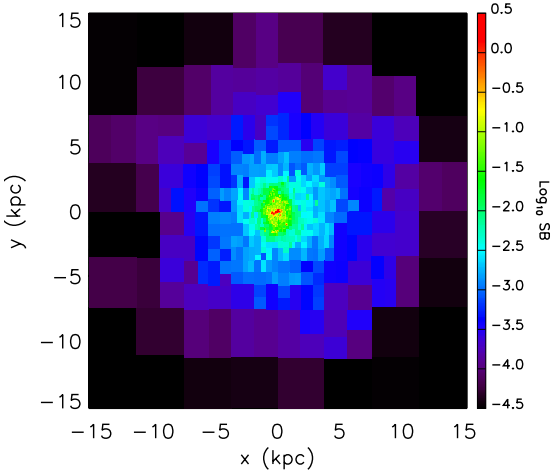
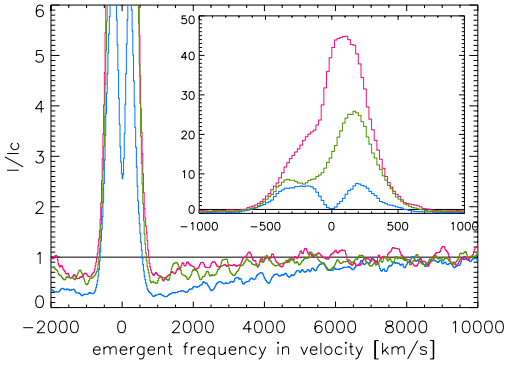
Lyman-α Radiation Transfer effects in galaxies

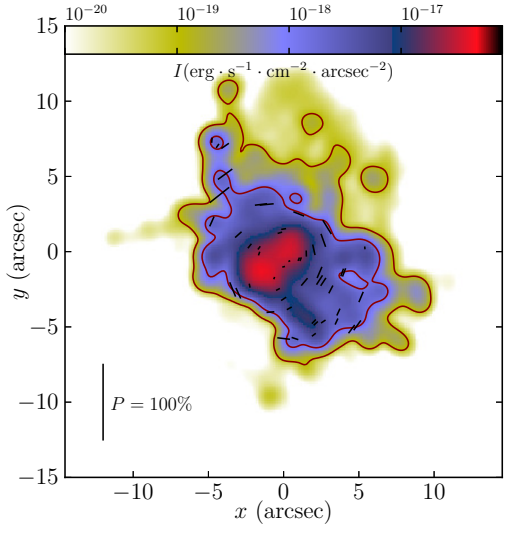
Anne Verhamme

Observatoire de Genève

anne.verhamme@unige.ch







Lyα : a unique tool...

...to observe the formation and evolution of galaxies

- Hydrogen constitues $\sim$ 90% of the atoms in the Universe
- Lyα is the strongest recombination line
- UV line, redshifted to visible at $2 < z < 6.6$ and to IR until $z \sim 20$!

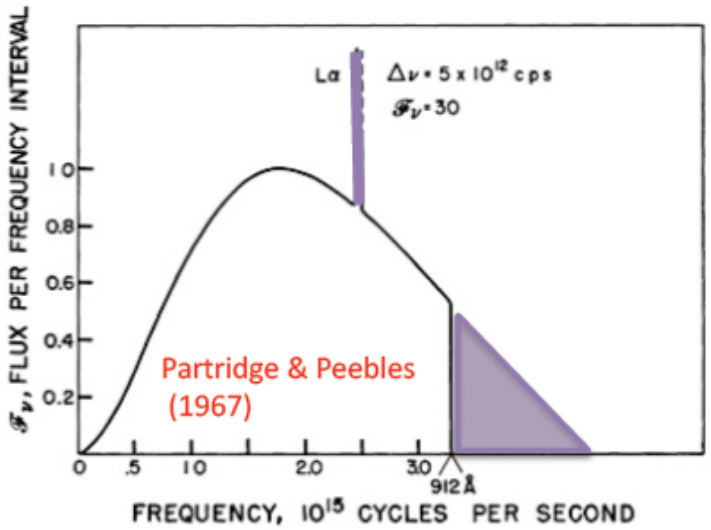


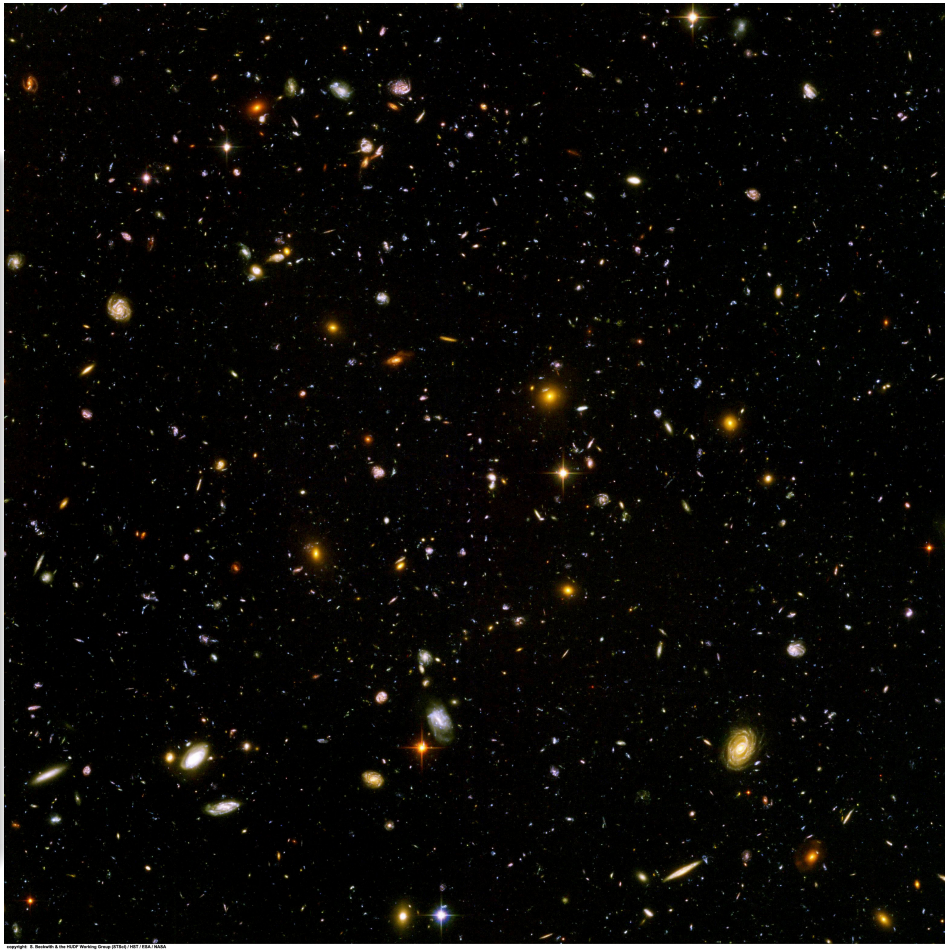
FIG. 3.—This curve represents semi-quantitatively the expected spectra of young galaxies in the extreme case that all photons of ionizing radiation have been converted to Lyman photons (§ IIe). The expected Lyman-α flux is calculated with $\Delta\nu = 0.002\ \nu$ for the line.

$\rightarrow$ the same observational signature to probe all epochs

Lyα : a unique tool...

...to observe the formation and evolution of galaxies

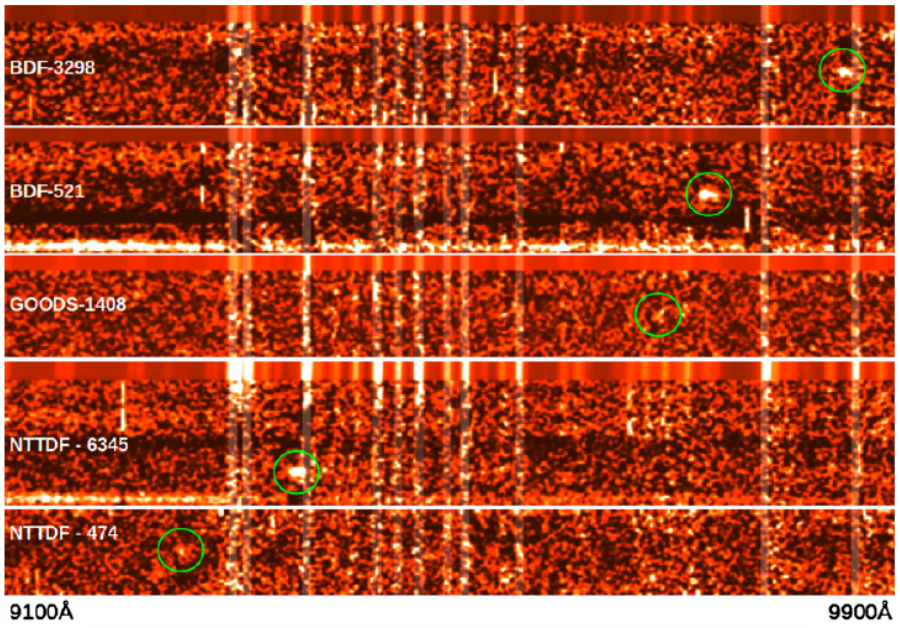
- Hydrogen constitues $\sim$ 90% of the atoms in the Universe
- Lyα is the strongest recombination line
- UV line, redshifted to visible at $2 < z < 6.6$ and to IR until $z \sim 20$!

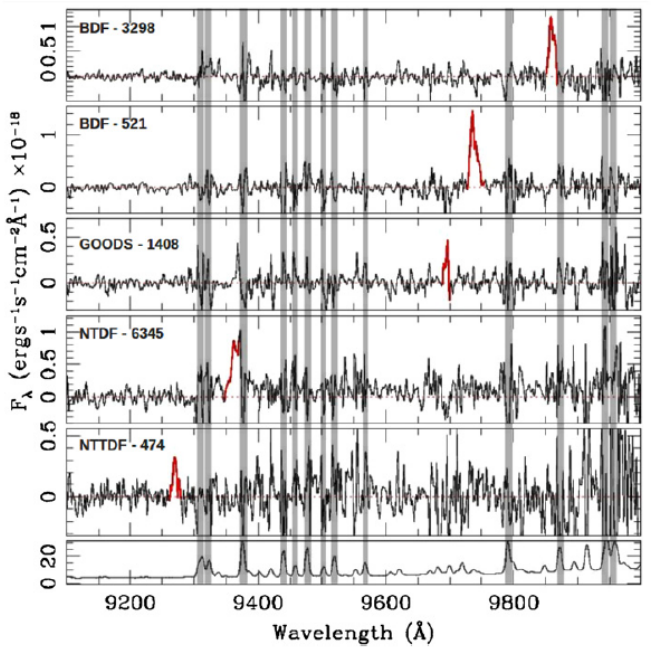


$\rightarrow$ the same observational signature to probe all epochs

Most distant galaxies are Lyα emitters

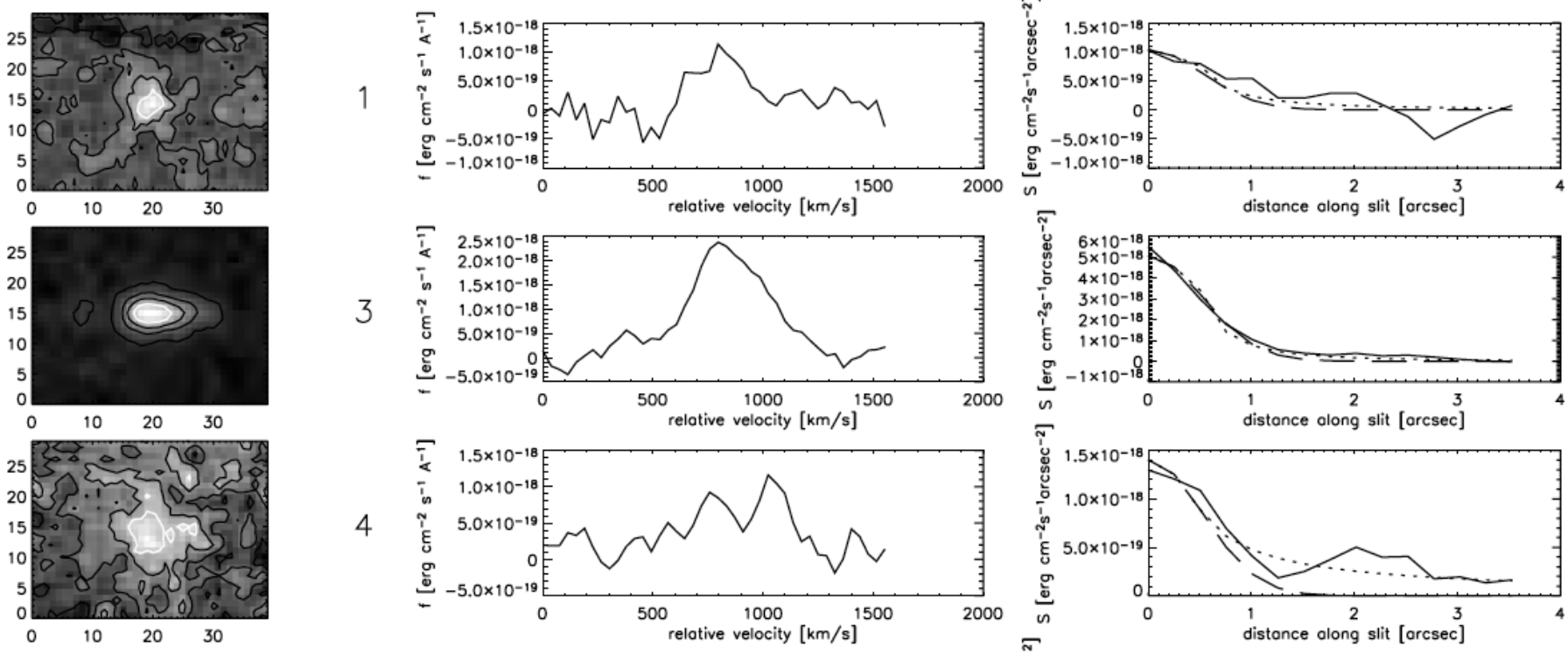
Pentericci et al. 2011 (see also Iye+06, Rhoads+12, Ono+12, Schenker+12)





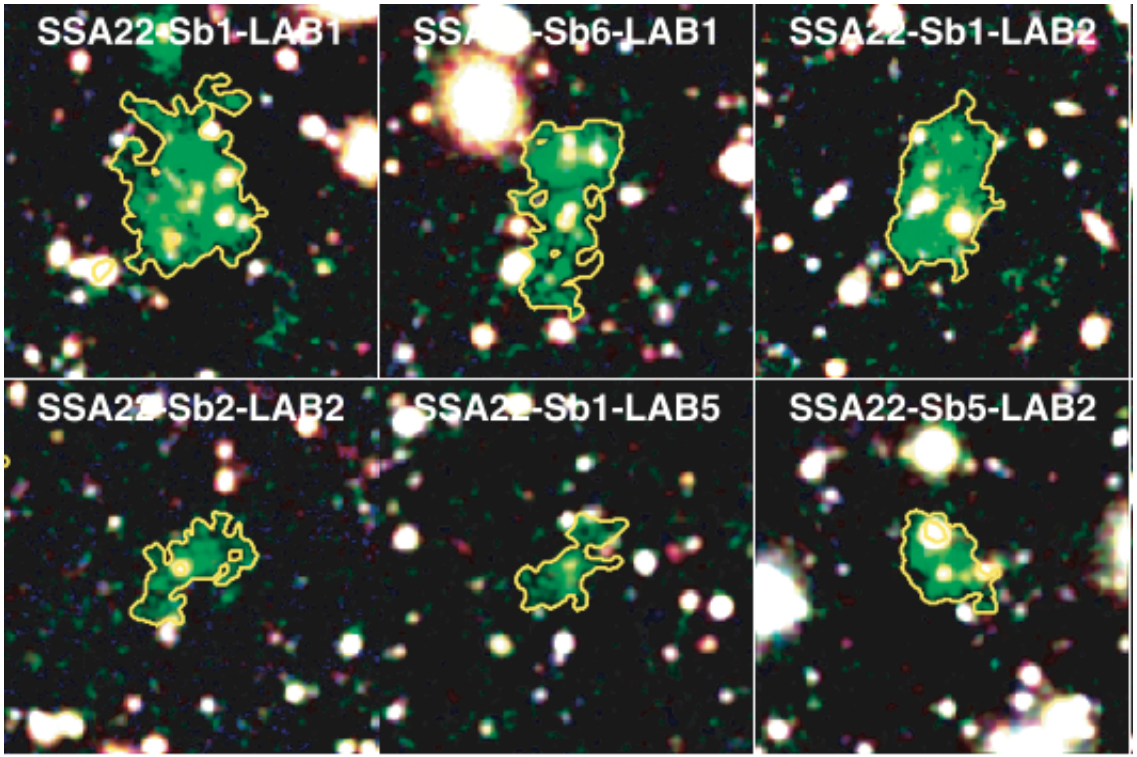
Faintest galaxies are Lyα emitters

Rauch et al 2008 (see also Cassata et al 2011)

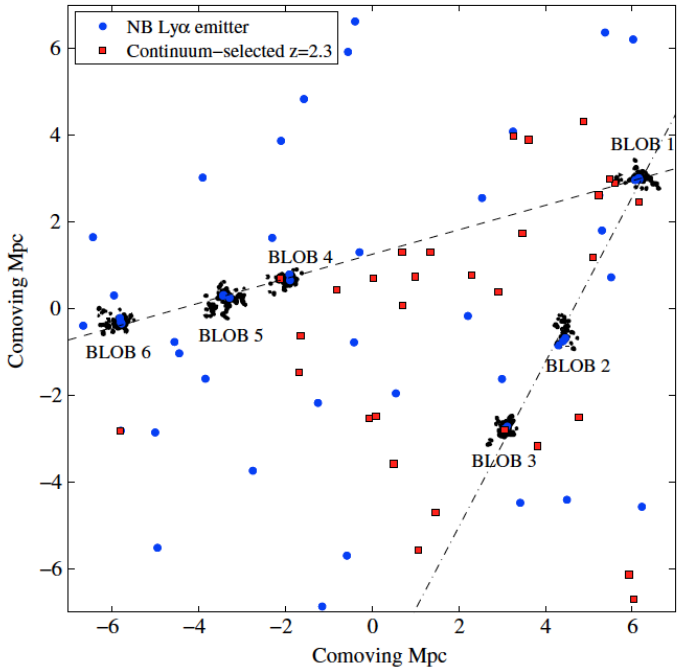


Not only galaxies emit Lyα

Matsuda et al. 2011



Erb et al. 2012



Lyα, a unique tool to model galaxy formation and evolution

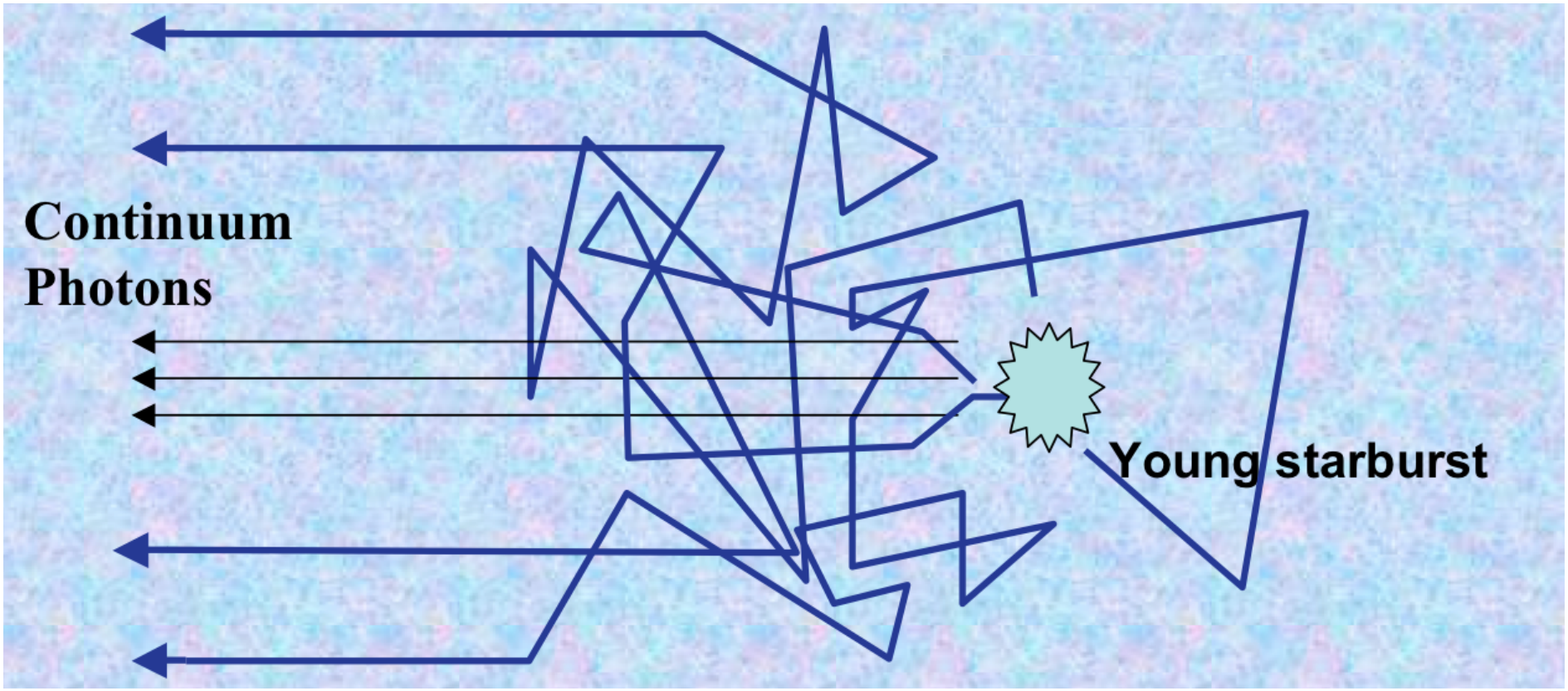
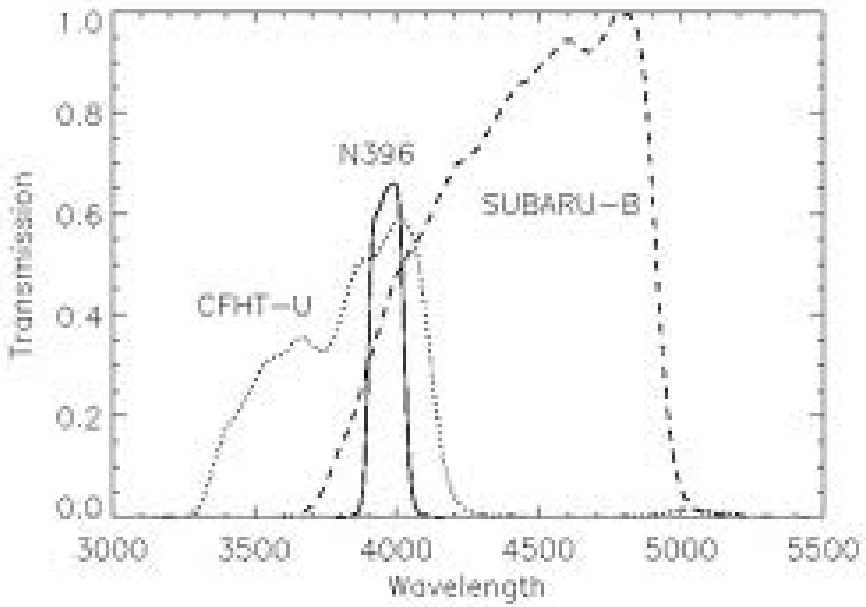


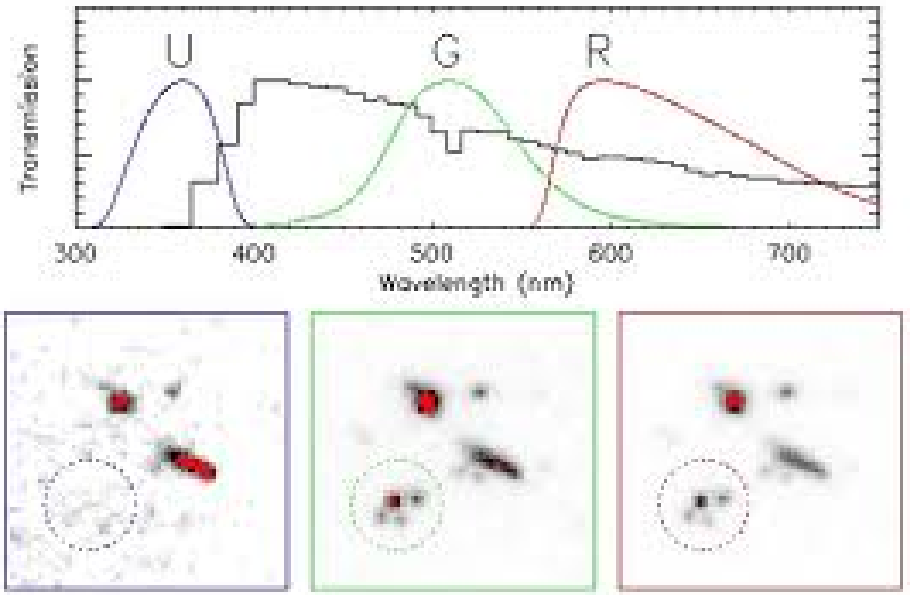
Table of Contents

Lyα emission from unresolved sources : LAEs /LBGs

Lyman-Alpha Emitters LAEs



Lyman Break Galaxies LBGs

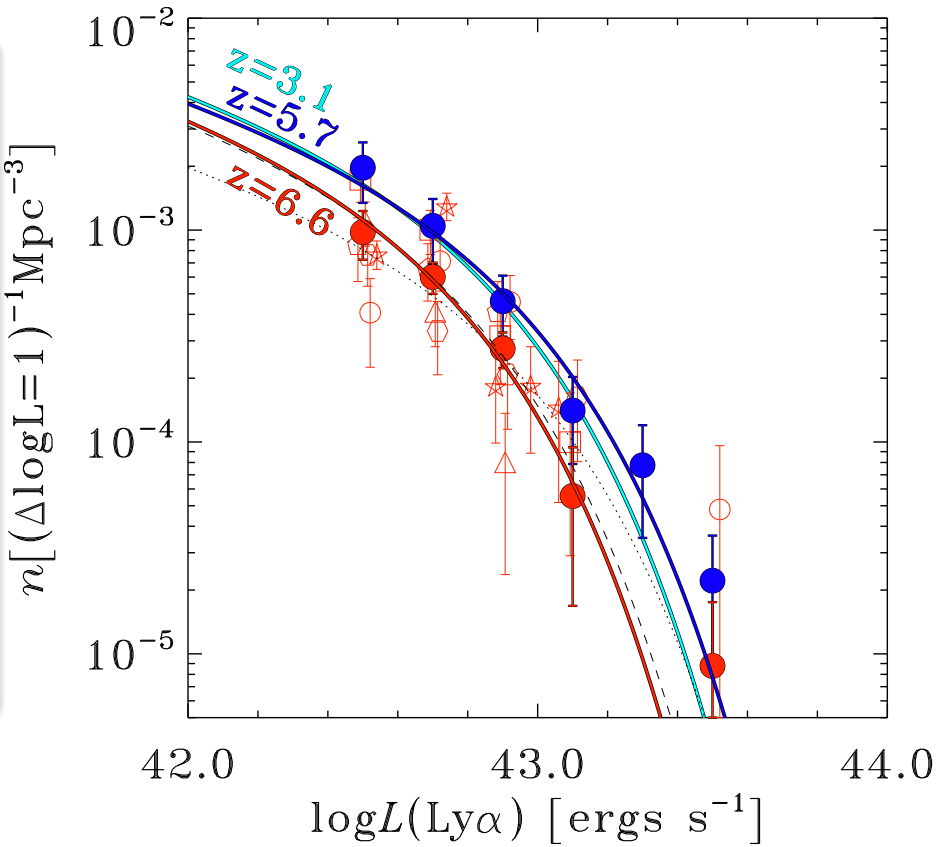


Lyα emission from unresolved sources : LAEs /LBGs

Observational constraints

- Lyα luminosity functions

Ouchi et al. 2010

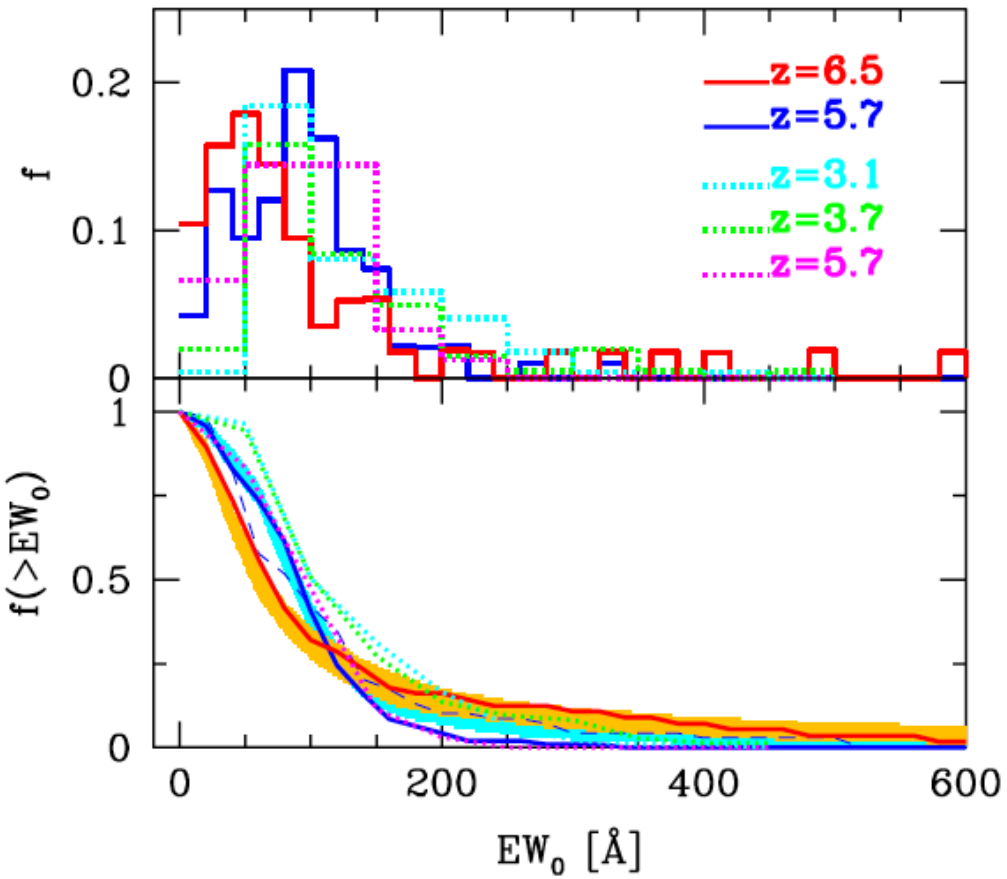


Lyα emission from unresolved sources : LAEs /LBGs

Observational constraints

- Lyα luminosity functions
- Lyα EW distributions

Kashikawa et al. 2011

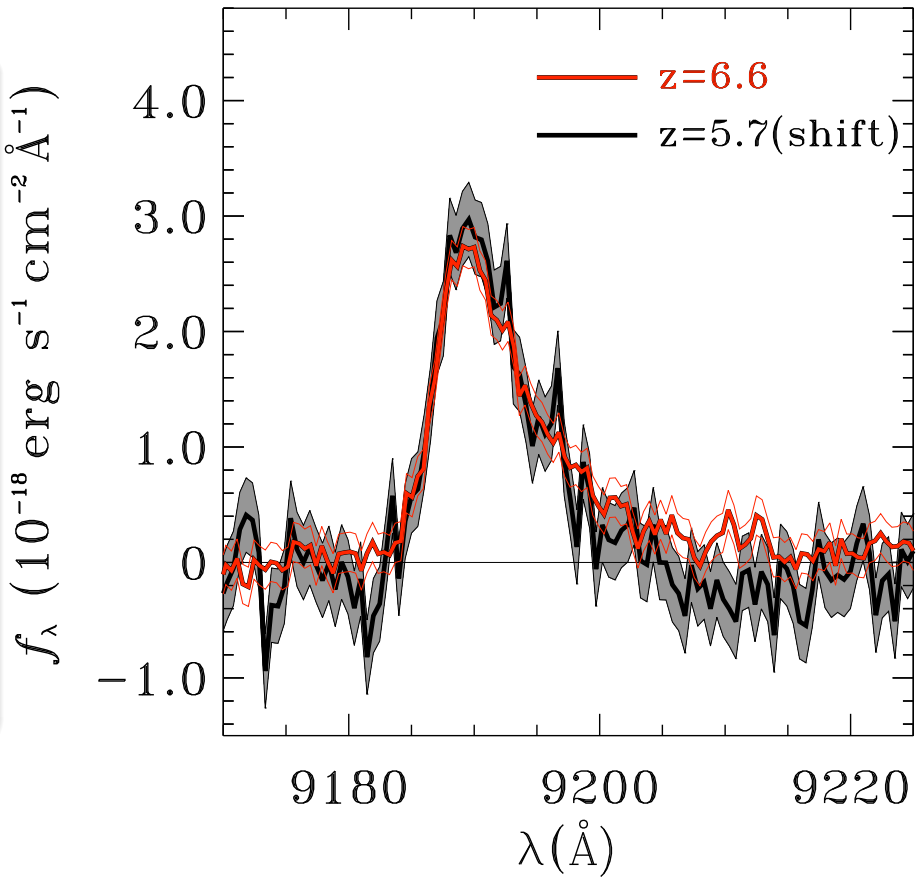


Lyα emission from unresolved sources : LAEs /LBGs

Observational constraints

- Lyα luminosity functions
- Lyα EW distributions
- Lyα spectral shapes

Ouchi et al. 2010

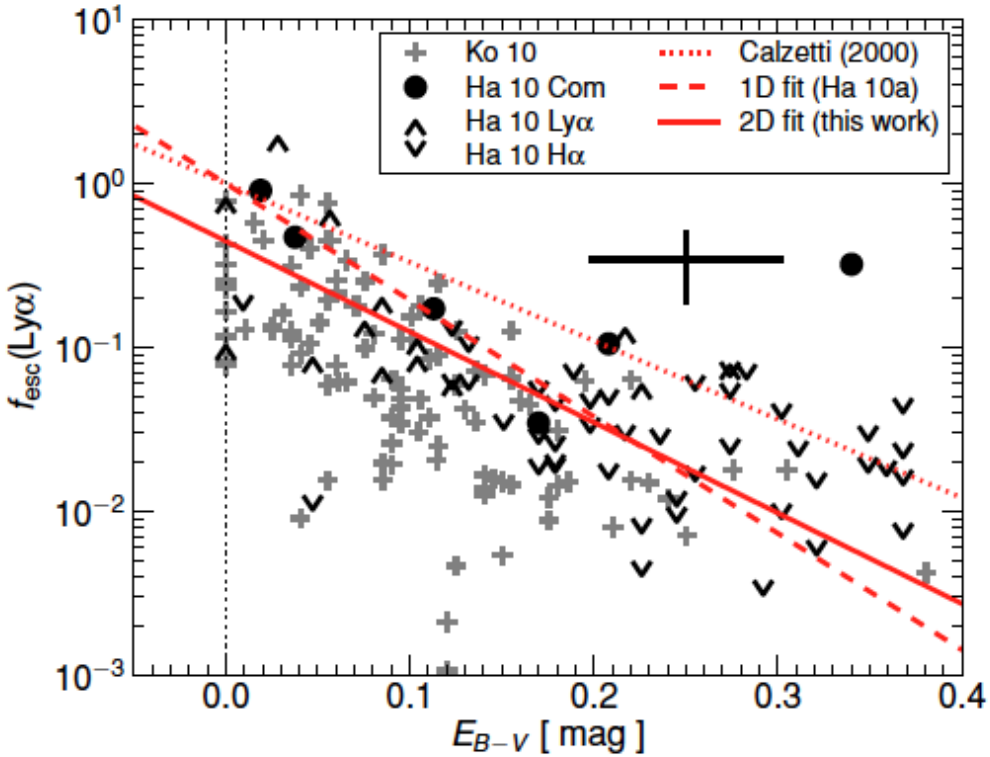


Lyα emission from unresolved sources : LAEs /LBGs

Observational constraints

- Lyα luminosity functions
- Lyα EW distributions
- Lyα spectral shapes
- Lyα escape fractions

Hayes et al. 2010

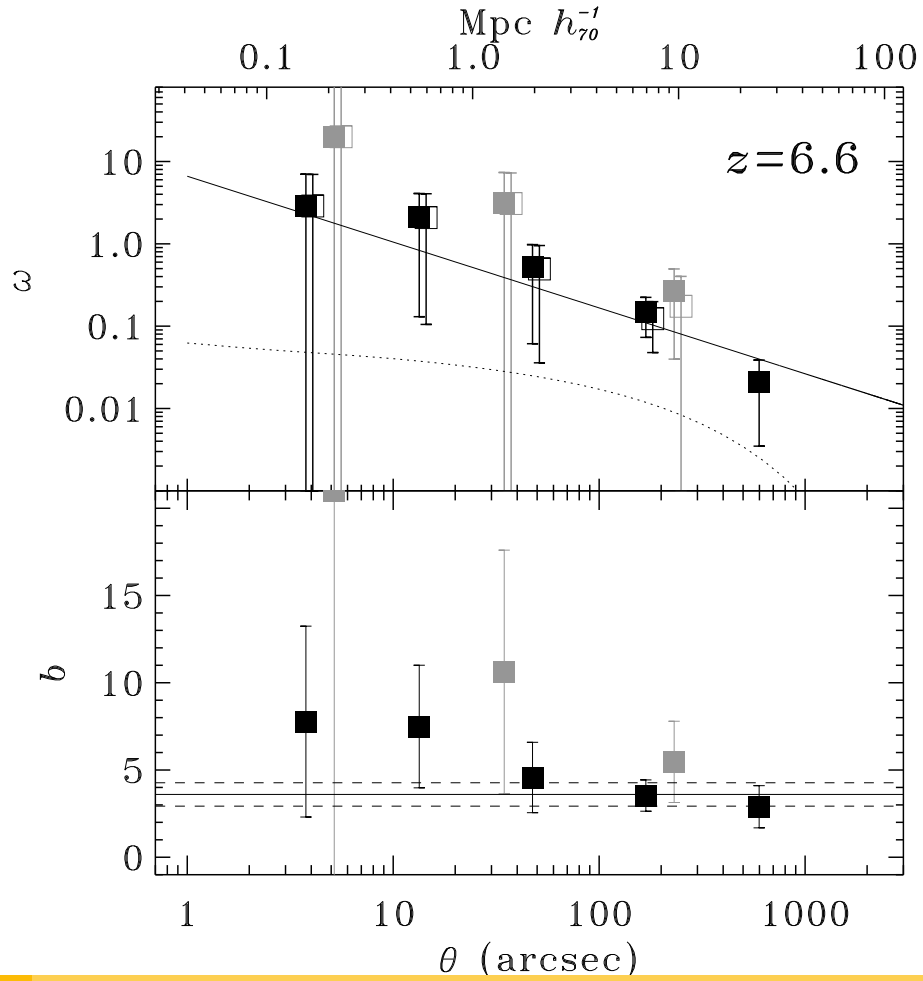


Lyα emission from unresolved sources : LAEs /LBGs

Observational constraints

- Lyα luminosity functions
- Lyα EW distributions
- Lyα spectral shapes
- Lyα escape fractions
- clustering of Lyα sources

Ouchi et al. 2010



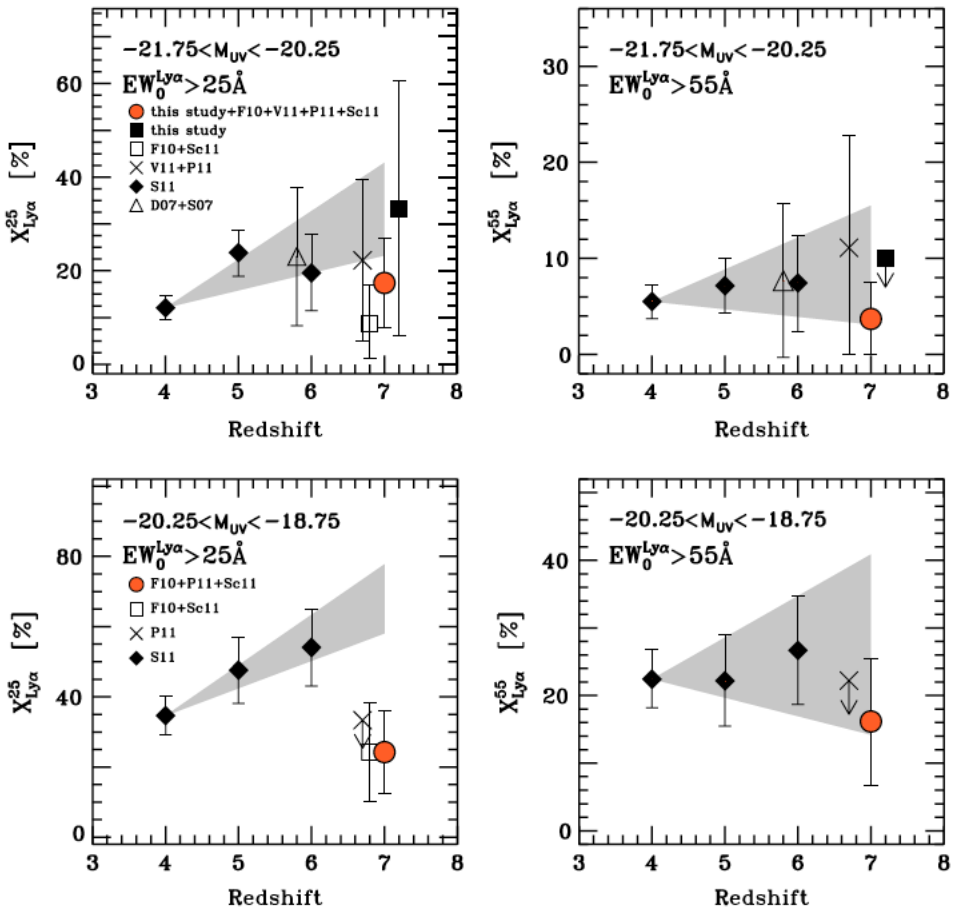
Lyα emission from unresolved sources : LAEs /LBGs

Observational constraints

- Lyα luminosity functions
- Lyα EW distributions
- Lyα spectral shapes
- Lyα escape fractions
- clustering of Lyα sources
- comparison studies LAEs vs LBGs

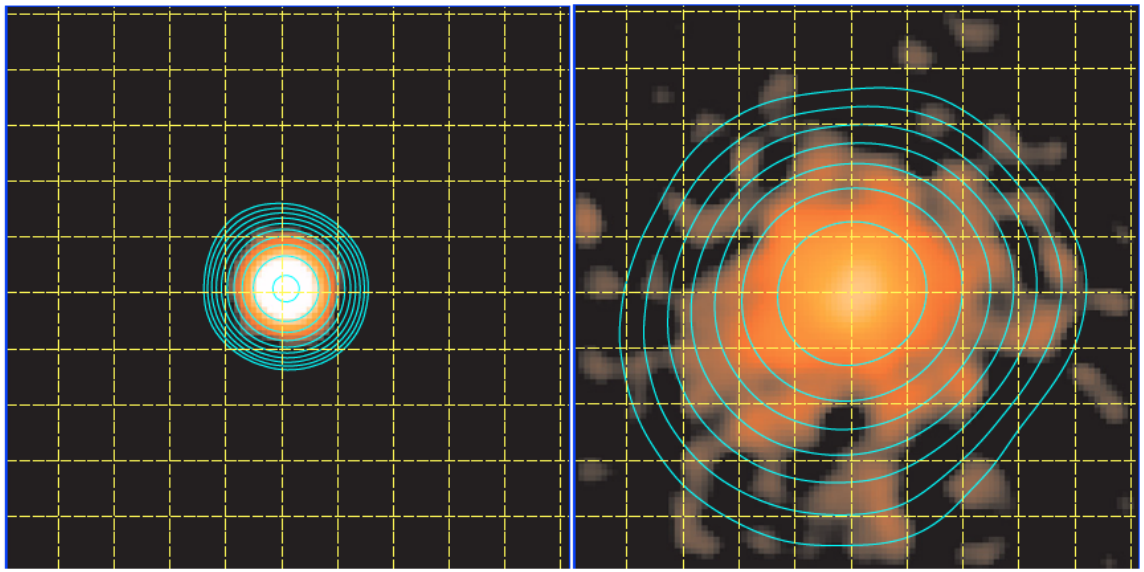
Ono et al. 2012

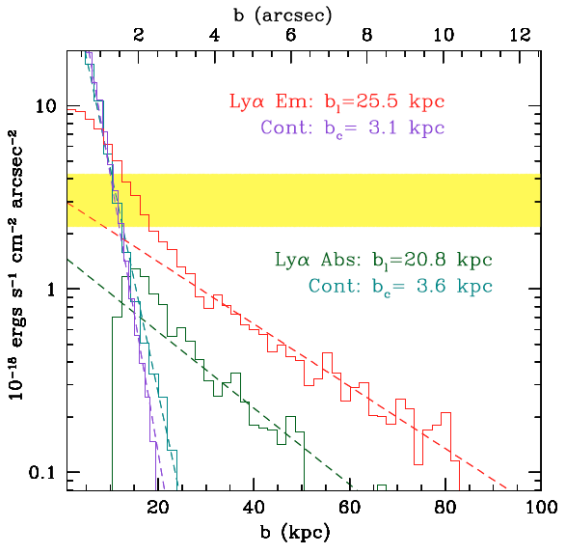
(see also Pentericci et al. 2011, Stark et al. 2011)



Lyα diffuse emission from spacially resolved sources

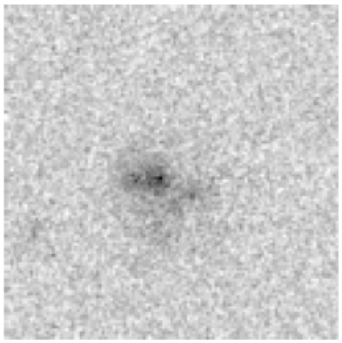
Steidel et al. 2011 (see also Matsuda+12... and Feldmeier+13)

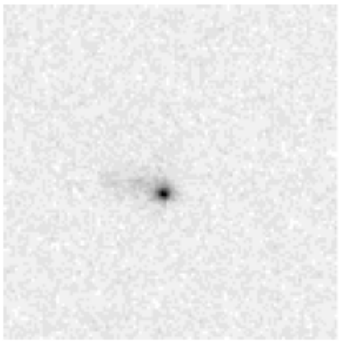


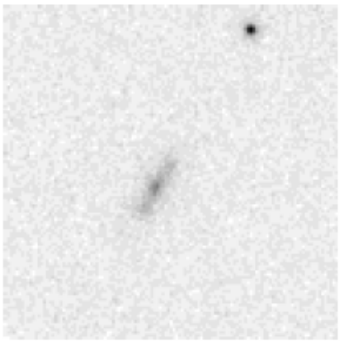


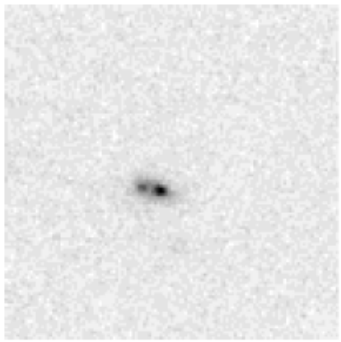
Lyα diffuse emission from spacially resolved sources

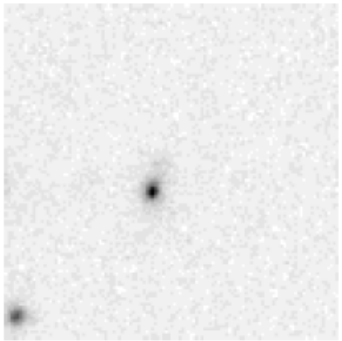
Pentericci et al. 2010

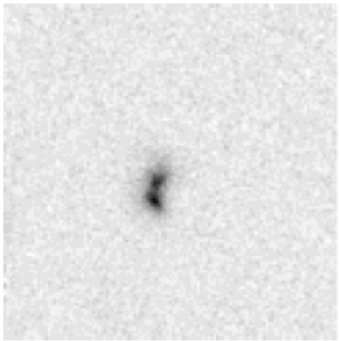

z=2.42

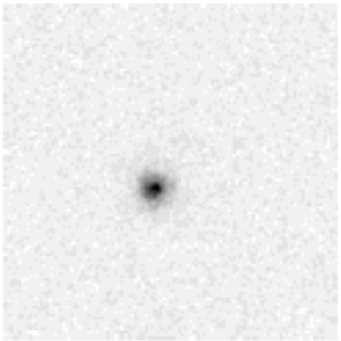

z=2.54

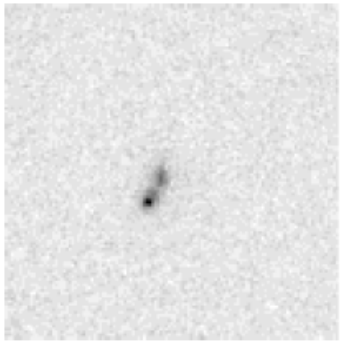

z=2.54


z=2.61


z=2.62

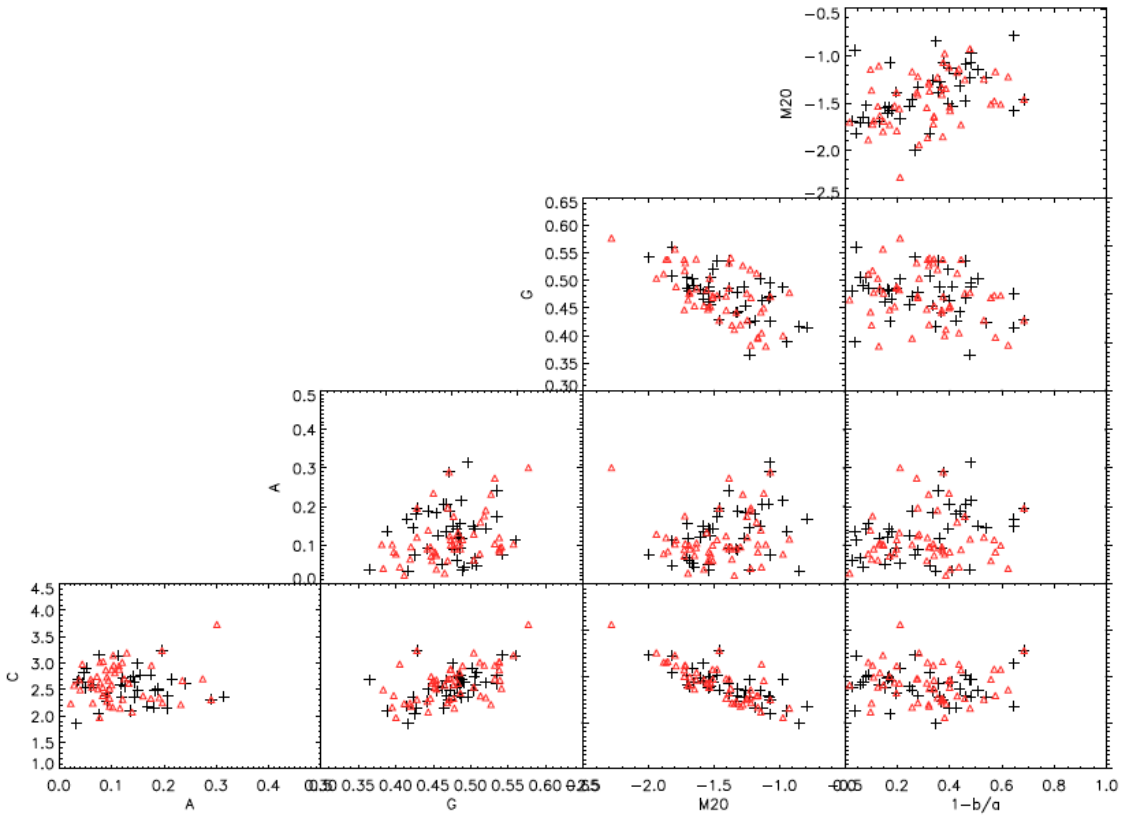

z=2.65


z=2.67


z=2.70

Lyα diffuse emission from spacially resolved sources

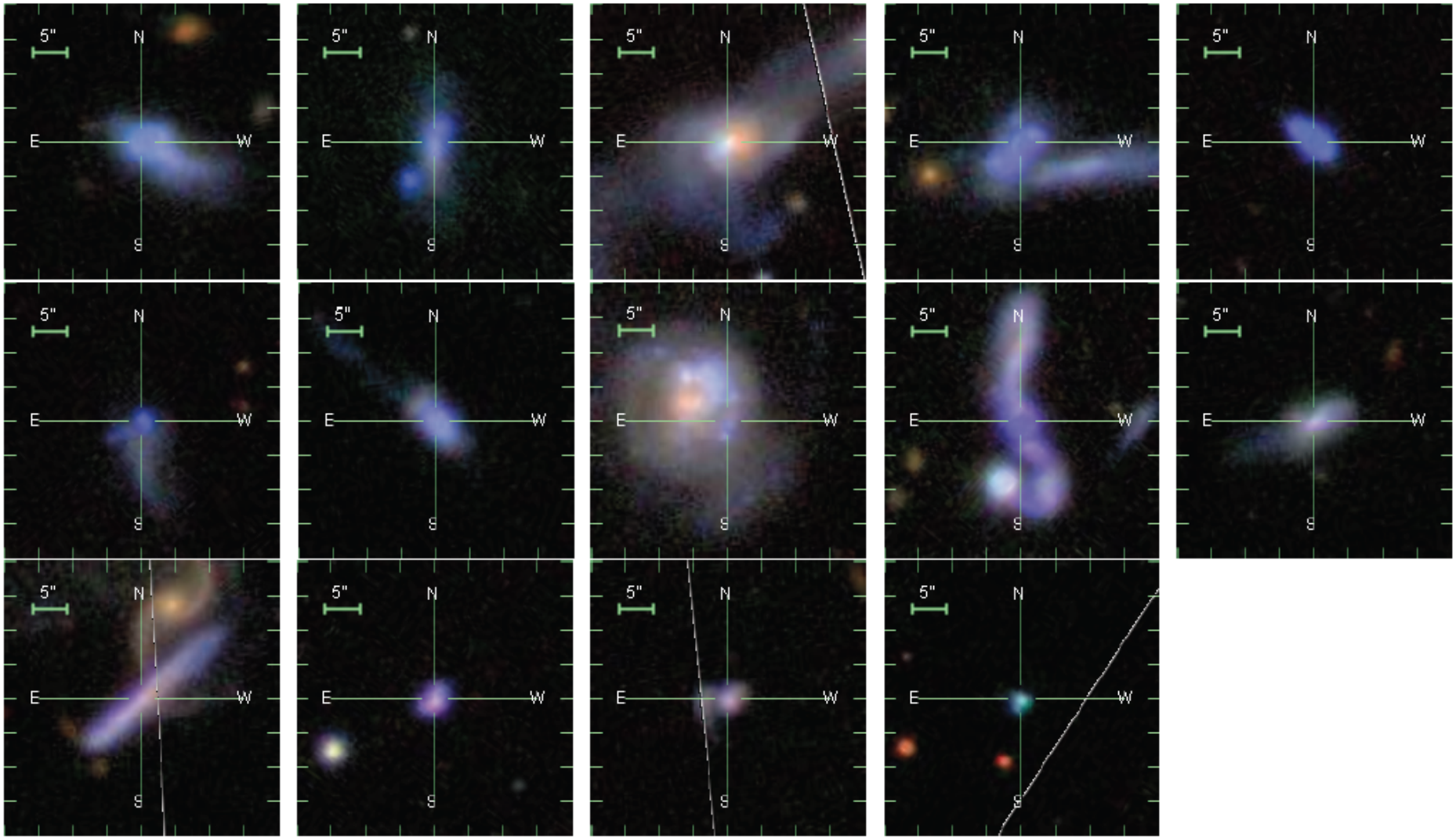
Pentericci et al. 2010



LARS, the Lyman Alpha Reference Sample

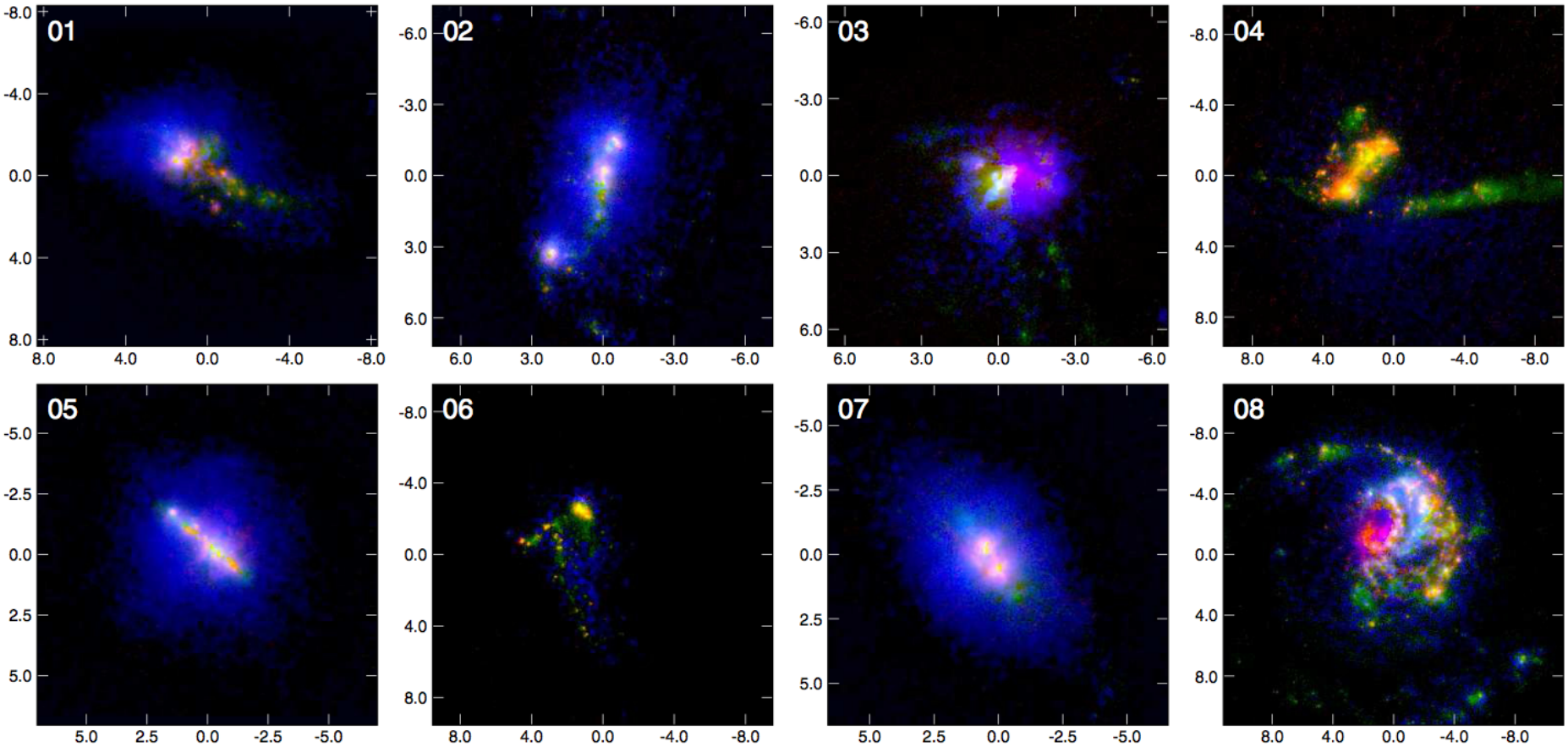
- 14 star-forming galaxies from SDSS + GALEX
- GALEX FUV luminosities 9.3 to 10.7 Lo
- $0.029 < z < 0.18$
- Hα EW > 90Å
- Removal of AGN from BPT diagram
- the LARS team : G. Ostlin(PI), M. Hayes(PI), A. Adamo, H. Atek, N. Bergvall, J. Cannon, F. Duval, L. Guaita, D. Kunth, P. Laursen, C. Leitherer, T. Marquart, J. M. Mas-Hesse, J. Melinder, H. Oti-Floranes, I. Orlitova, T. Rivera-Thorsen, A. Sandberg, D. Schaerer, A. Verhamme

LARS, the Lyman Alpha Reference Sample

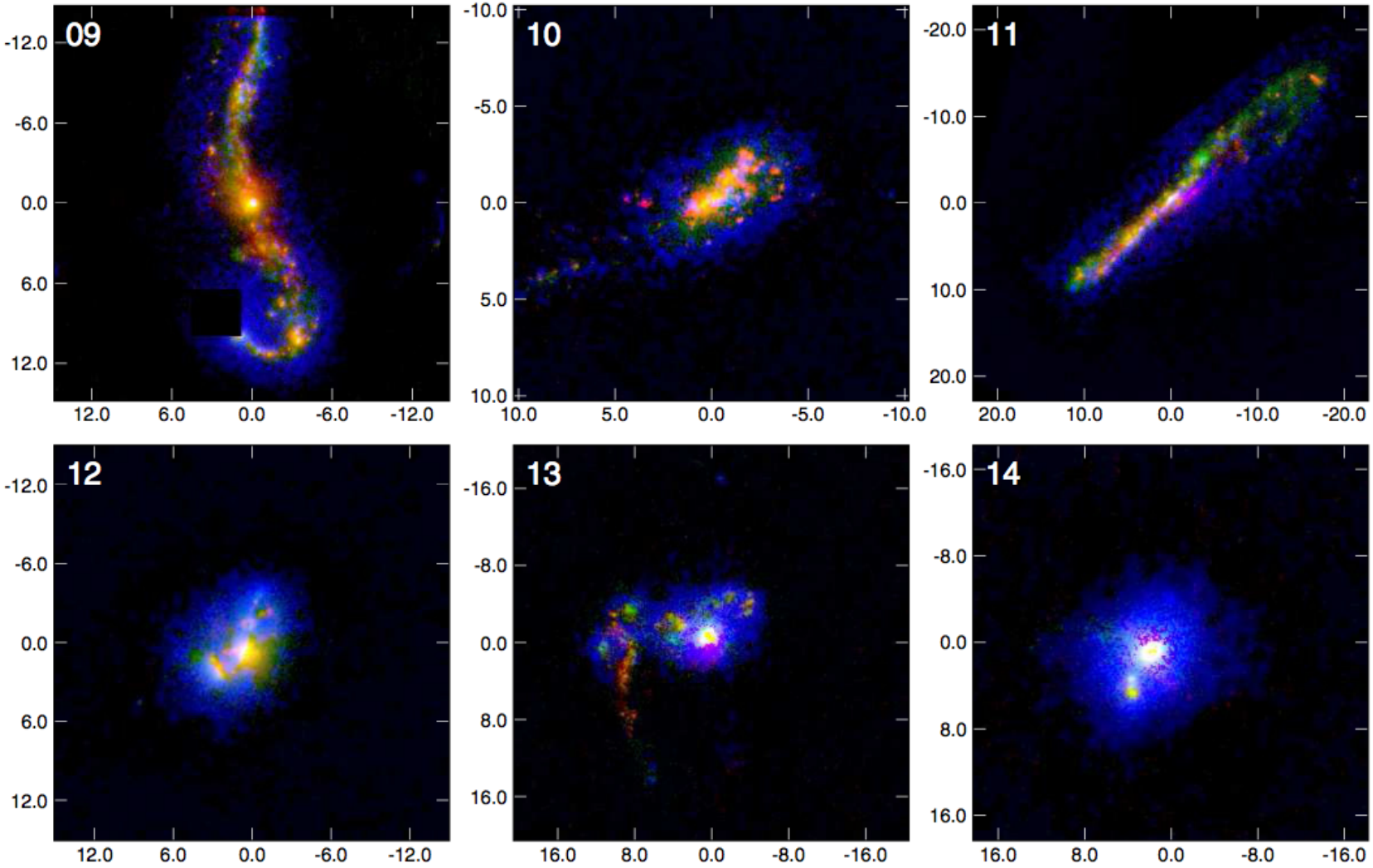


LARS, the Lyman Alpha Reference Sample *Hayes+13*

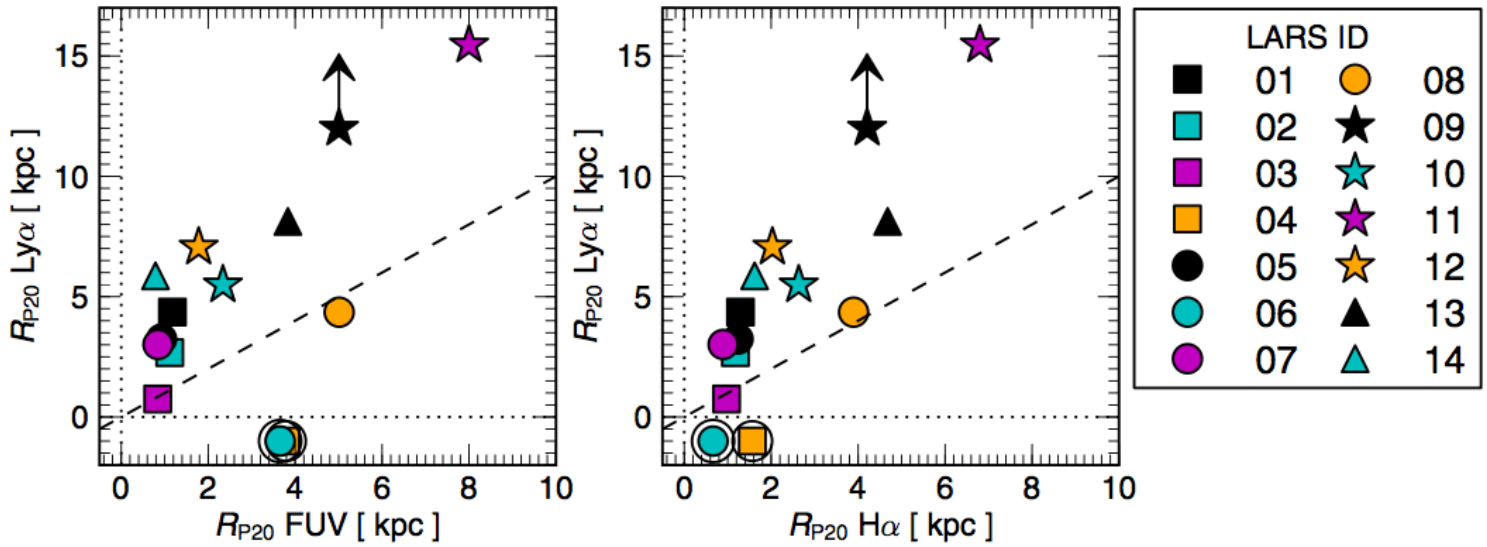
HST-WFC3 images, Lyα in blue, Hα in red, UV continuum in green

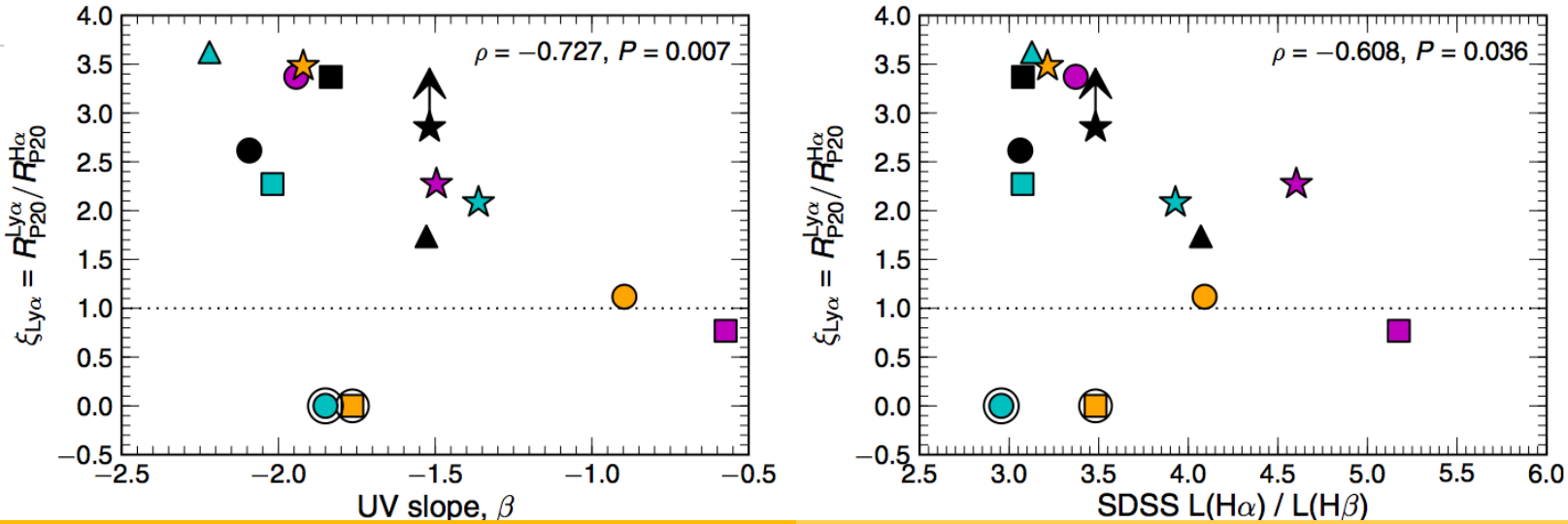


LARS, the Lyman Alpha Reference Sample *Hayes+13*

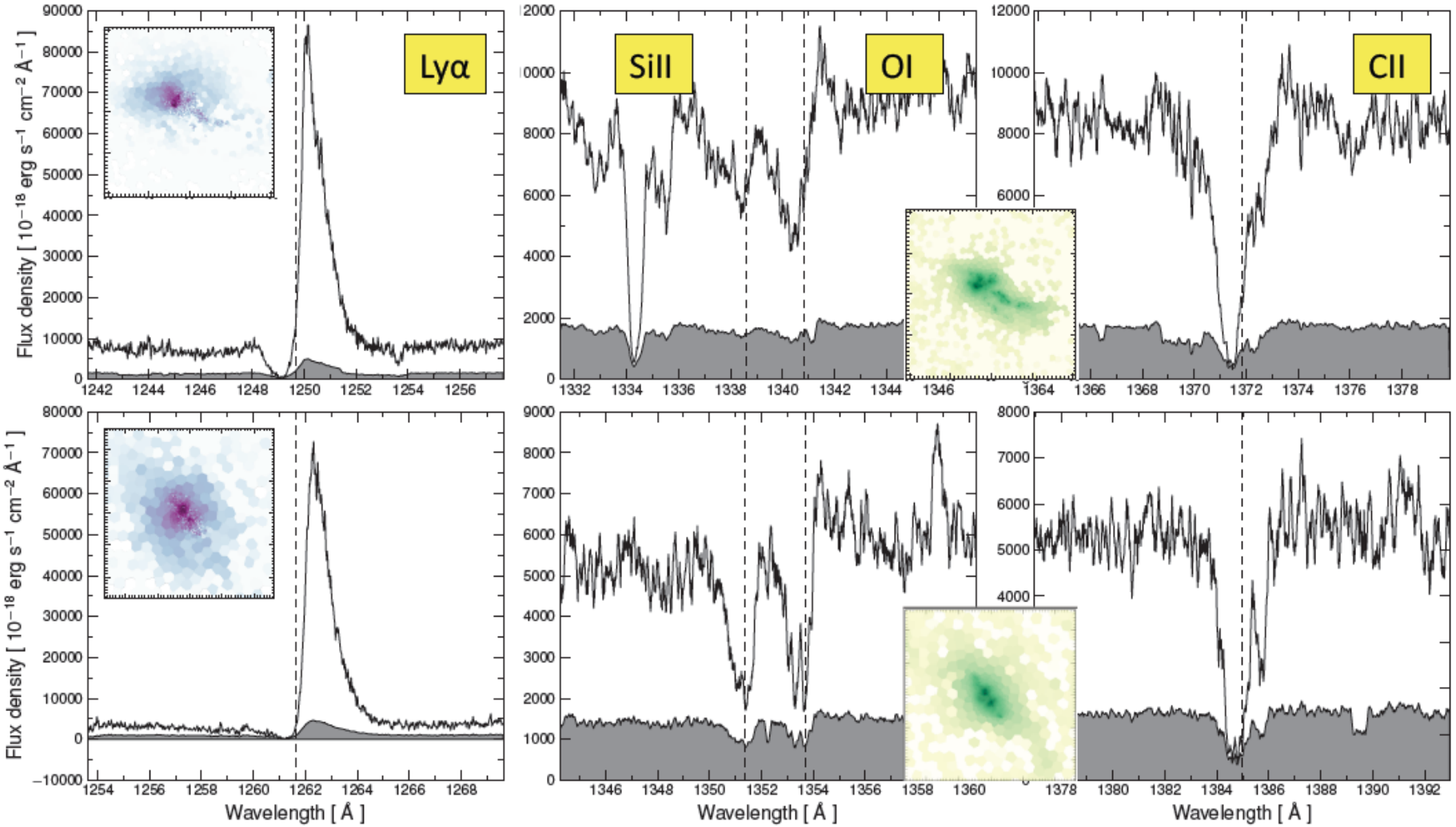


LARS, the Lyman Alpha Reference Sample *Hayes+13*





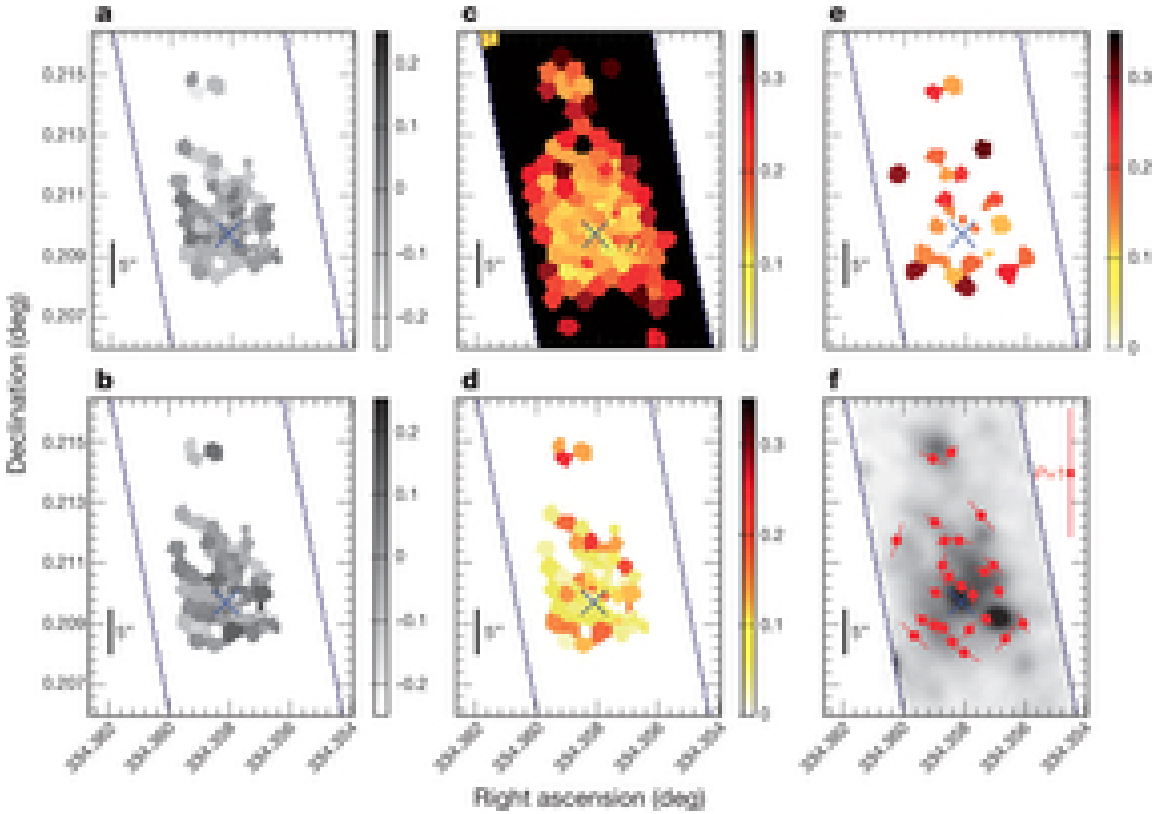
LARS, the Lyman Alpha Reference Sample

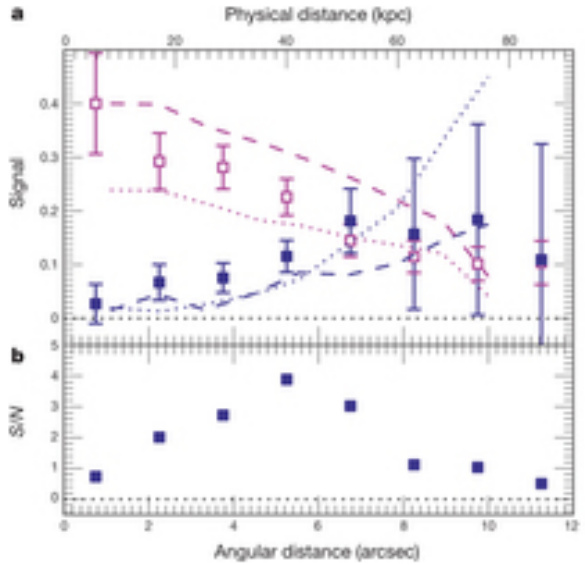


Lyα diffuse emission from spacially resolved sources

Polarisation of Lyα-blobs *Dijkstra+08, Prescott+11*

Hayes et al. 2011

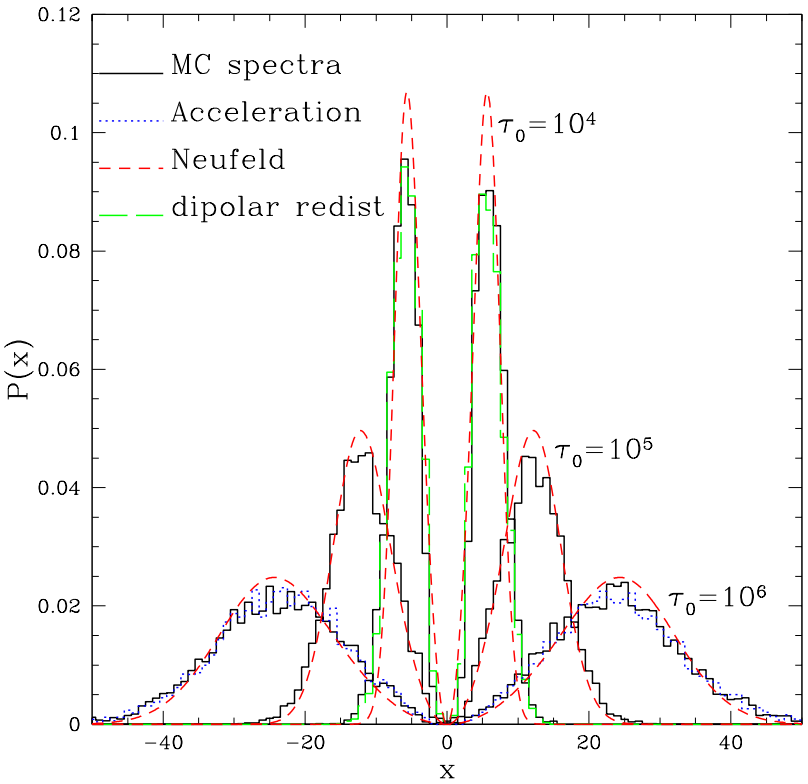


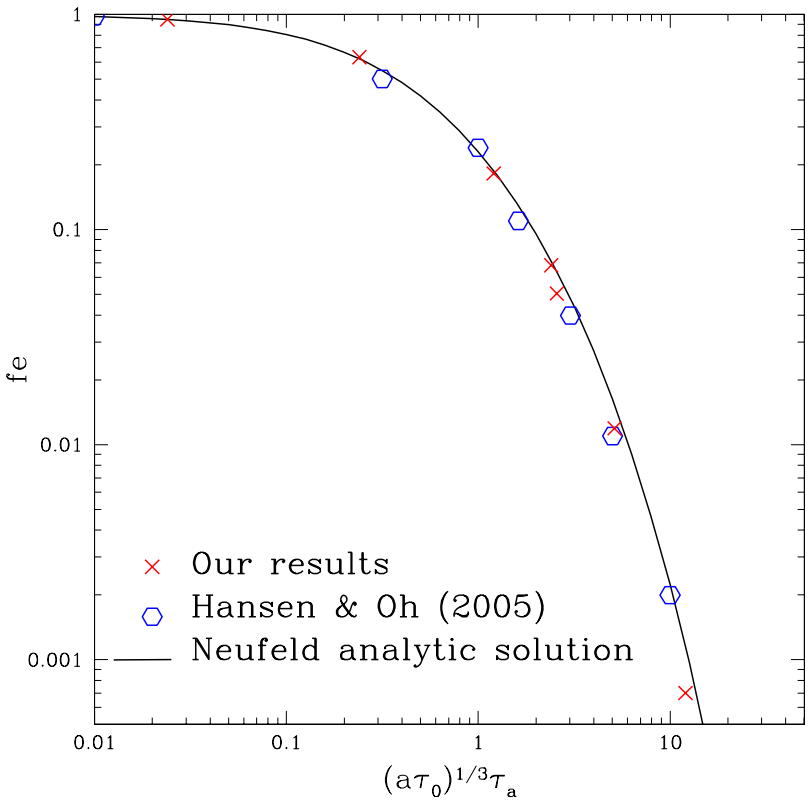


Analytic Lyα RT

through slab or sphere

- *Neufeld 1990, Dijkstra+2006, Roy+2009, Meiksin+2012*
- Lyα emergent spectra and escape fraction

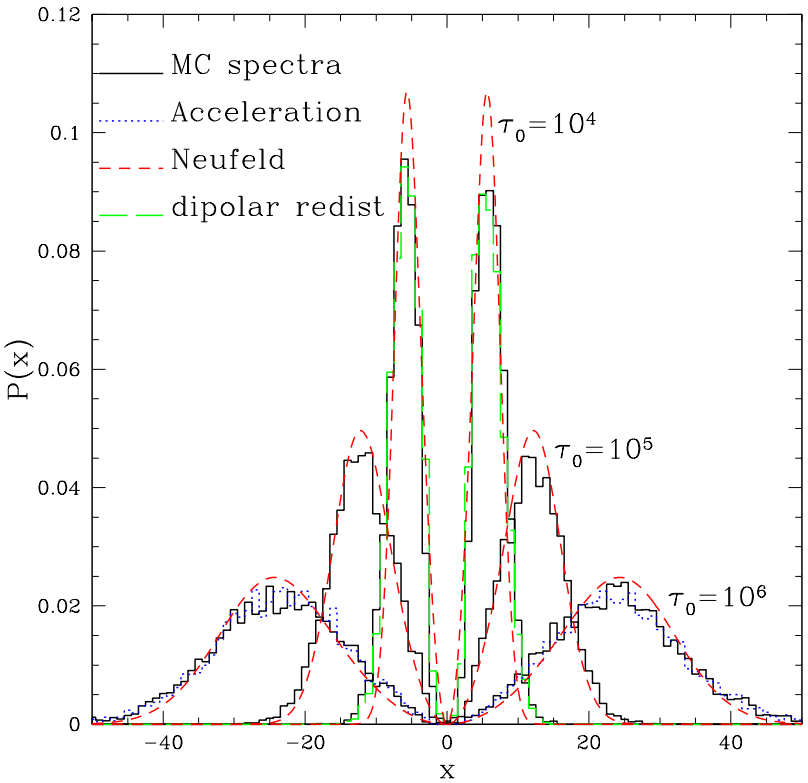


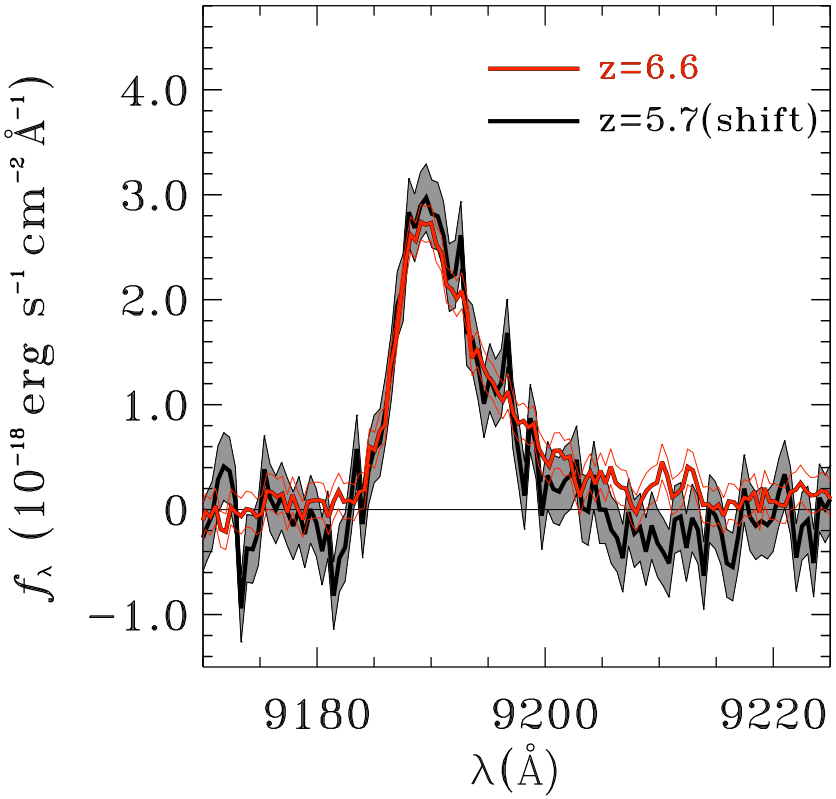


Analytic Lyα RT

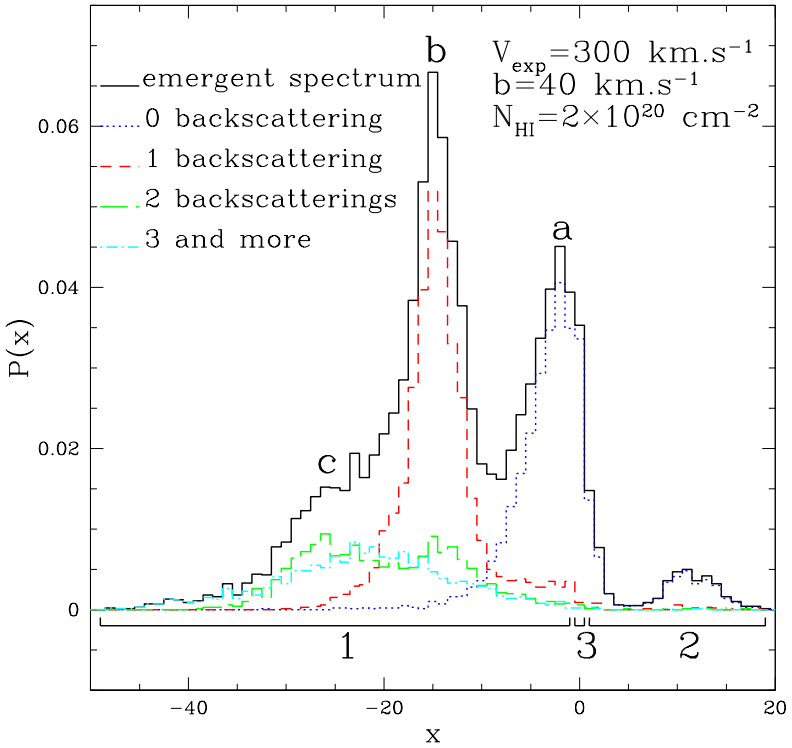
through slab or sphere

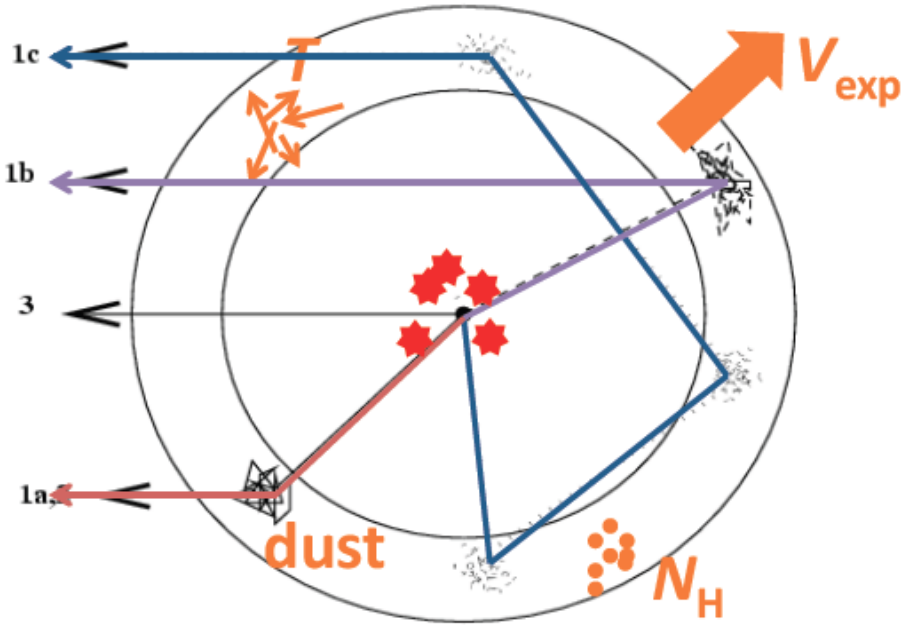
- *Neufeld 1990, Dijkstra+2006, Roy+2009, Meiksin+2012*
- Lyα emergent spectra and escape fraction



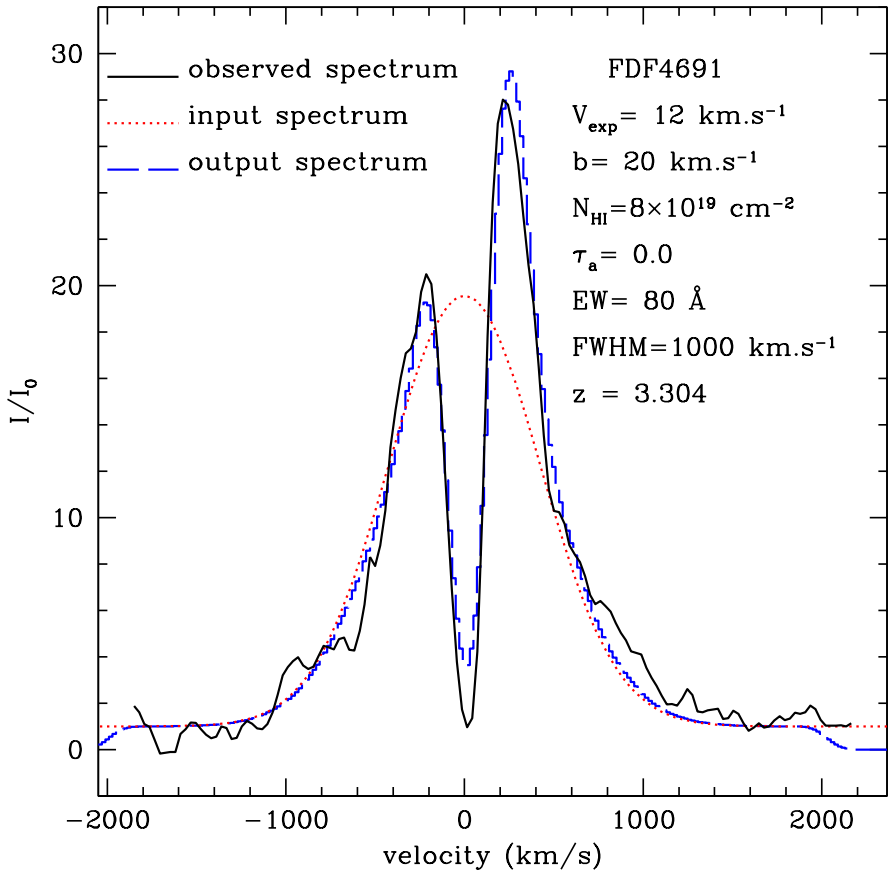


Expanding shells *Verhamme et al. 2006*





Fitting of observed Lyα spectra



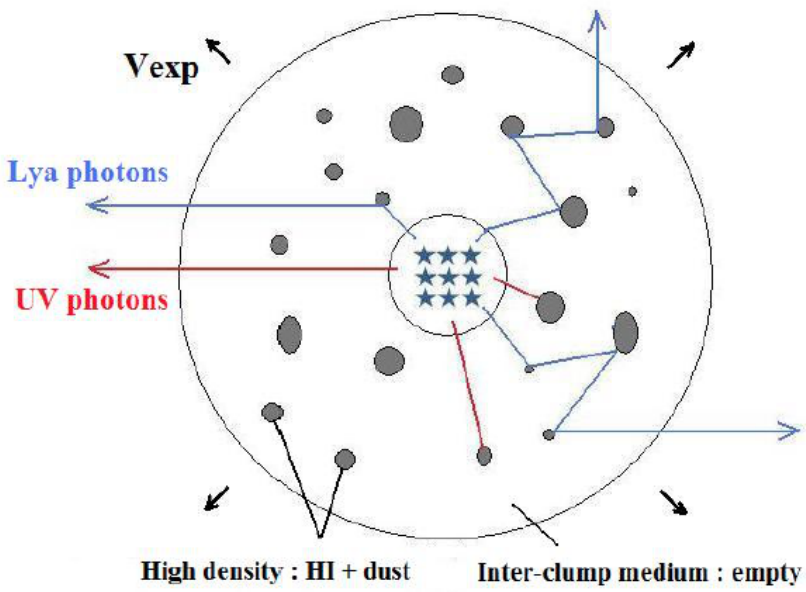
12 LBGs at $3 < z < 5$

Schaerer& Verhamme 2008, Verhamme+08, Schaerer+11

- profiles diversity reproduced by a single model
- librairy of $\sim$ 6500 synthetic spectra for the use of the community
- used by several collaborators
  Atek+09,Hayes+10,Vanzella+10,
  Lidman+12,Dessauges+12,Garel+12

Fitting of observed Lyα spectra

Duval+13

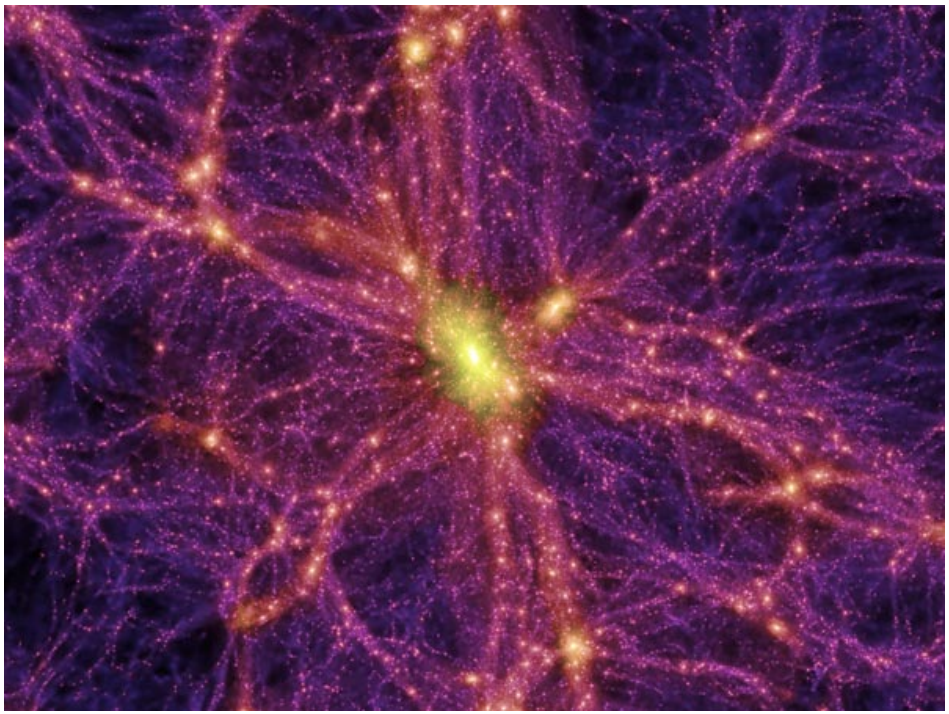


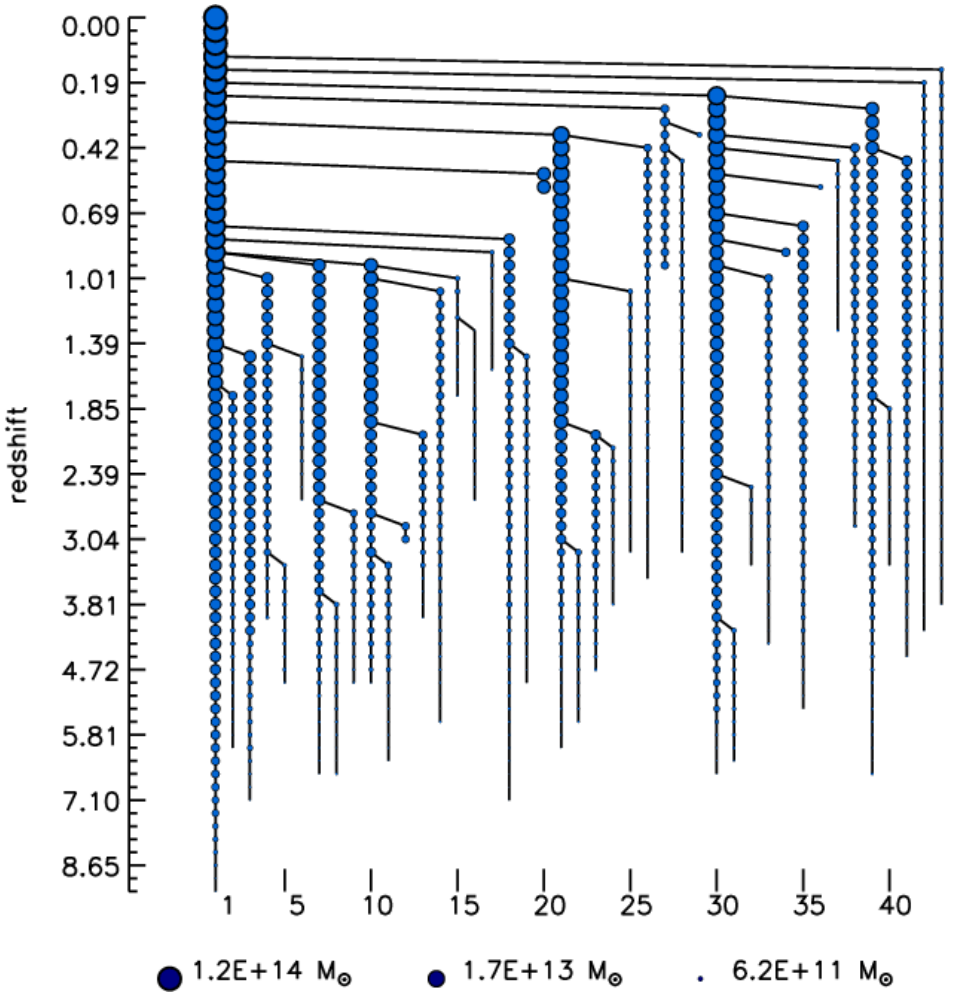
12 LBGs at $3 < z < 5$

Schaerer& Verhamme 2008, Verhamme+08, Schaerer+11

- profiles diversity reproduced by a single model
- librairy of $\sim$ 6500 synthetic spectra for the use of the community
- used by several collaborators
  Atek+09,Hayes+10,Vanzella+10,
  Lidman+12,Dessauges+12,Garel+12
- clumpy outflows
  Dijkstra+12,Duval+13,Laursen+13

semi-analytical modeling





semi-analytical modeling including Lyα RT

modeling high-z LAEs

- a long-time effort

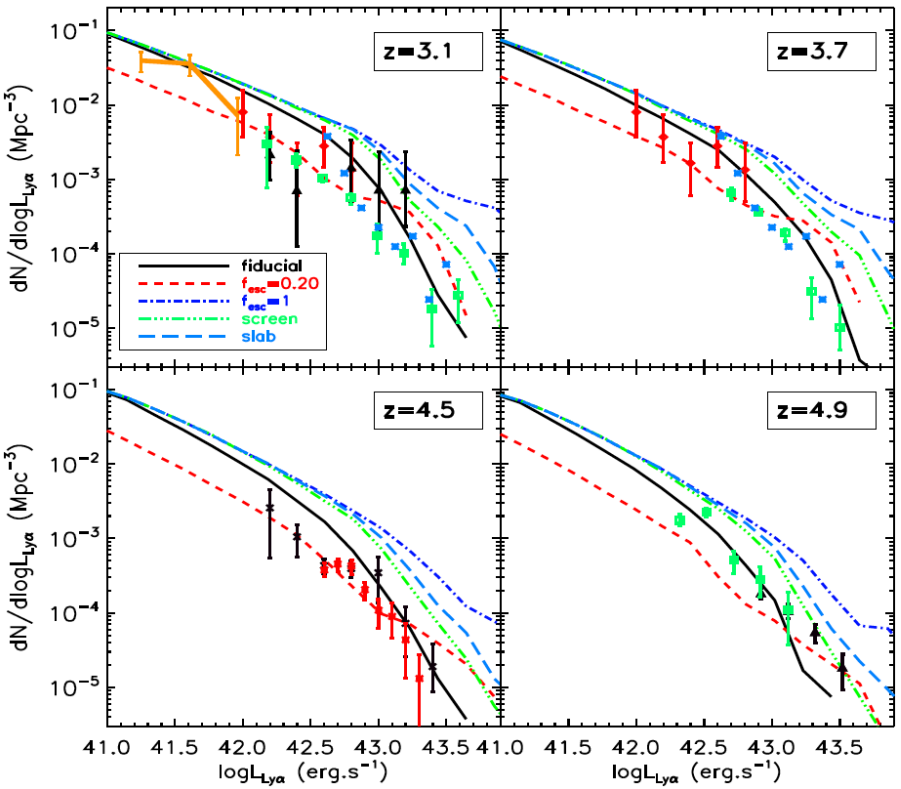
  Ledelliou+2006, Kobayashi+07-10,Dayal+08-09-11

- new coupling Lyα RT results with SAM

  Forrero-romero+11-12, Garel+12, Orsi+12

- Statistical approach

Garel+2012



semi-analytical modeling including Lyα RT

modeling high-z LAEs

- a long-time effort

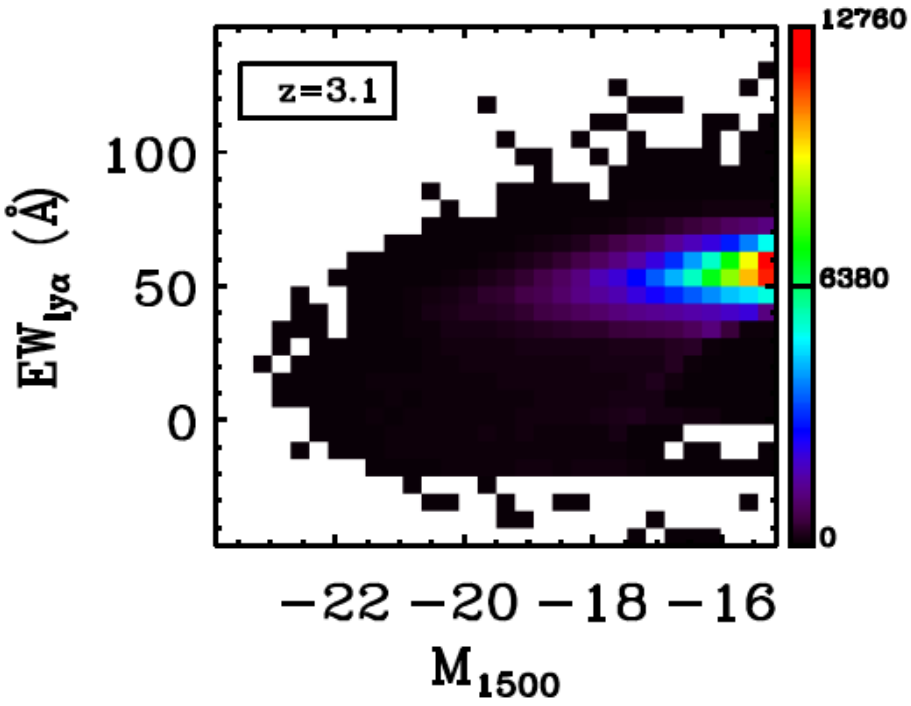
  Ledelliou+2006, Kobayashi+07-10,Dayal+08-09-11

- new coupling Lyα RT results with SAM

  Forrero-romero+11-12, Garel+12, Orsi+12

- Statistical approach

Garel+2012



semi-analytical modeling including Lyα RT

modeling high-z LAEs

- a long-time effort

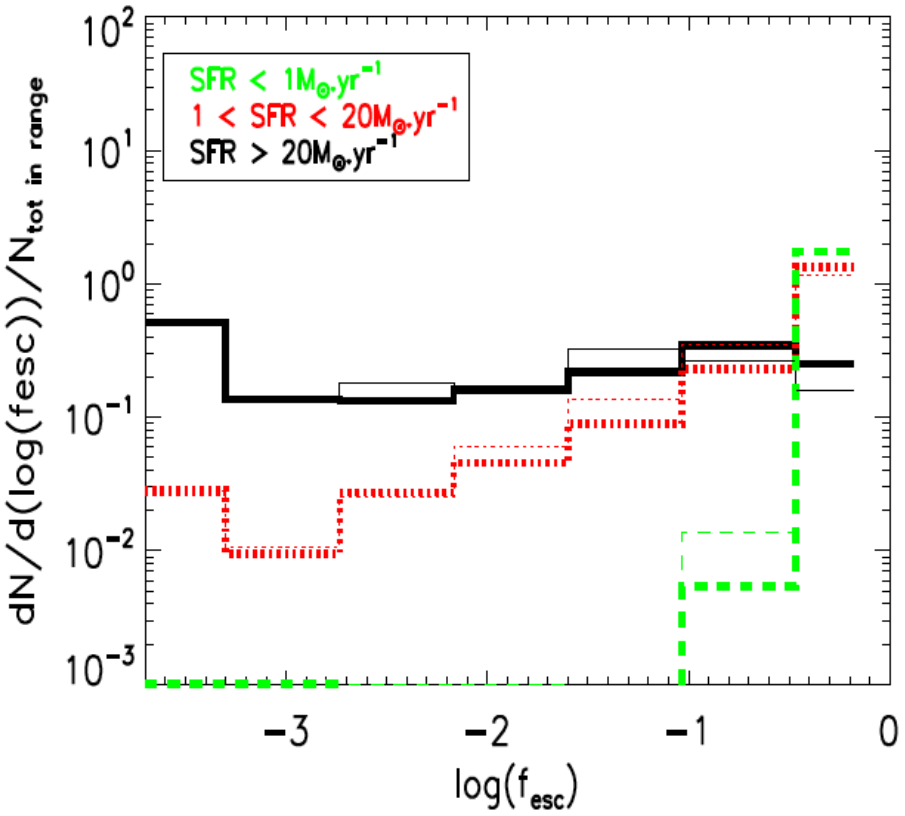
  Ledelliou+2006, Kobayashi+07-10,Dayal+08-09-11

- new coupling Lyα RT results with SAM

  Forrero-romero+11-12, Garel+12, Orsi+12

- Statistical approach

Garel+2012



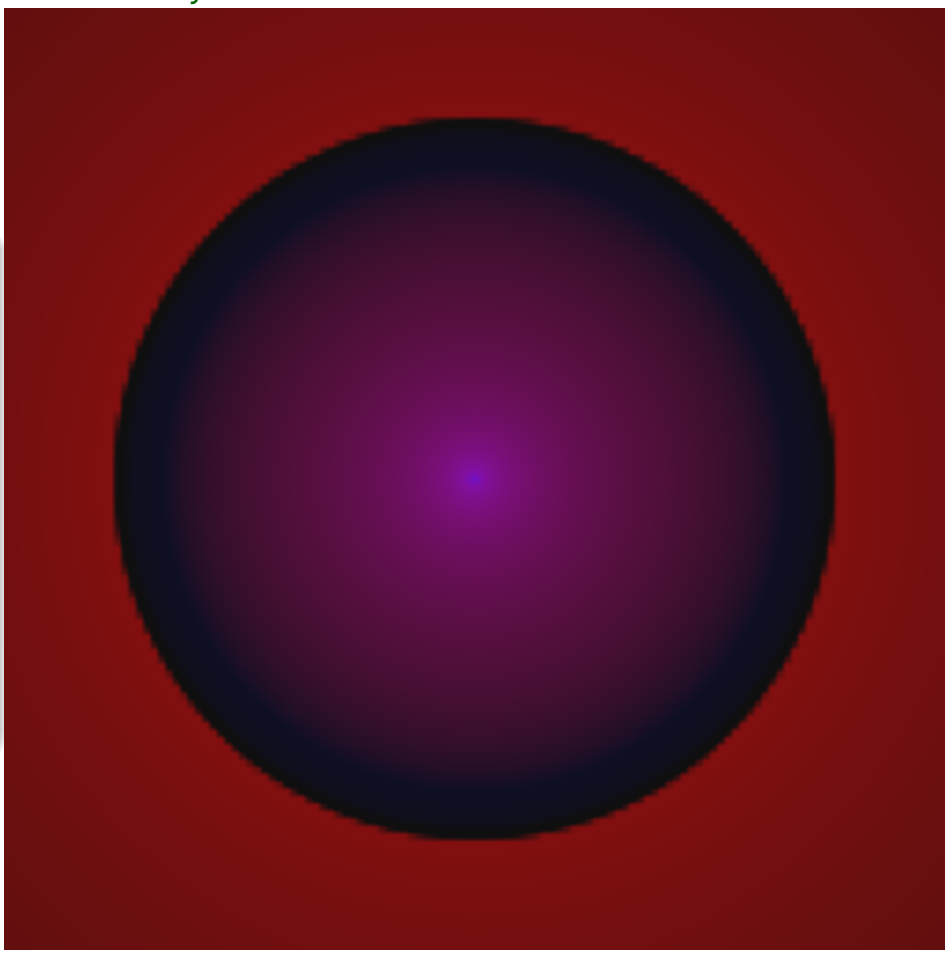
Hydrodynamical simulation of an idealised galaxy

hydrodynamics

- RAMSES *Teyssier 2002*
- AMR technics
- coupled ionising transfer

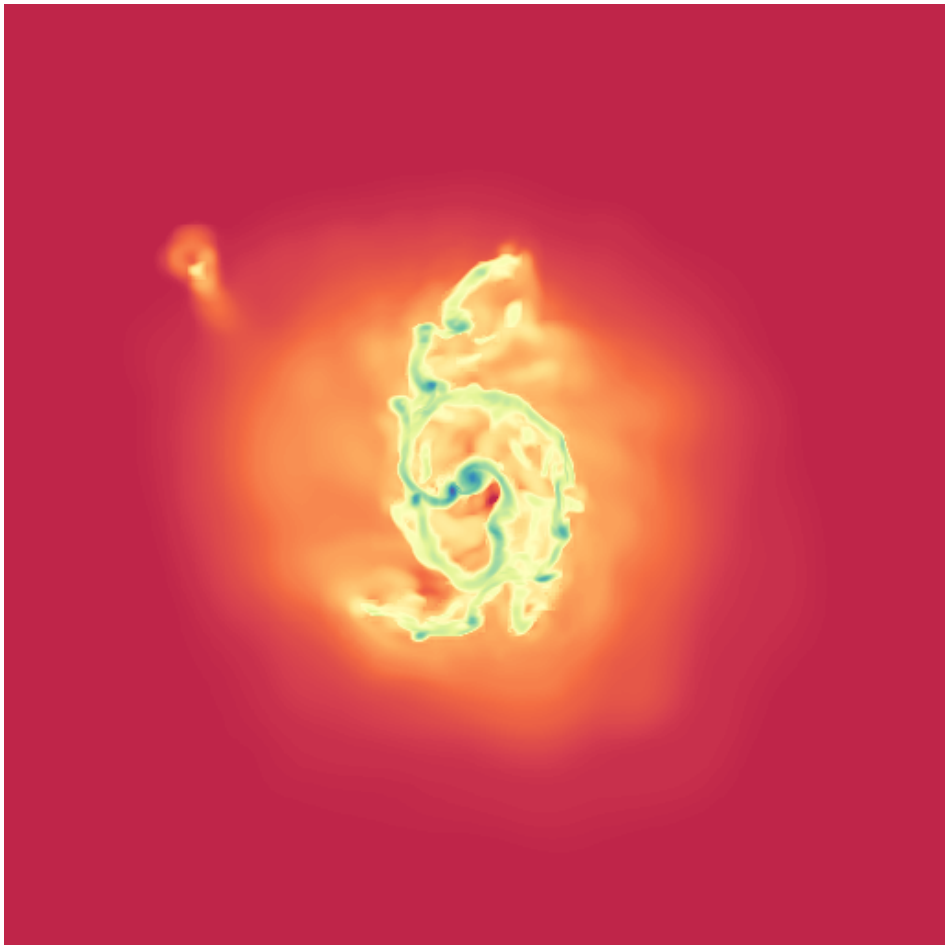
  Rosdahl & Blaizot 2012
- interfaced with McLya

Dubois & Teyssier 2008

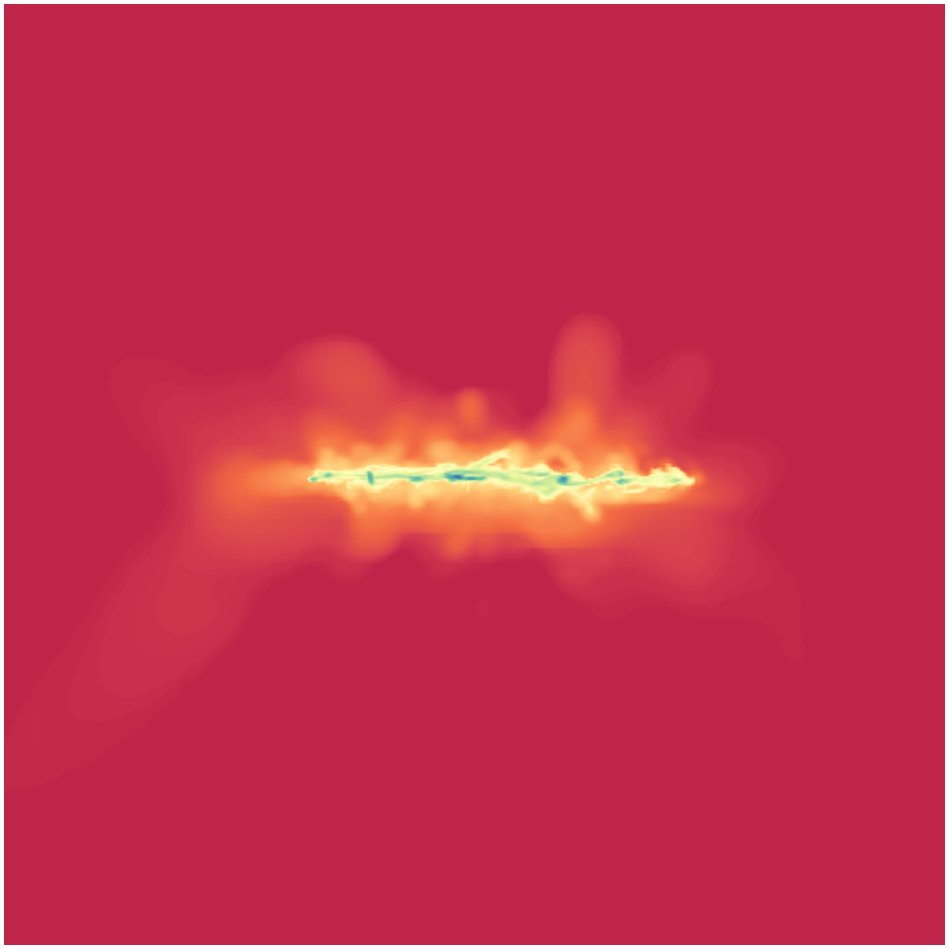


Orientation effects on Lyα properties *Verhamme+12*

G2 face-on

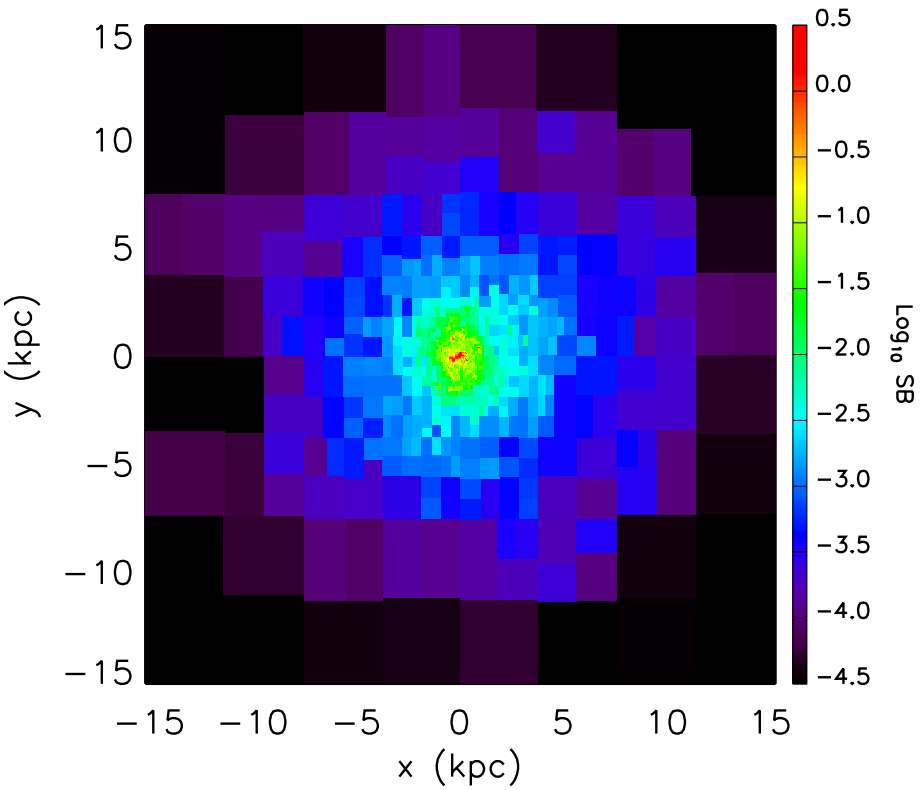


G2 edge-on

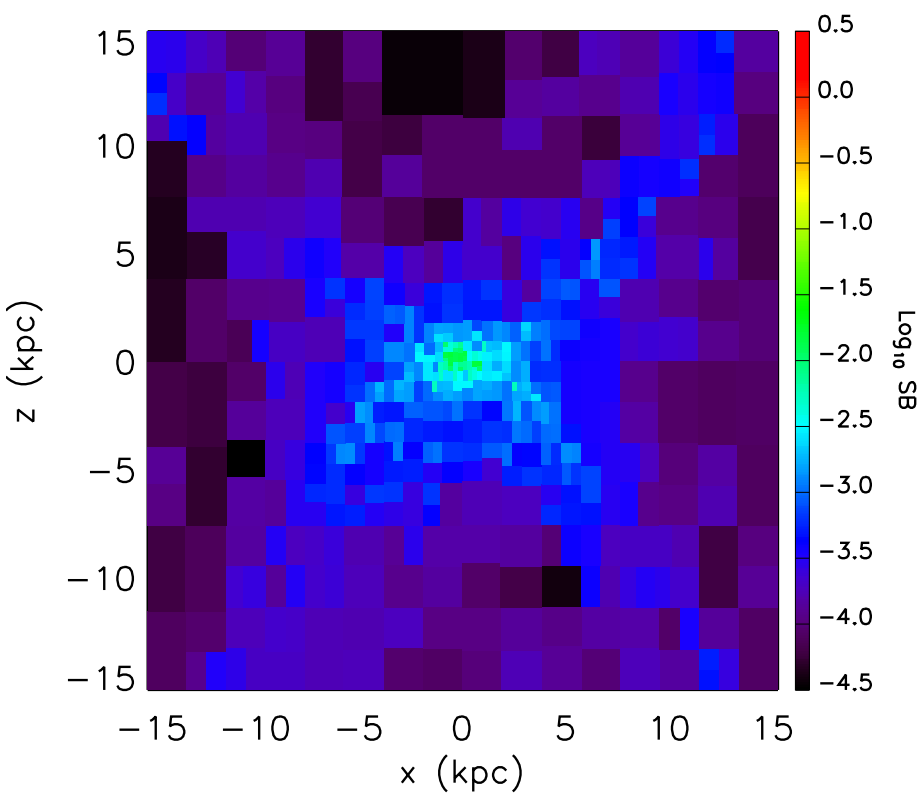


Orientation effects on Lyα properties

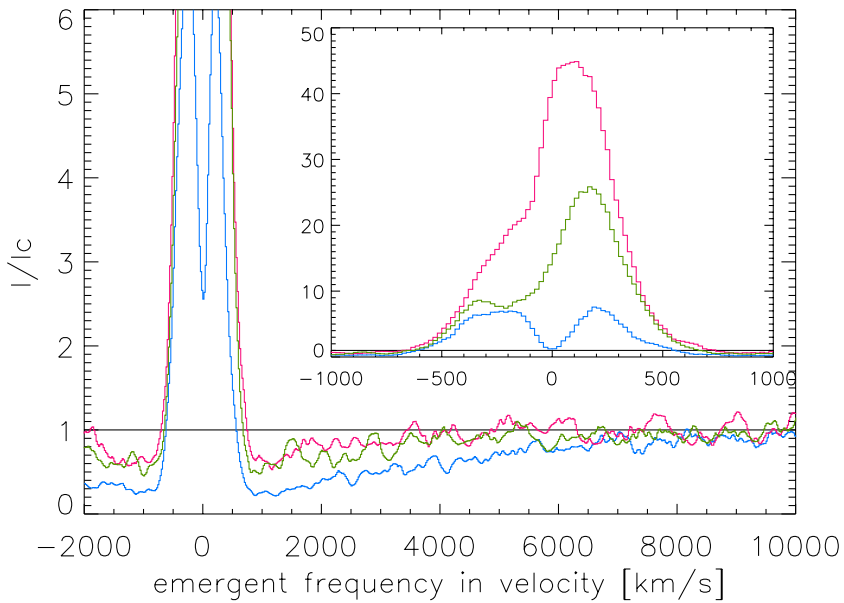
G2 face-on

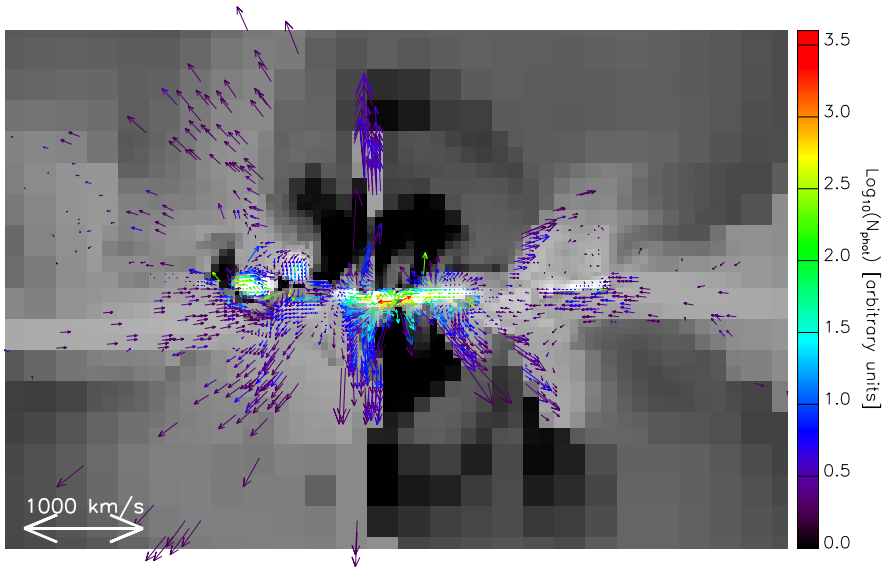


G2 edge-on

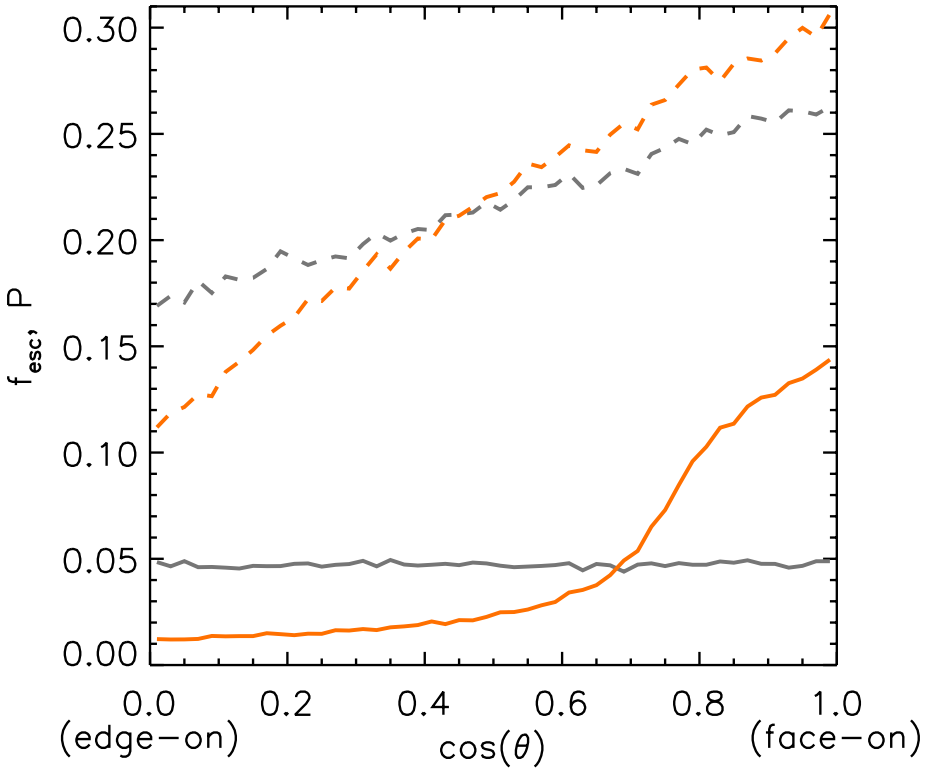


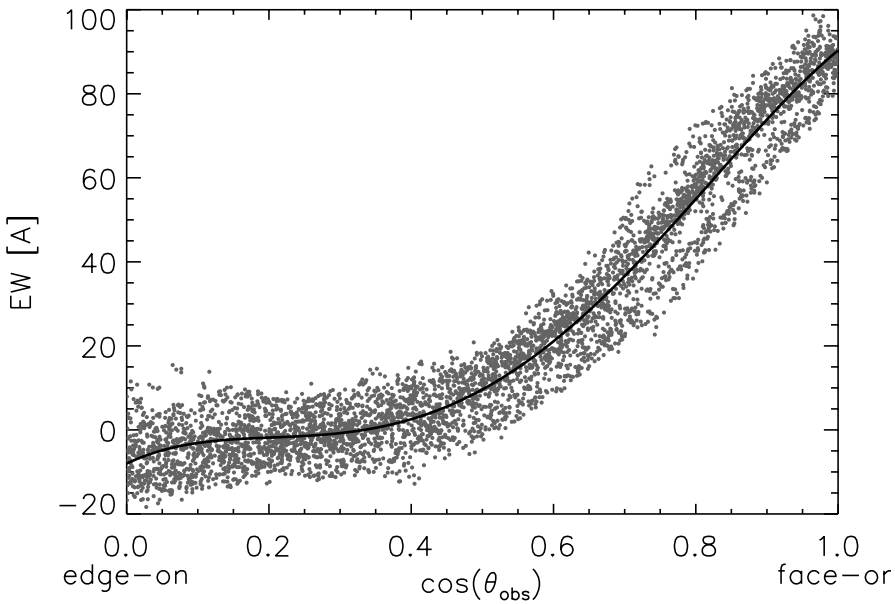
Orientation effects on Lyα properties



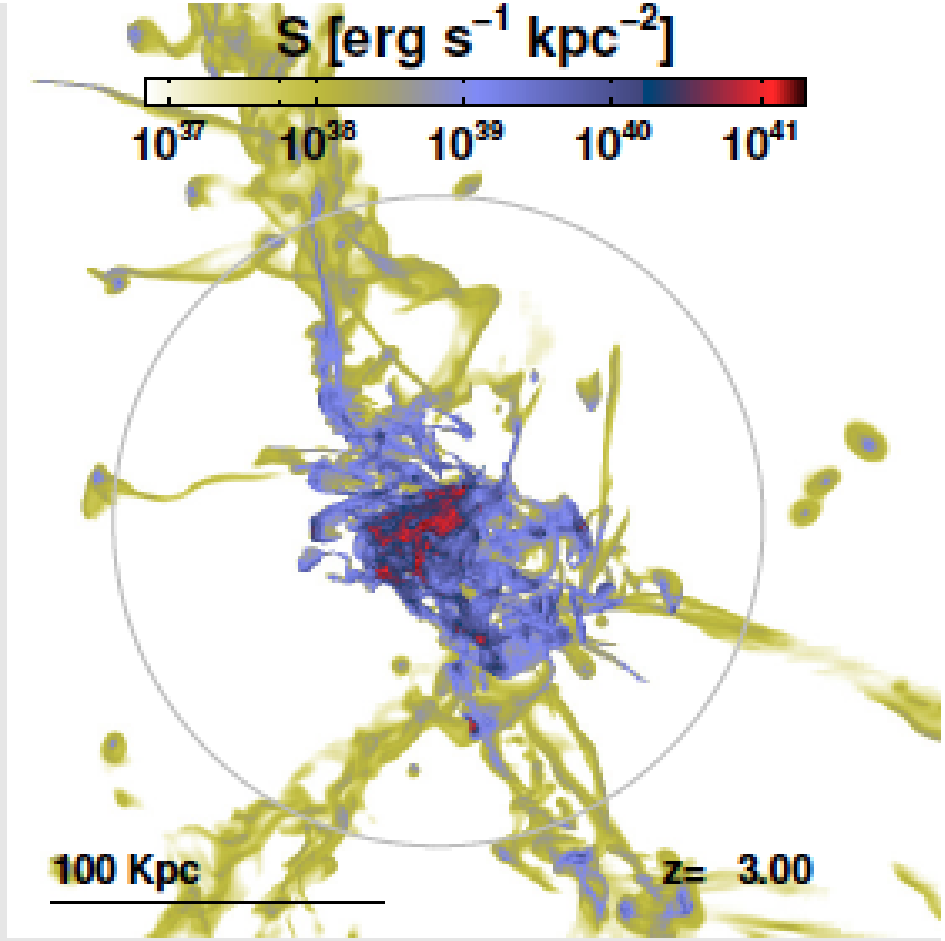


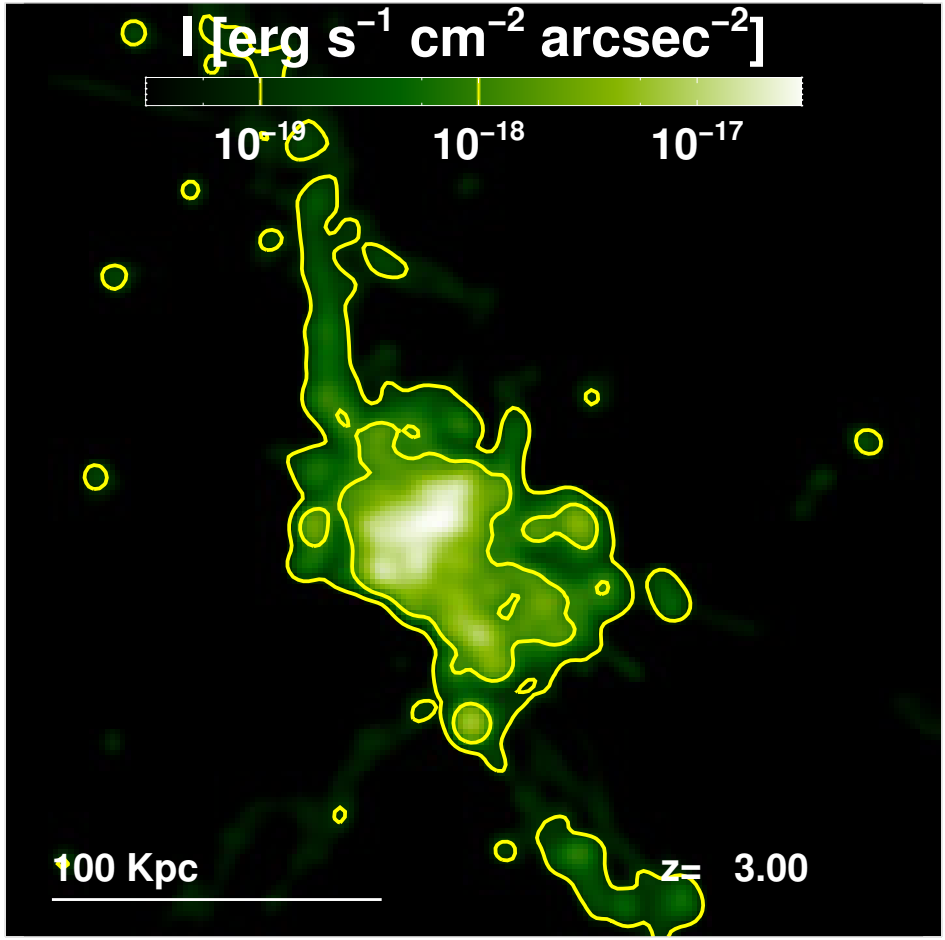
Orientation effects on Lyα properties





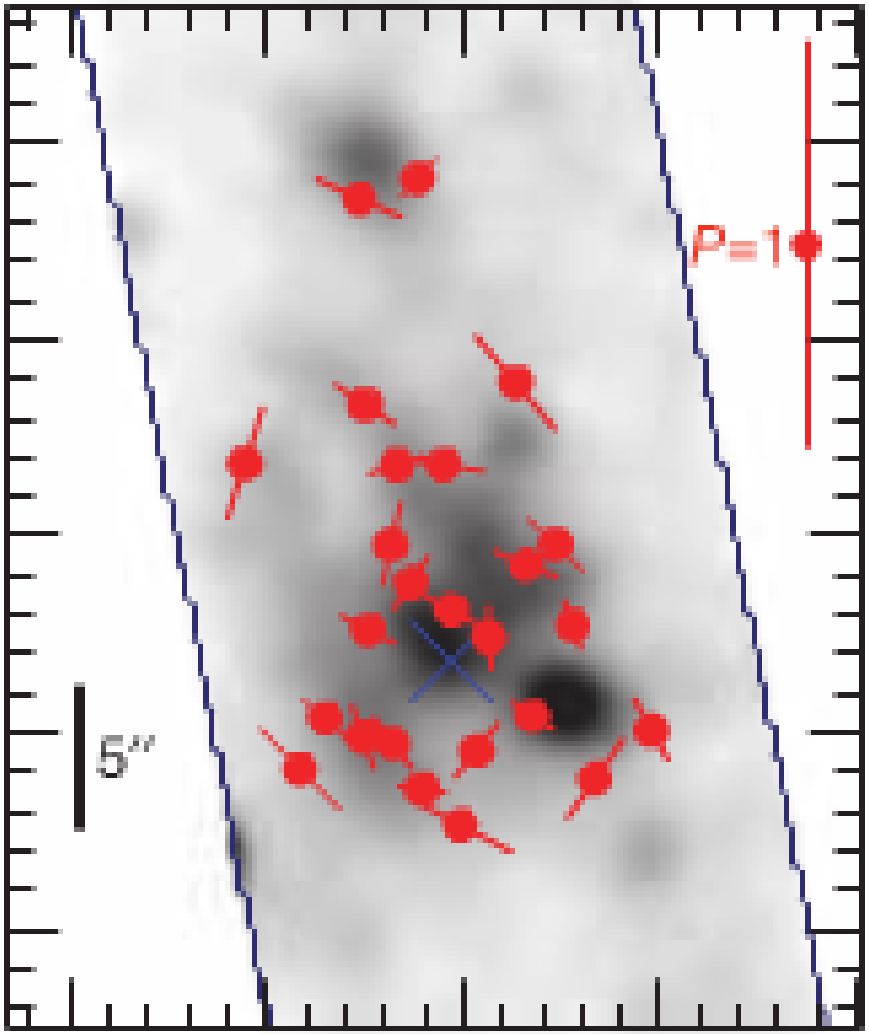
Simulations of Lyα-blobs *Rosdahl& Blaizot, 2012*



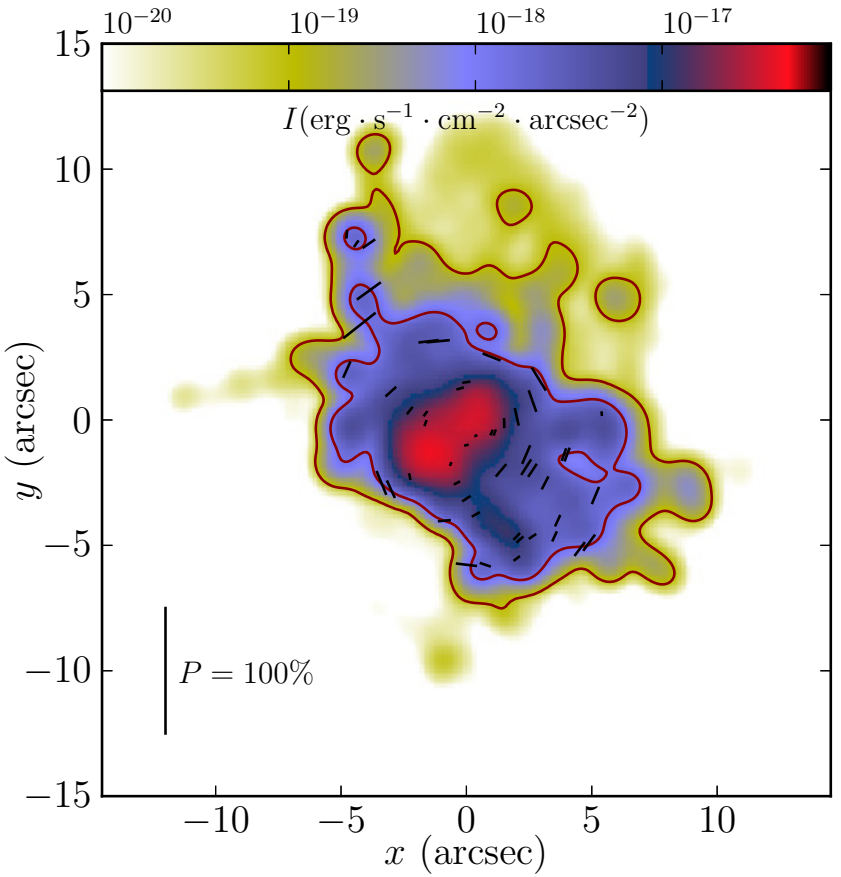


Lyα polarisation *Dijkstra+08, Trebitsch+13 et al in prep*

Hayes+11

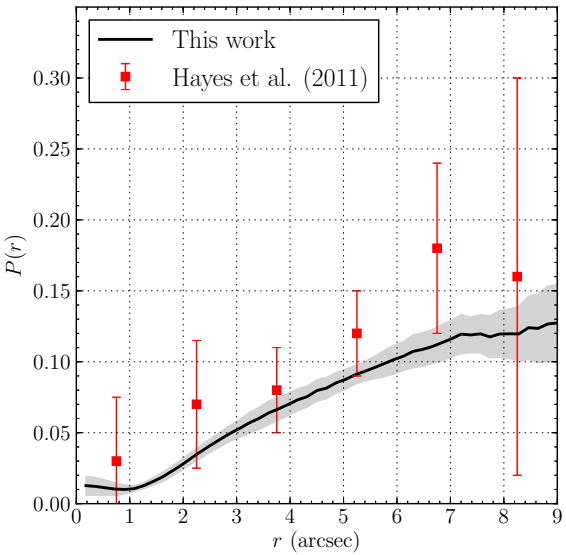


Trebitsch+13

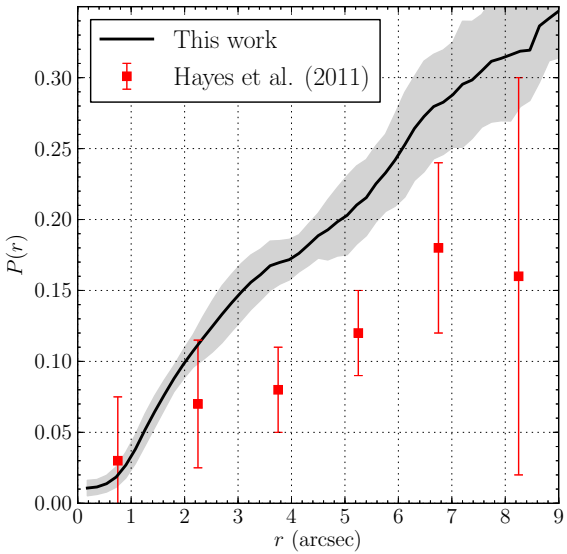


Is Lyα polarisation powered by central source ? Or in situ emission ?

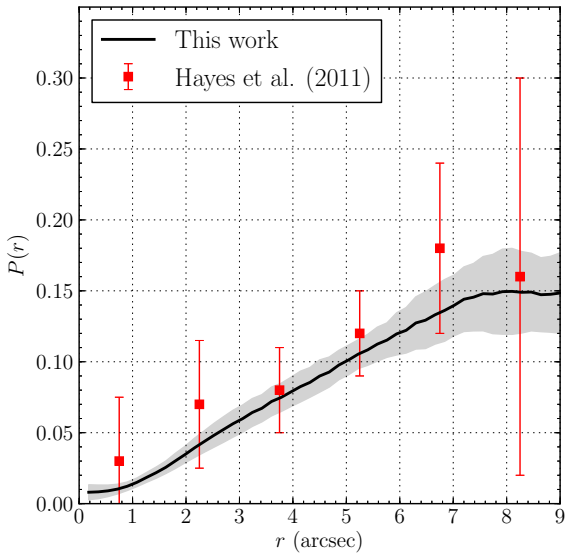
source = gas only



source = stars only



source = gas + stars



Trebitsch, Blaizot, Verhamme & Rosdahl 2013, submitted

Conclusions

Lyα radiation transfer studies help understanding/interpreting...

- Lyα spectral shapes of unresolved sources, to derive velocity fields, column densities, dust contents
- orientation effects on the Lyα properties of isolated disks
- or the mecanisms powering Lyα-blobs

Further prospects

- check the universality of our conclusions about blobs (only 1 obs and 1 sim !),
- and orientation in cosmological context,
- work on the impact of different sub-grid recipes used in the hydrodynamical simulations (star formation, SN feedback,etc...)
- work on spatially resolved Lyα properties of galaxies