Mark Dijkstra (MPA), Austin, May 2012

On the Detectability of Lyman Alpha Emission by Galaxies from the Epoch of Reionization

Mark Dijkstra (MPA, Garching)

Outline

Why we care about the HI Lya line.

Lya transfer basics.

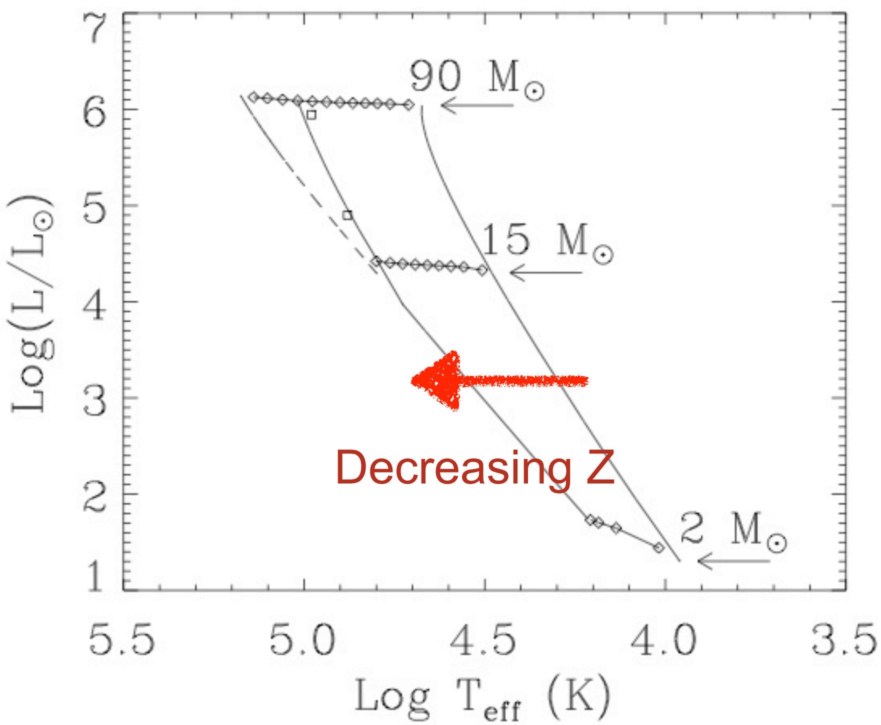
Why direct detection of Lya emission from galaxies during the early stages of reionization is plausible. A reionization signature on Lya emitters is subtle.

Observational fact that we see evolution in LAE LF + `Lya fraction' in drop-outs at $z>6$ potentially indicative of rapid changes in x_{HI}.

The Future.

Stellar atmospheres hotter at low metallicity.

Tumlinson & Shull `00

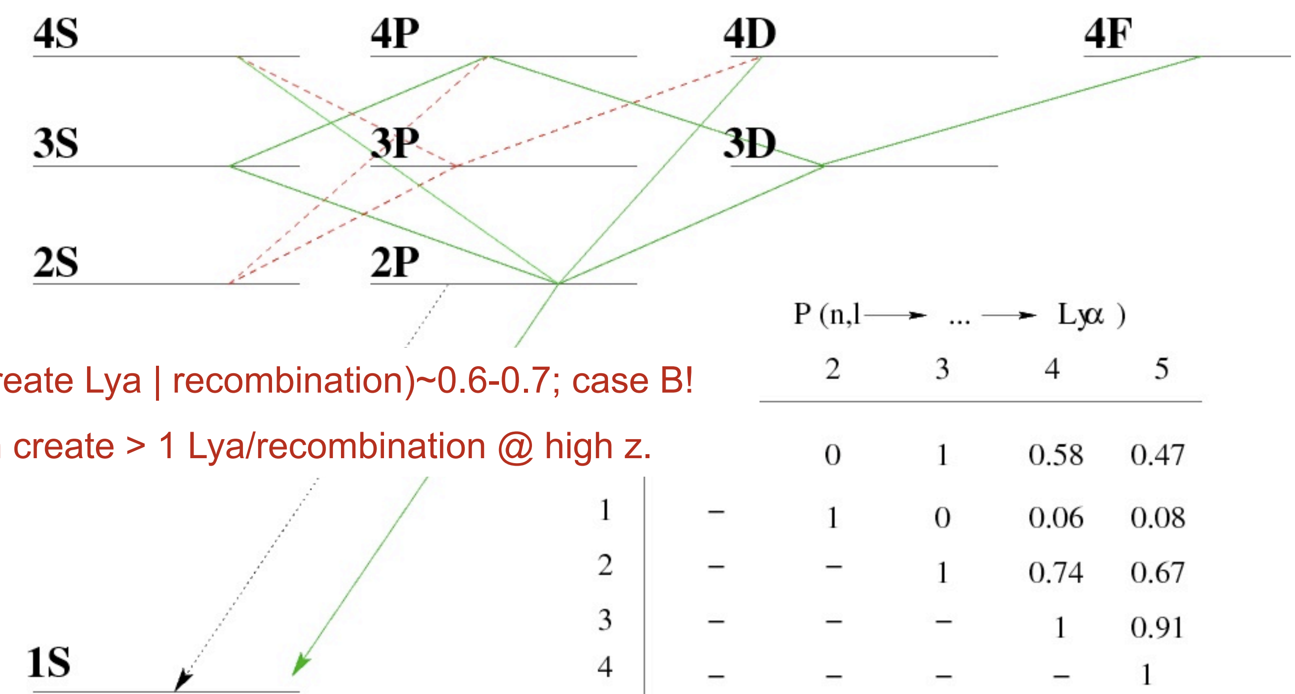


Massive stars: effective T increases from few tens kK to ~ 100 kK.

--> >10 times more ionizing photons!

Lyα from Recombination

- Radiative cascades following recombination into H level n,l



P(create Lya | recombination)~0.6-0.7; case B!

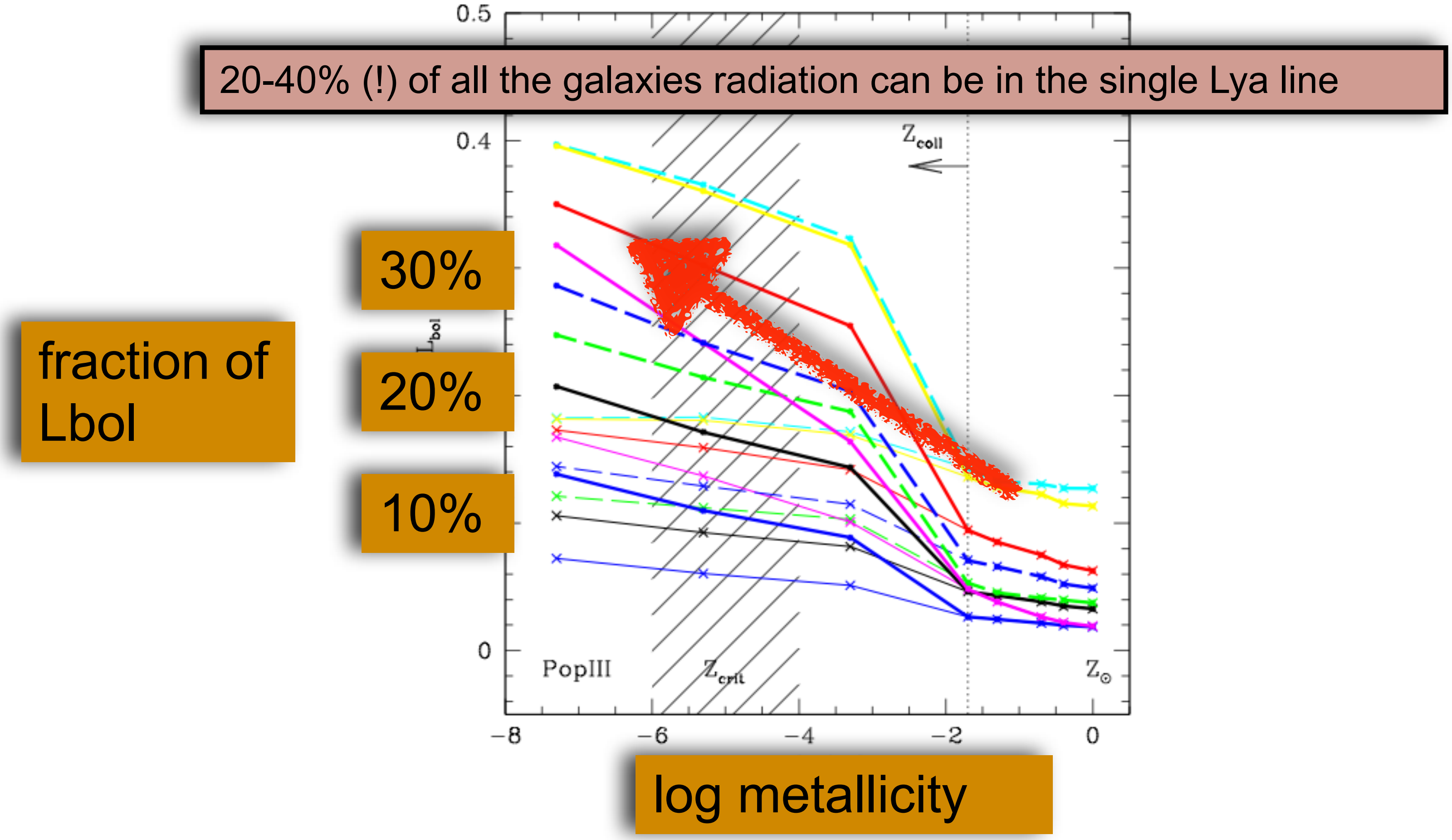
Can create > 1 Lya/recombination @ high z.

P (n,l → ... → Lyα)

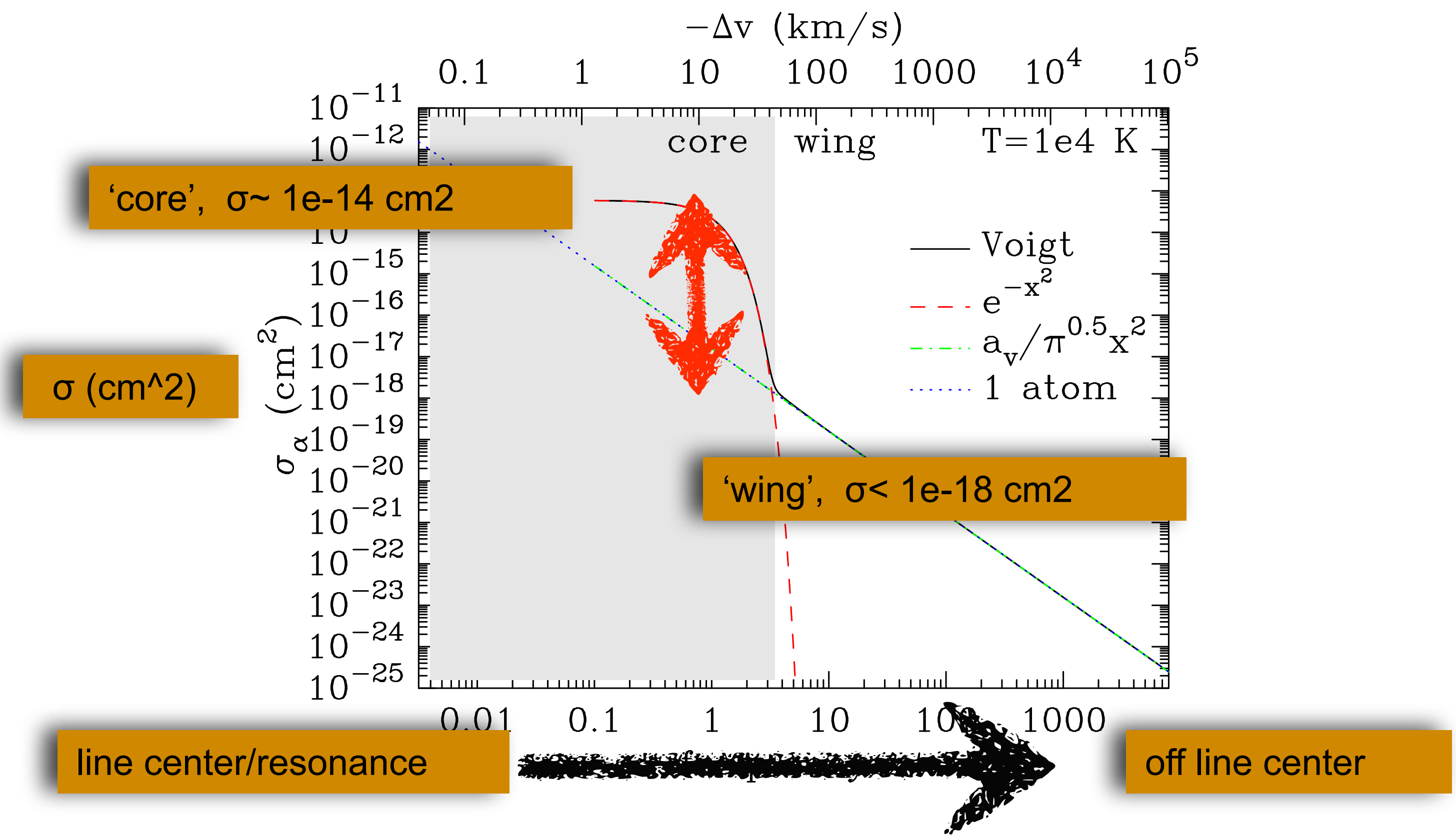
		2	3	4	5
		0	1	0.58	0.47
1	–	1	0	0.06	0.08
2	–	–	1	0.74	0.67
3	–	–	–	1	0.91
4	–	–	–	–	1

Lya Emission from `Early' Galaxies

Raiter et al. 2010



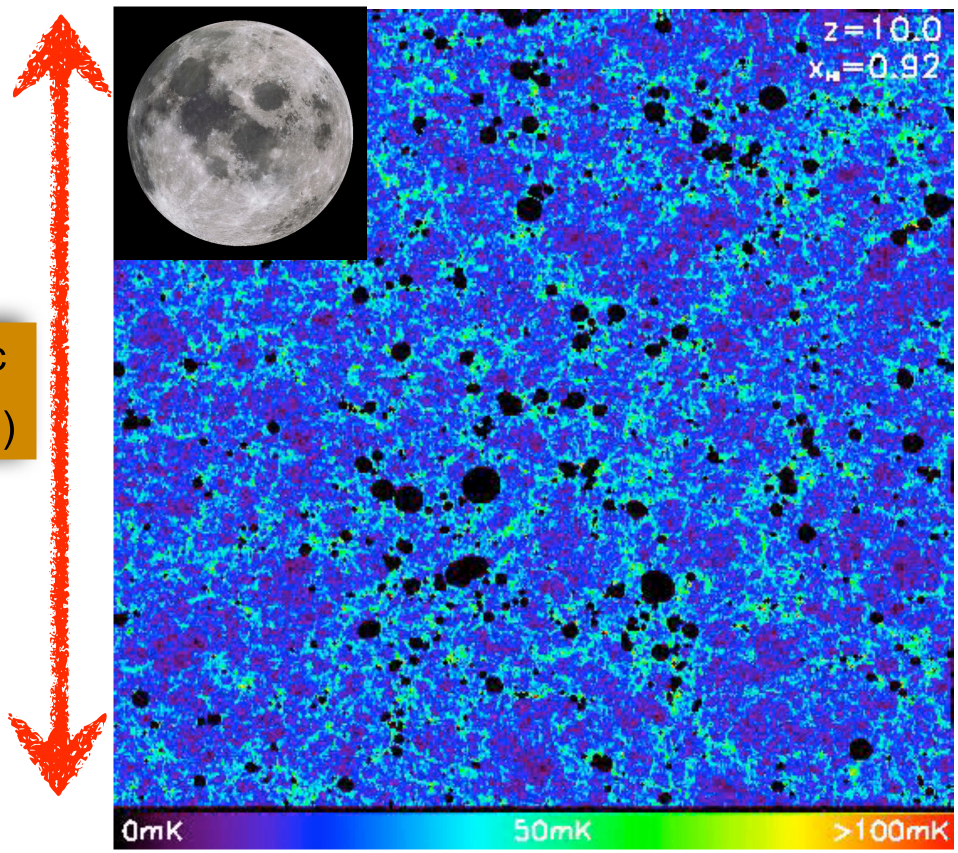
Lyman Alpha Transfer in a few slides I: the Lyα absorption cross-section.



`Inhomogeneous Reionization'

250 Mpc

(1-2 deg)



movie made by Andrei Mesinger

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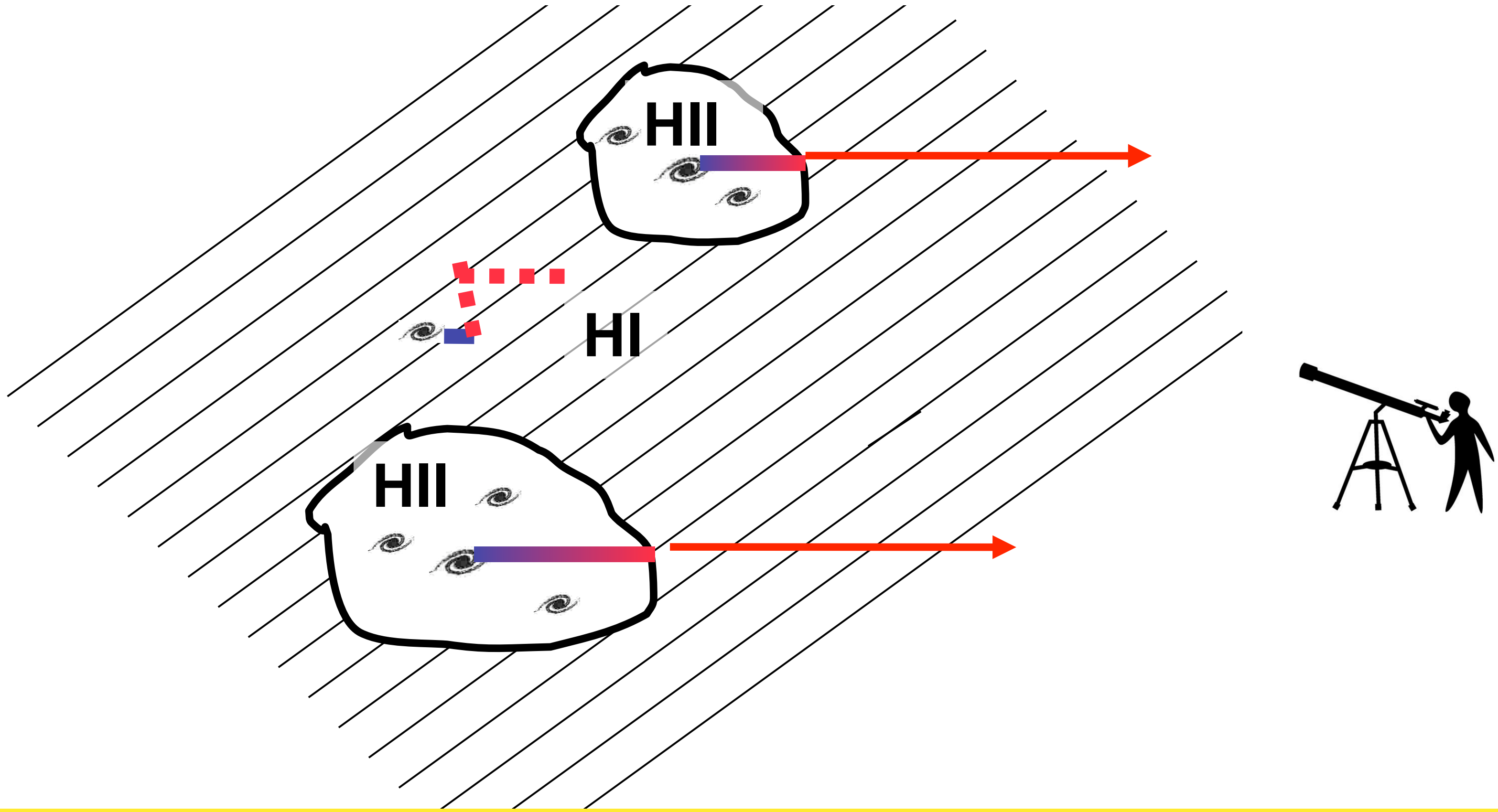
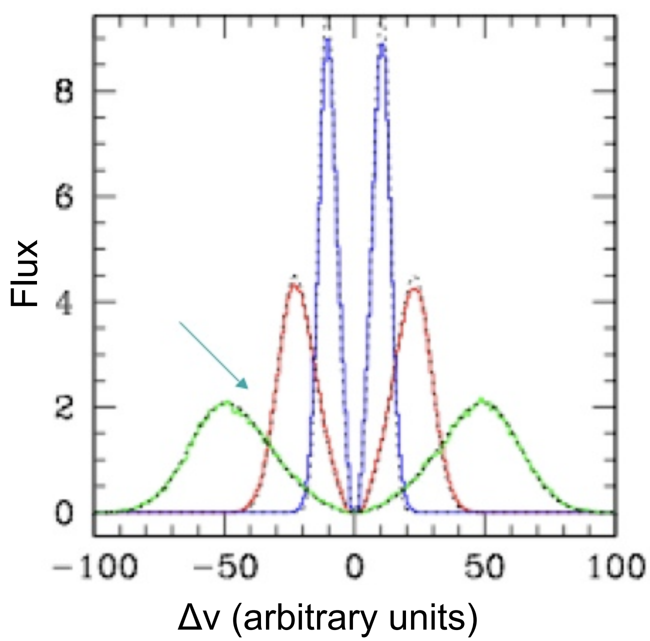
Lyα Transfer during the EoR

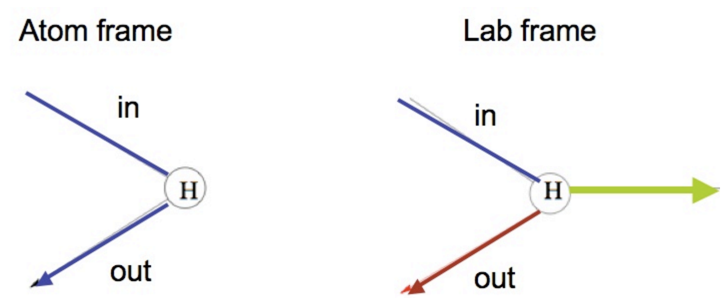


Inhomogeneous reionization boosts visibility of Lya emission line
(e.g. Furlanetto+05, McQuinn+07, Iliev+08, Mesinger & Furlanetto 08, MD+11)

Lyman Alpha Transfer in a few slides II: Frequency + real space 'diffusion'

- Following absorption -reemission occurs instantly -> 'scattering'.
- As Lyα scatters through real space, it diffuses in frequency space. Further from line center, Lyα photons escape easier from very opaque media.



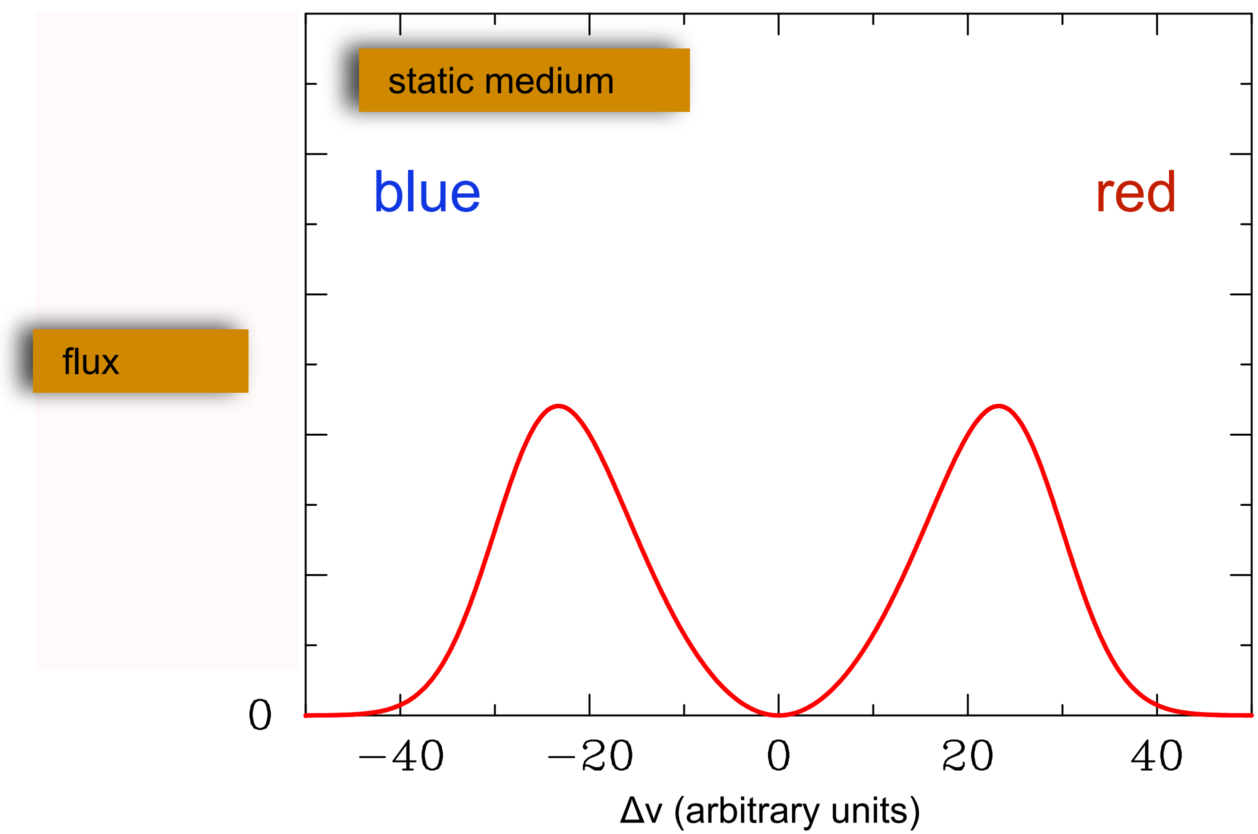


For uniform static slab/sphere

$\Delta v = \pm 160 (N_{HI}/1e20)^{1/3} (T/1e4)^{1/6}$ km/s

e.g. Adams 1972, Neufeld 1990

Lyman Alpha Transfer in a few slides III: the spectrum



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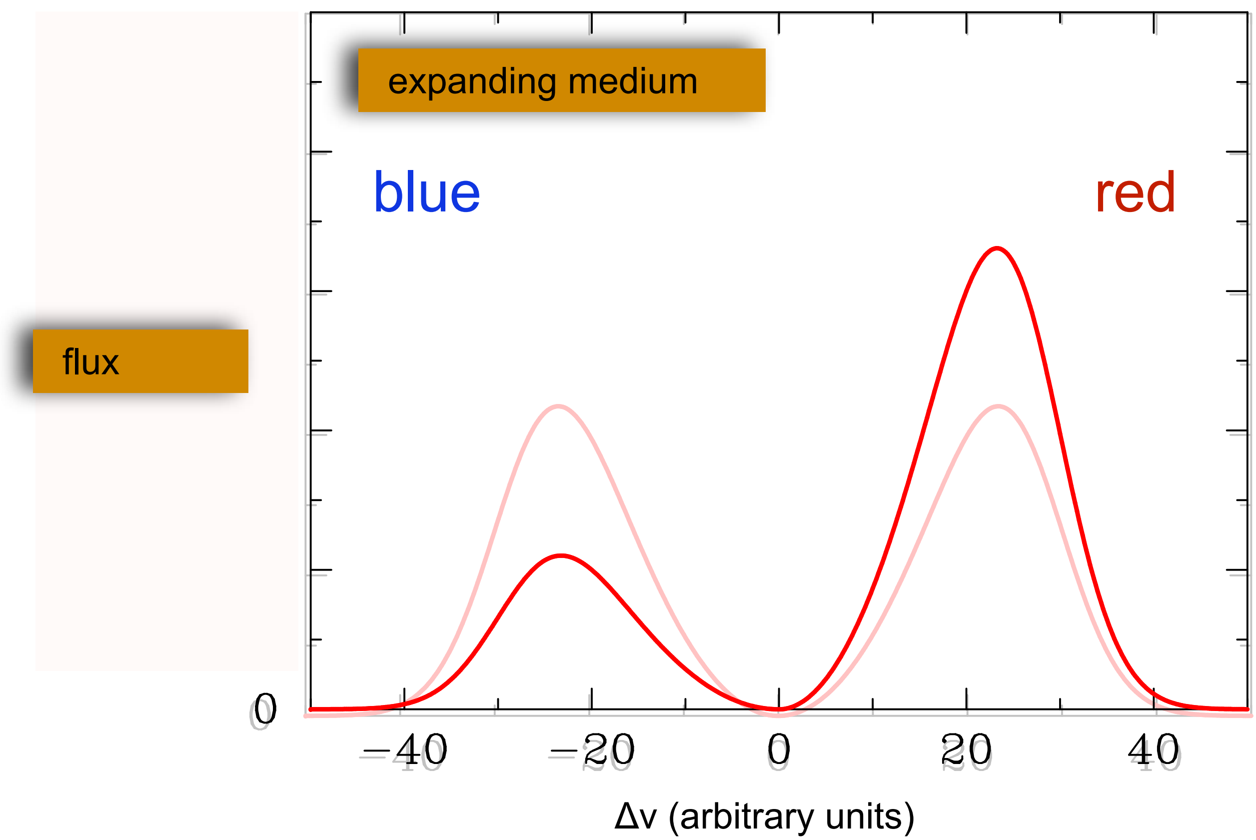
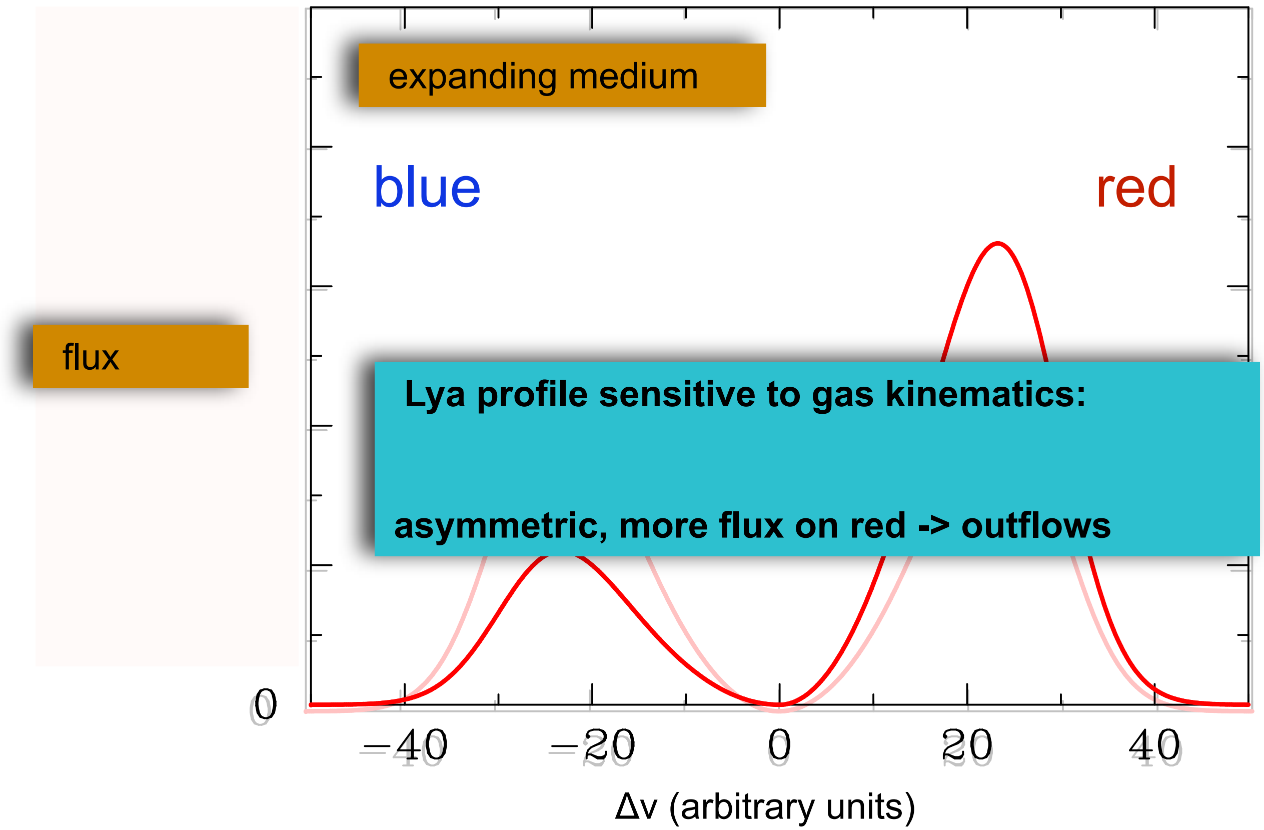
Lyman Alpha Transfer in a few slides III: the spectrum



Lyman Alpha Transfer in a few slides III: the spectrum



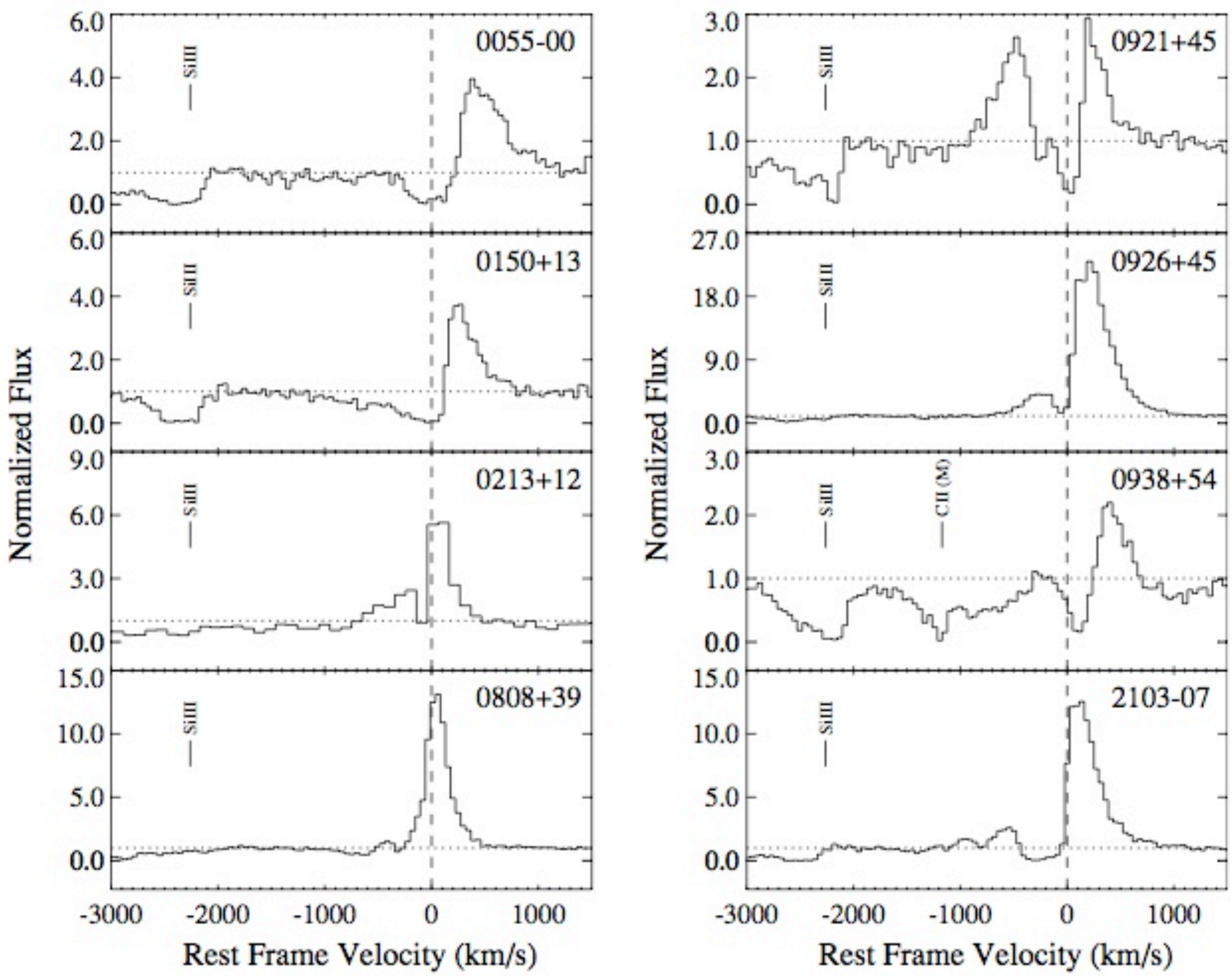
Lya profile sensitive to gas kinematics:

asymmetric, more flux on red -> outflows

Some Observed Line Profiles I: z~0

Heckman+11

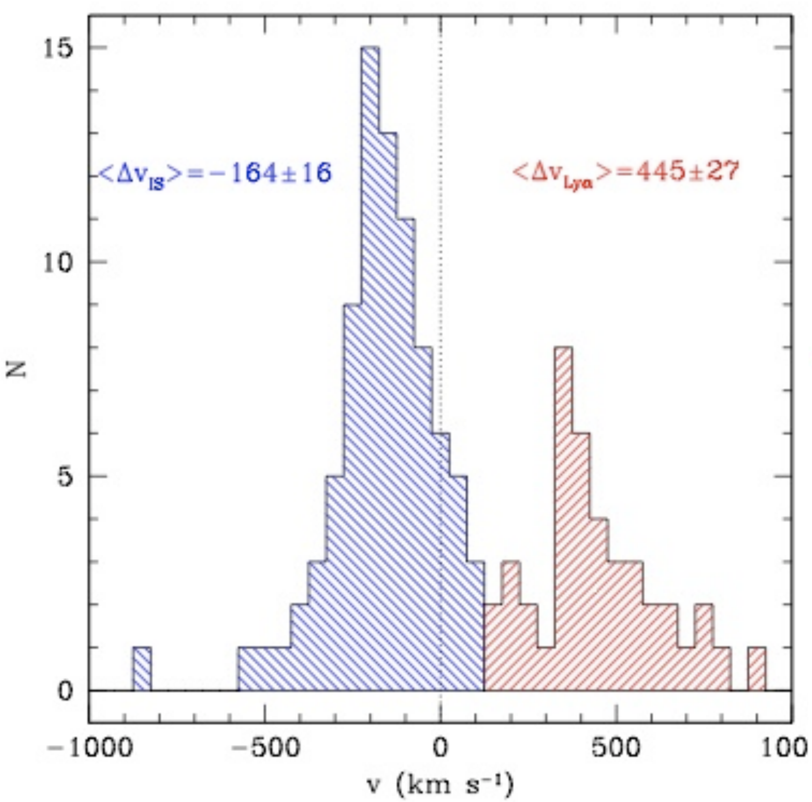
blue

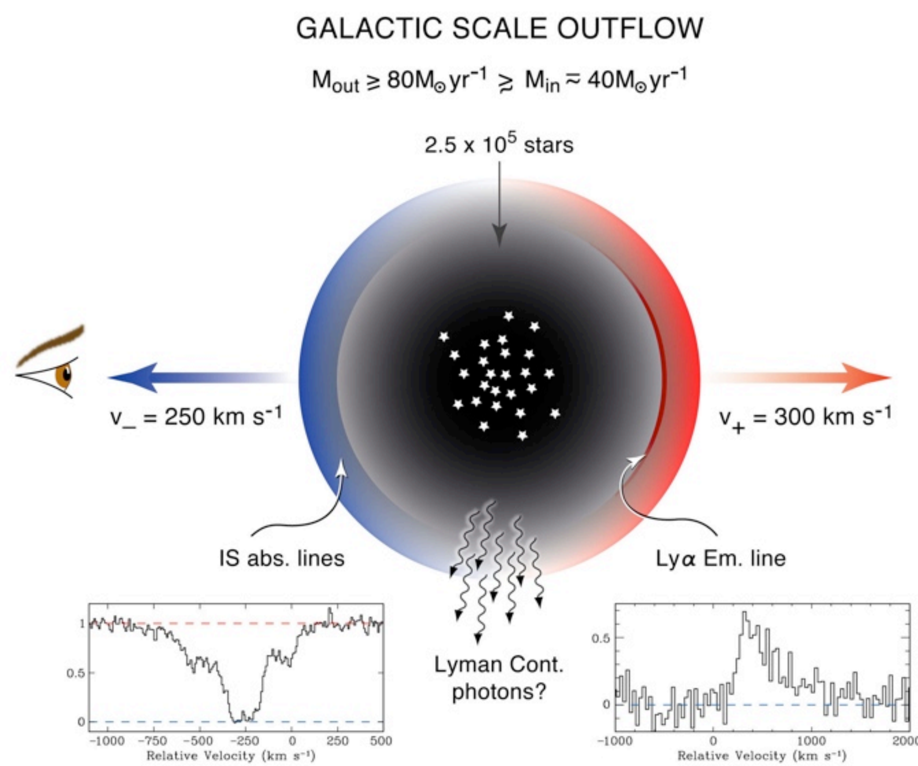


red

Lya Transfer in Observed Galaxies:

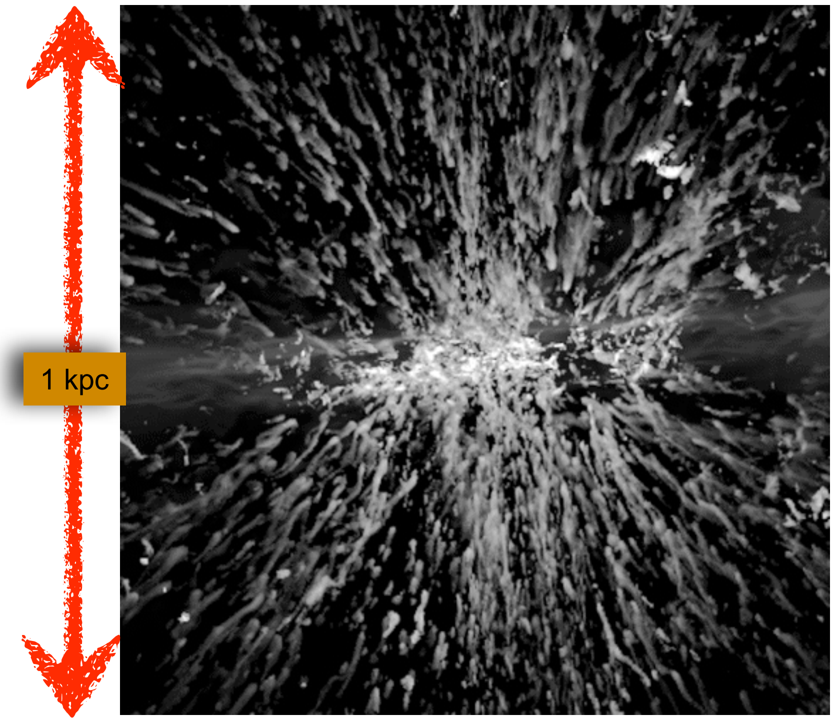
- Winds present in all galaxies (Steidel+10) AND winds affects Lya spectrum.





credit: Max Pettini

Modeling Cold Gas in Outflows is Hard



Cooper et al. 2008

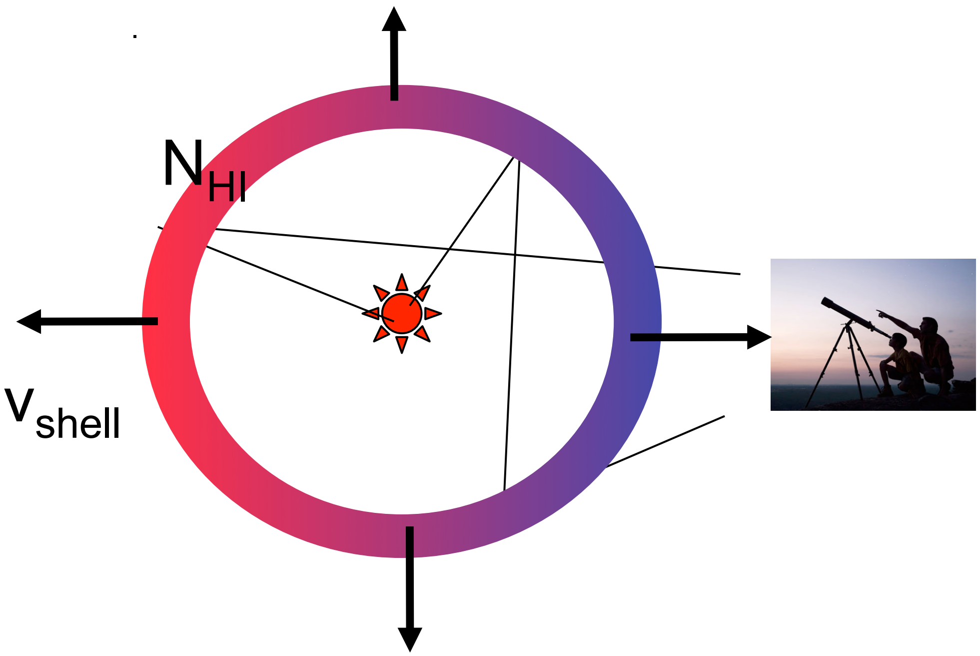
1. important to resolve instabilities -> determines acceleration. Requires ~0.1 pc res. (Fujita+2009)

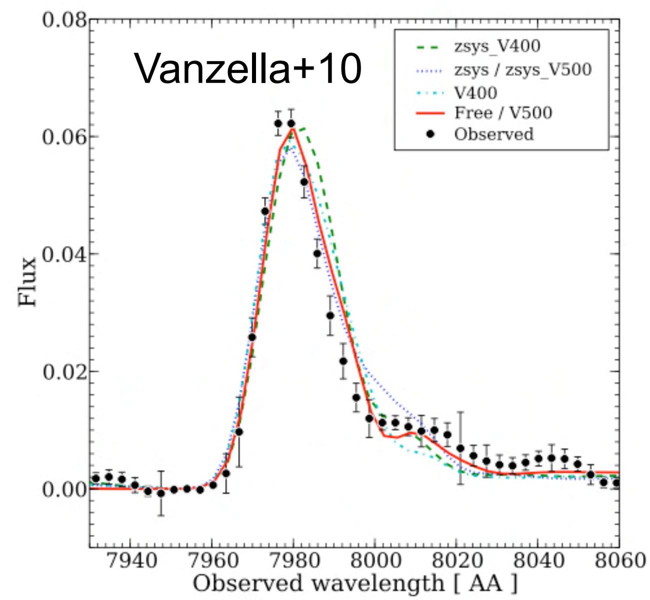
2. fate of cold clumps in hot wind?

3. Physics not included:
   a. magnetic fields
   b. thermal conduction
   c. radiation pressure (cosmic ray pressure)
   d. non-equilibrium cooling
   e. photoionization
   .....

Shells as `Subgrid' Model for Lyα Transfer in Galaxies

Observed Lya line shape (z<6) can be reproduced using spherical shells of outflowing HI gas, with column density N_{HI} and outflow speed v_{shell}





Ahn+03, Verhamme+06,+08, Atek+08,09, Vanzella+09, Dessauges-Zadavsky+10

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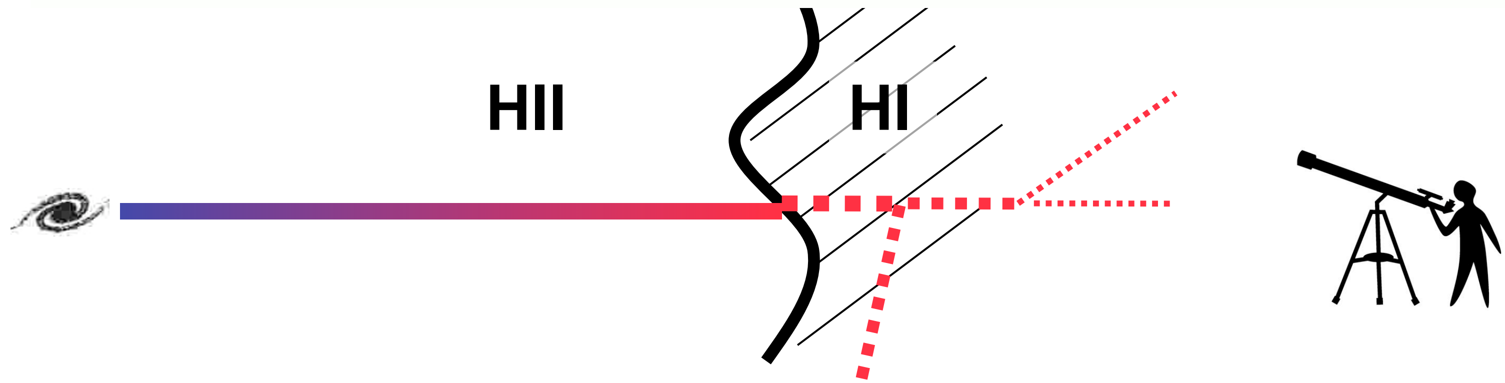
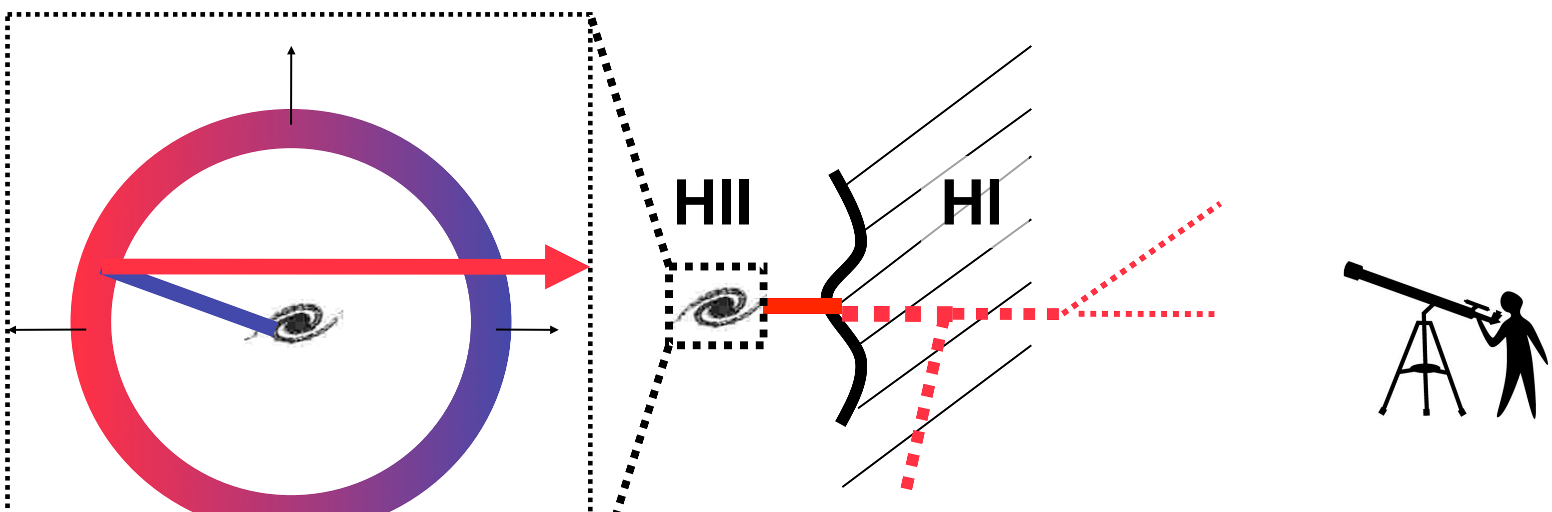
Getting a head-start: Winds in Galaxies

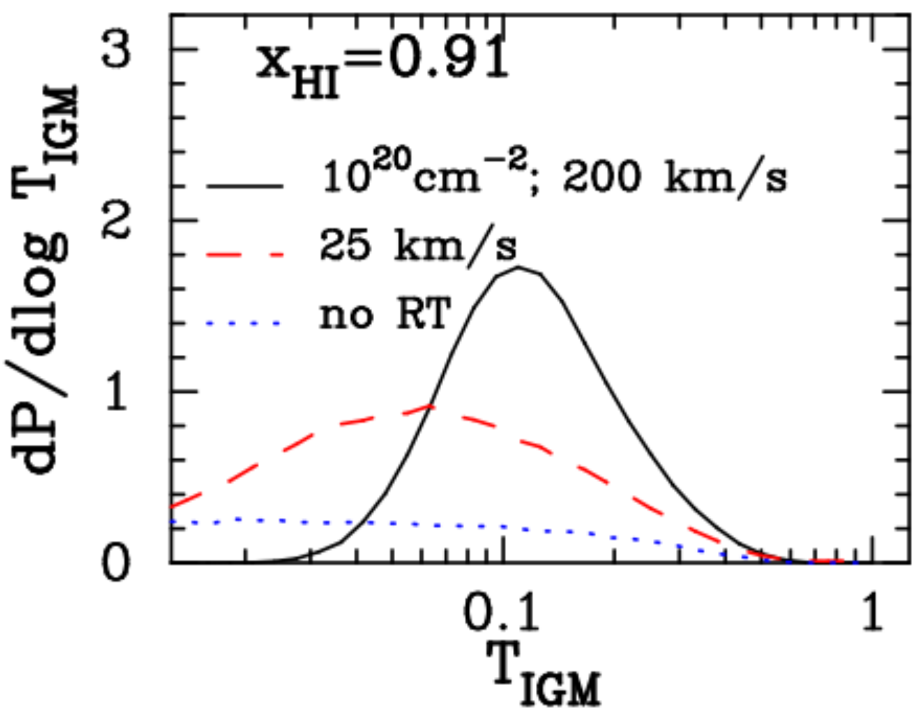




MD & Wyithe 2010, MNRAS

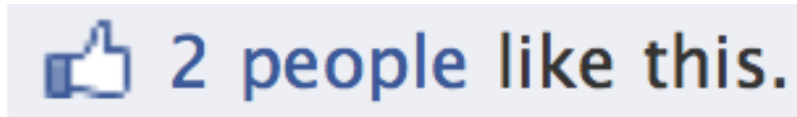
Inhomogeneous reionization + winds both help to boost visibility of Lya emission line

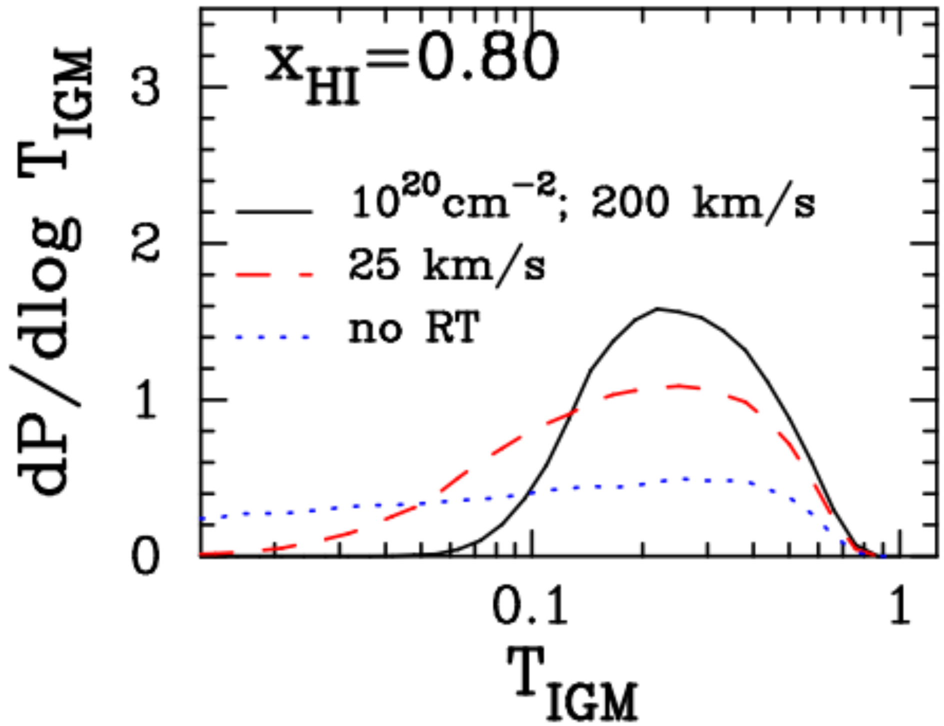
The visibility of LAEs during the EoR



MD, Mesinger & Wyithe 2011, MNRAS

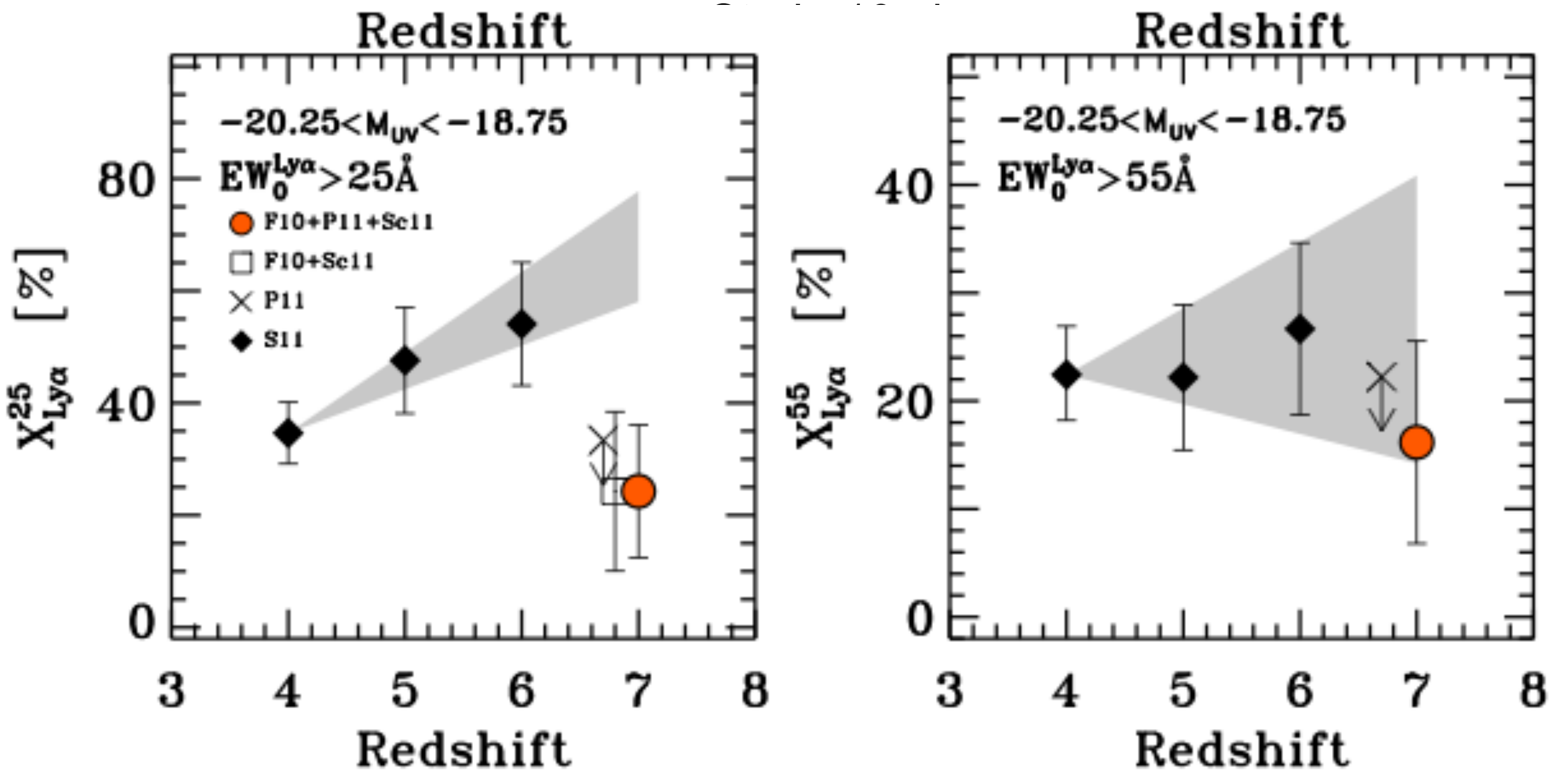
The visibility of LAEs during the EoR





MD, Mesinger & Wyithe 2011, MNRAS

LBG Observations



Lya emission less prominent from drop-out samples towards higher-z
(also see Stark+10, Fontanot+10, Stark+11, Pentericci+12, Schenker+12)

Conclusions & Outlook

HI Lya may account for up to ~40% of bolometric luminosity of the first, young galaxies.

The reionization signature on Lya emitters more subtle than suggested by `naive' models.

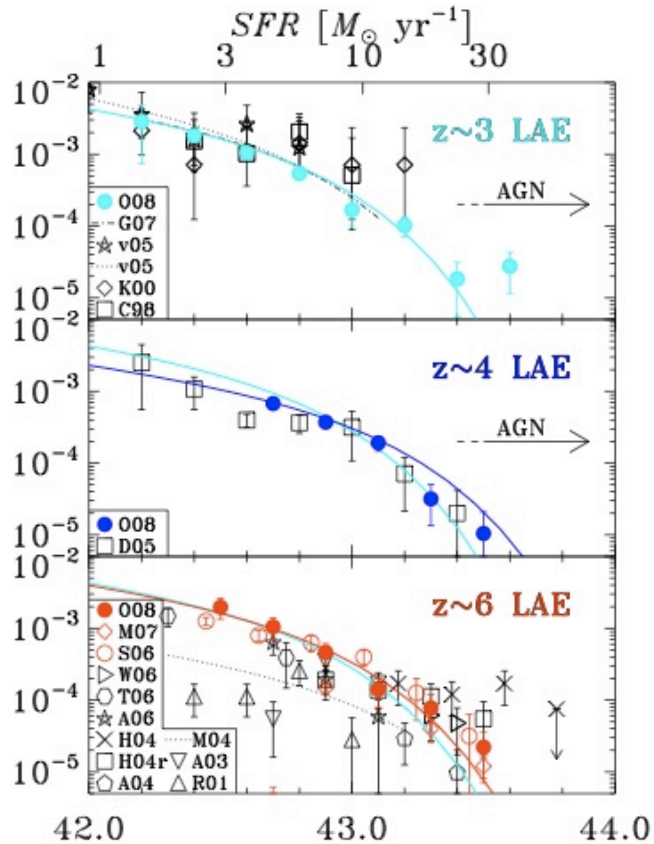
1. Inhomogenous reionization.
2. Lya transfer through outflows on < kpc scale.

Observational fact that we see evolution in LAE LF + `Lya fraction' in drop-outs at z>6 + very interesting, and potentially indicative of rapid changes in x_HI.

Tremendously promising field. Hyper Supreme Cam on Subaru + HET telescopes will increase the sample of LAEs by orders of magnitude, providing unique constraints on

1. reionization
2. gas flows in interstellar & circumgalactic medium

Redshift Evolution of LAEs at z<6:



number density

log Lya Luminosity

Ouchi+08

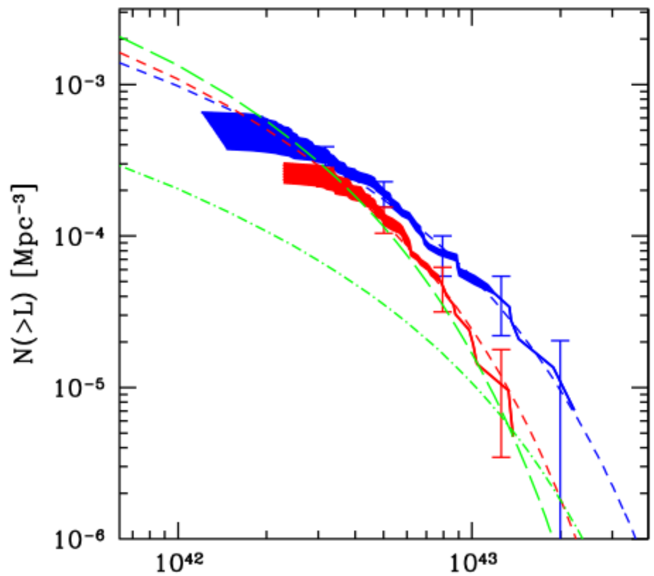
also see Hu+96

Redshift Evolution of LAEs at z>6:

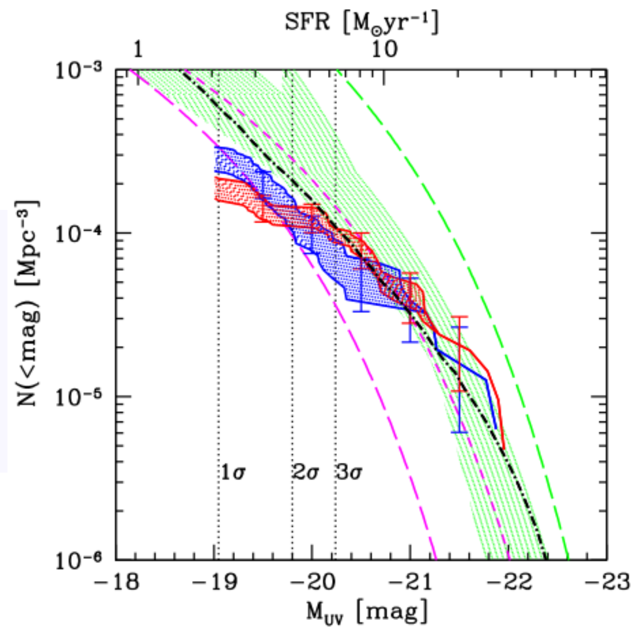
are we seeing an EoR signature?

number

density



Lya Luminosity



UV cont' Luminosity

89 LAEs observed at z=5.7 (blue)

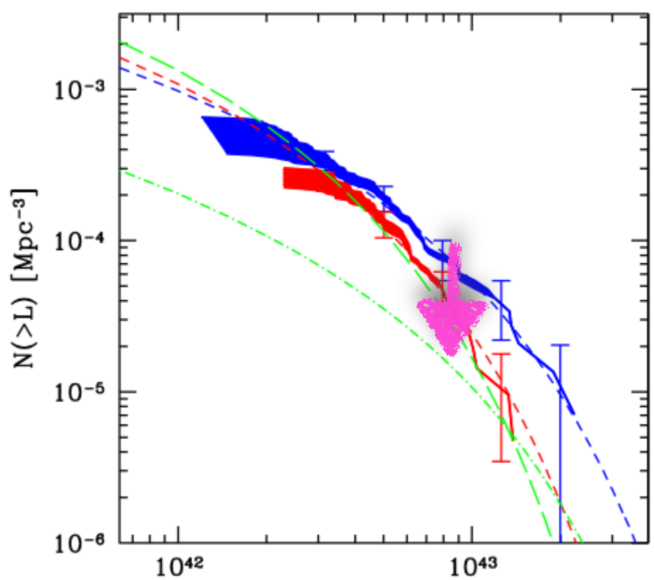
57 LAEs observed at z=6.5 (red, Kashikawa+11, also see Ouchi+10, Kashikawa+06)

Redshift Evolution of LAEs at z>6:

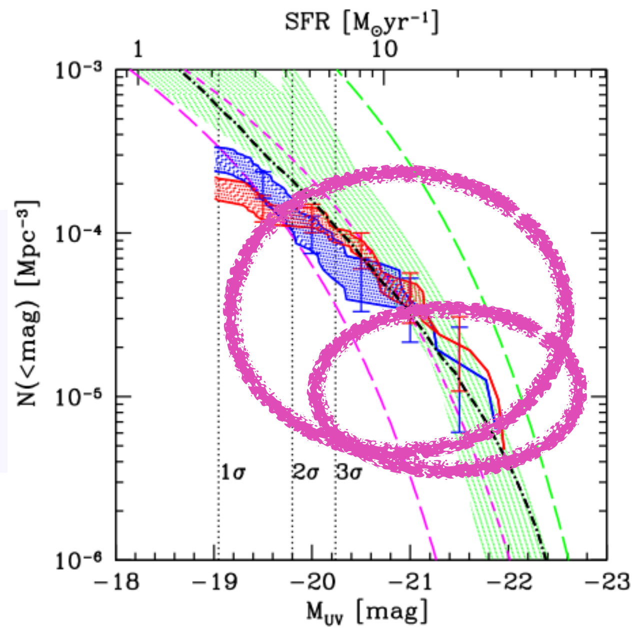
are we seeing an EoR signature?

number

density



Lya Luminosity



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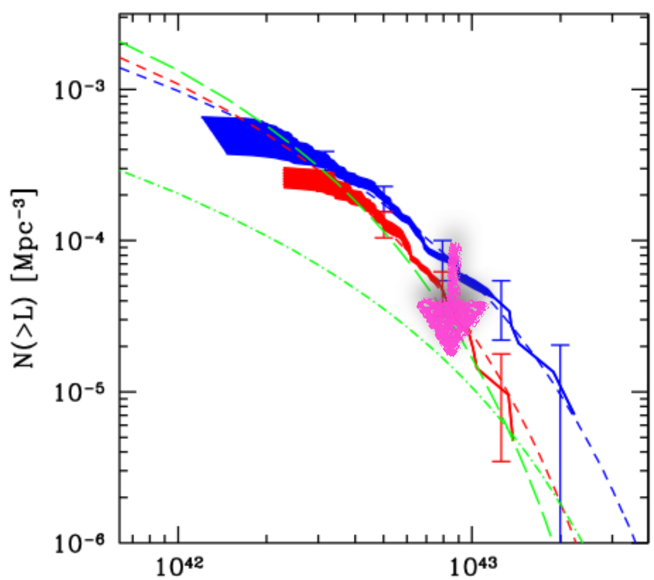
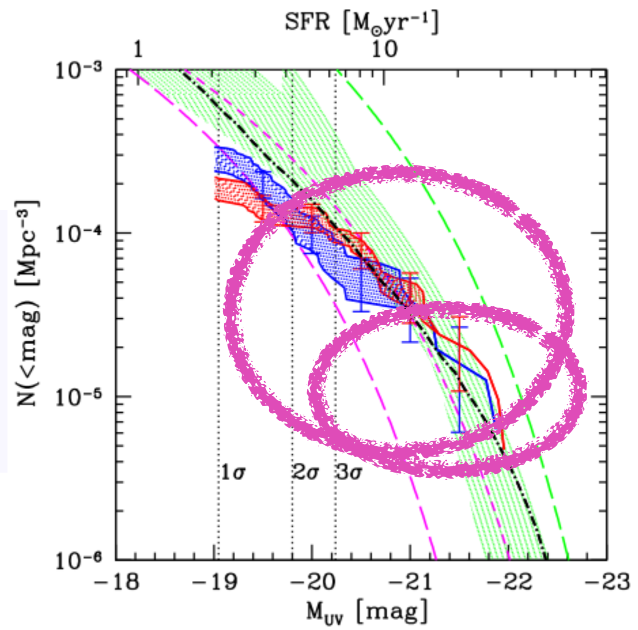


Lya Luminosity



UV cont' Luminosity

We observe ~ 30% less Lyman alpha photons per UV continuum photon from LAEs at z=6.5 compared to z=5.7 (MD+07, also see Ouchi+10)