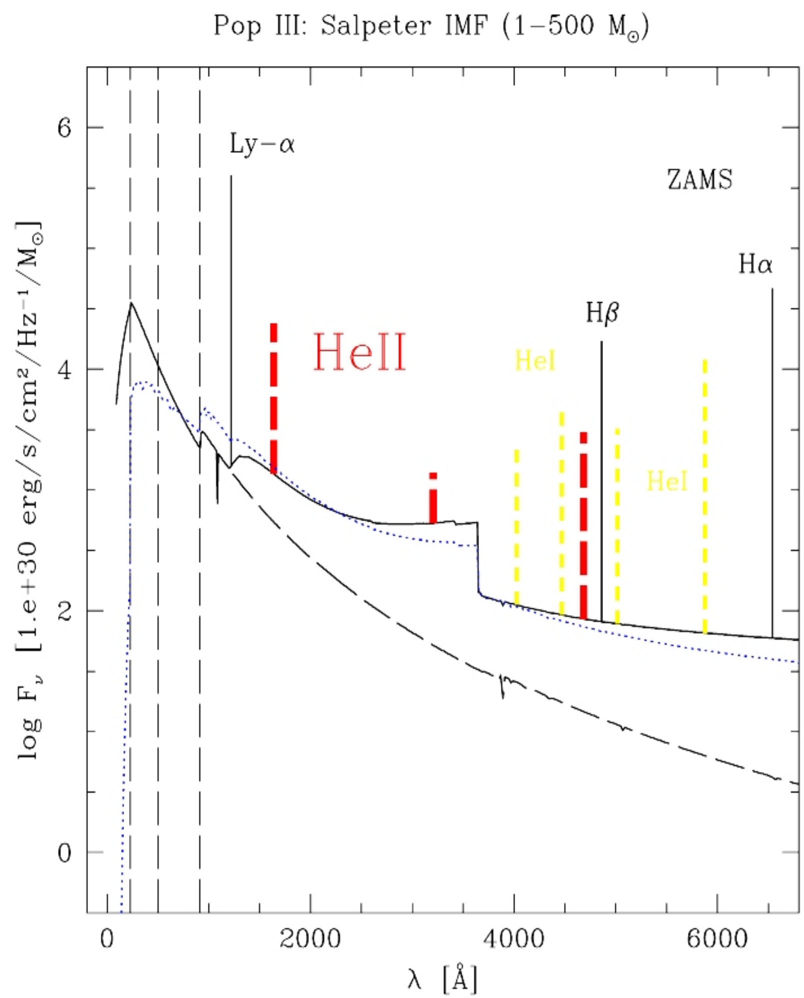


FIG. 3.—This curve represents semi-quantitatively the expected spectra of young galaxies in the extreme case that all photons of ionizing radiation have been converted to Lyman photons (§ IIe). The expected Lyman-α flux is calculated with Δν = 0.002 ν for the line.

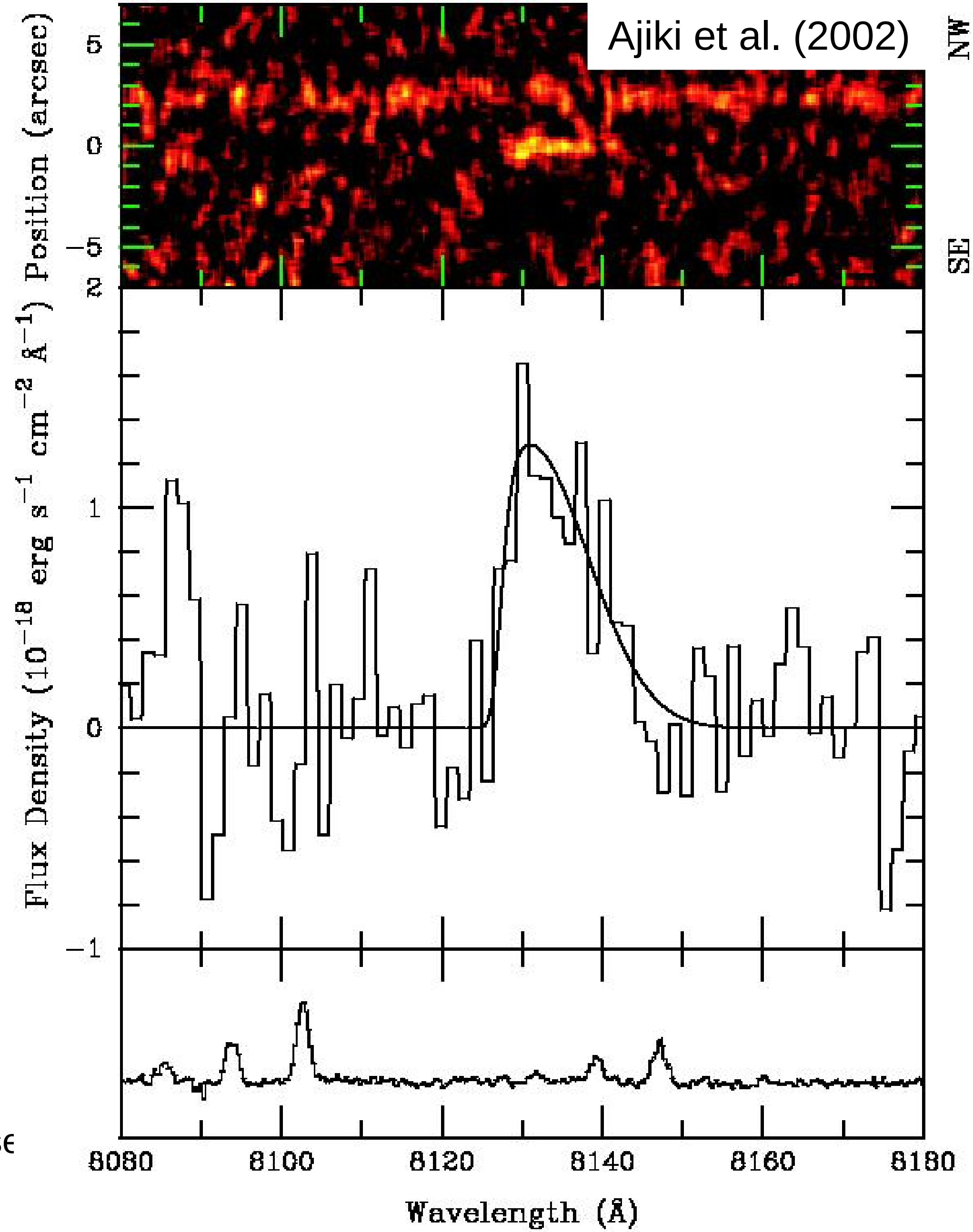


High-z Lyman α emission

+ Breakthrough about 10 years ago (Hu & McMahon 1996) thanks to larger collecting areas and fainter flux limits.

+ Lyα narrow band imaging surveys are now very successful in detecting faint galaxies, with typical luminosity below that of LBGs (e.g. Fynbo et al. 2001, Ouchi et al. 2003, Malhotra & Rhoads 2002 and SUBARU team).

+ Lyα also is found to have P-Cygni profile: superwinds of neutral gas!



High-z Lyman α emission

+ The number of high-z emitters is, however, still an order of magnitude smaller than predicted by models (Pritchet 1994).

- Is the true number of primeval galaxies smaller than predicted?

or

- Does only a fraction emit Lyα?

It’s too early for conclusions, but ...

Many evolutionary effects may be at work between high-*z* and low-z.
Certainly, we can’t claim our sample is representative.

→ But physics can’t evolve, *and therefore*

+ MUST treat Lyα-derived properties with caution!

+ MUST have a low-*z* statistically significant sample!