Cold streams into galaxies

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Outline

Cold streams in theory and simulations

Lyman alpha blob observations

The AMR simulations

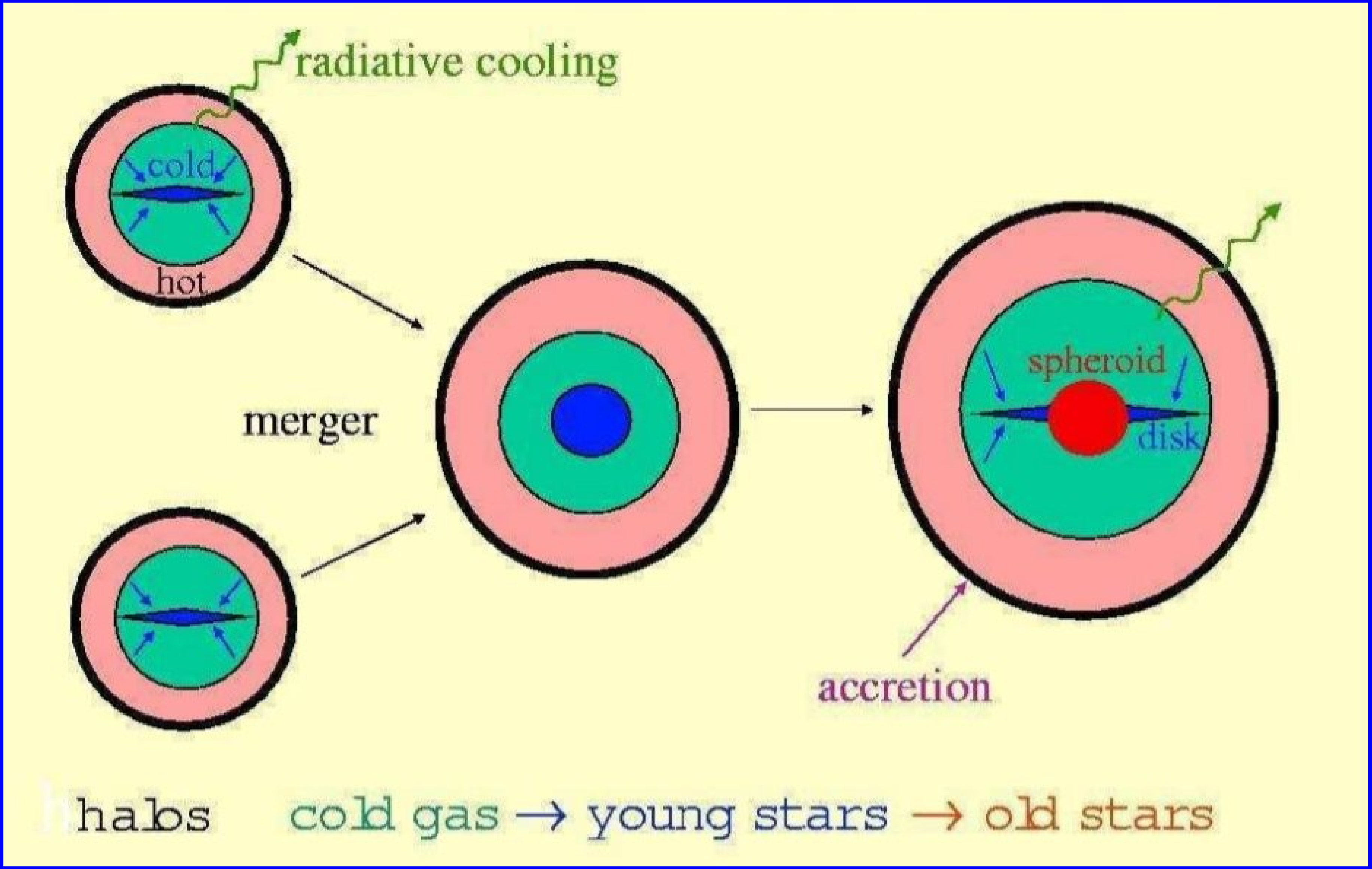
Computing the Lyman alpha luminosity

Resulting surface brightness maps

Comparisons to observations

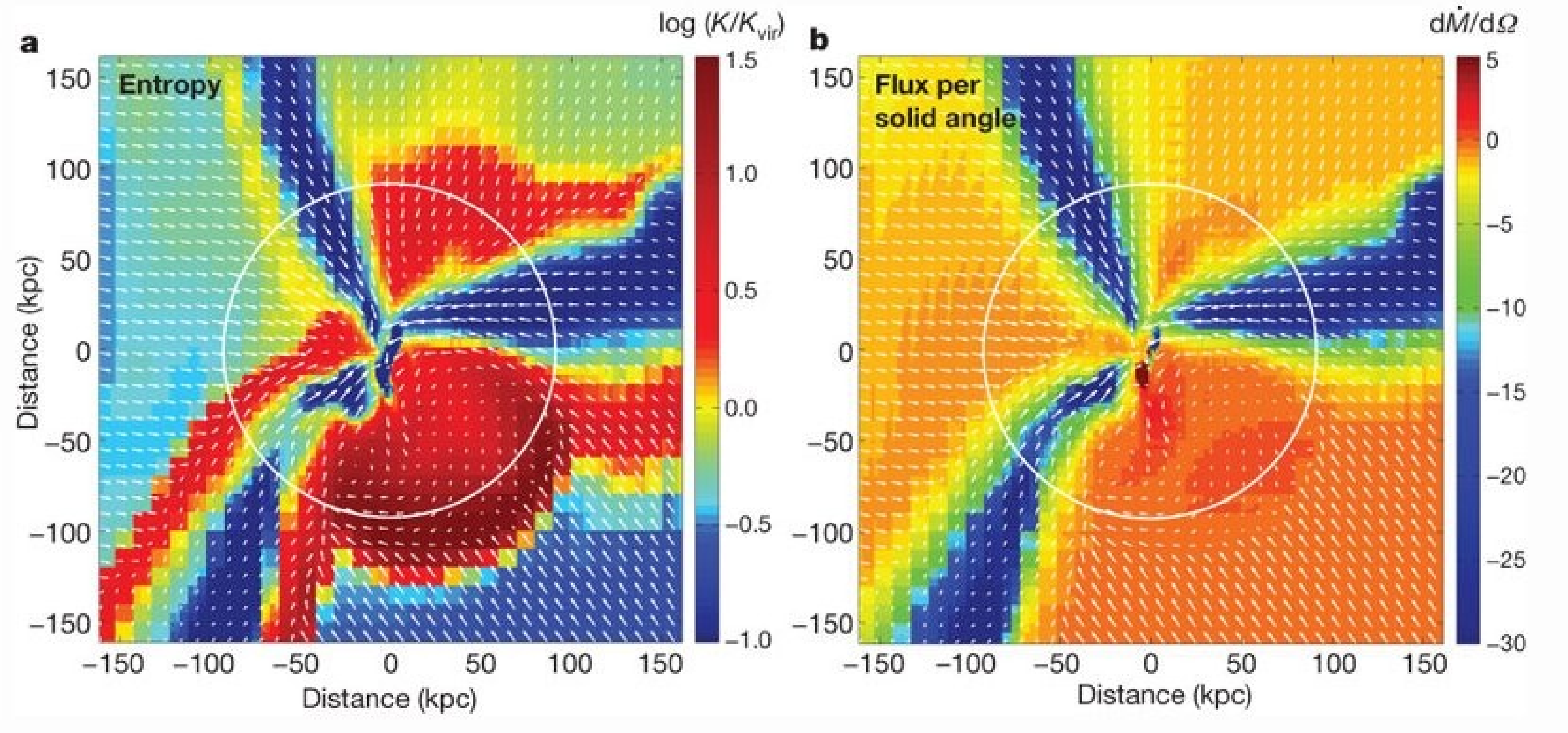
Detectability in absorption

Classical picture of galaxy formation



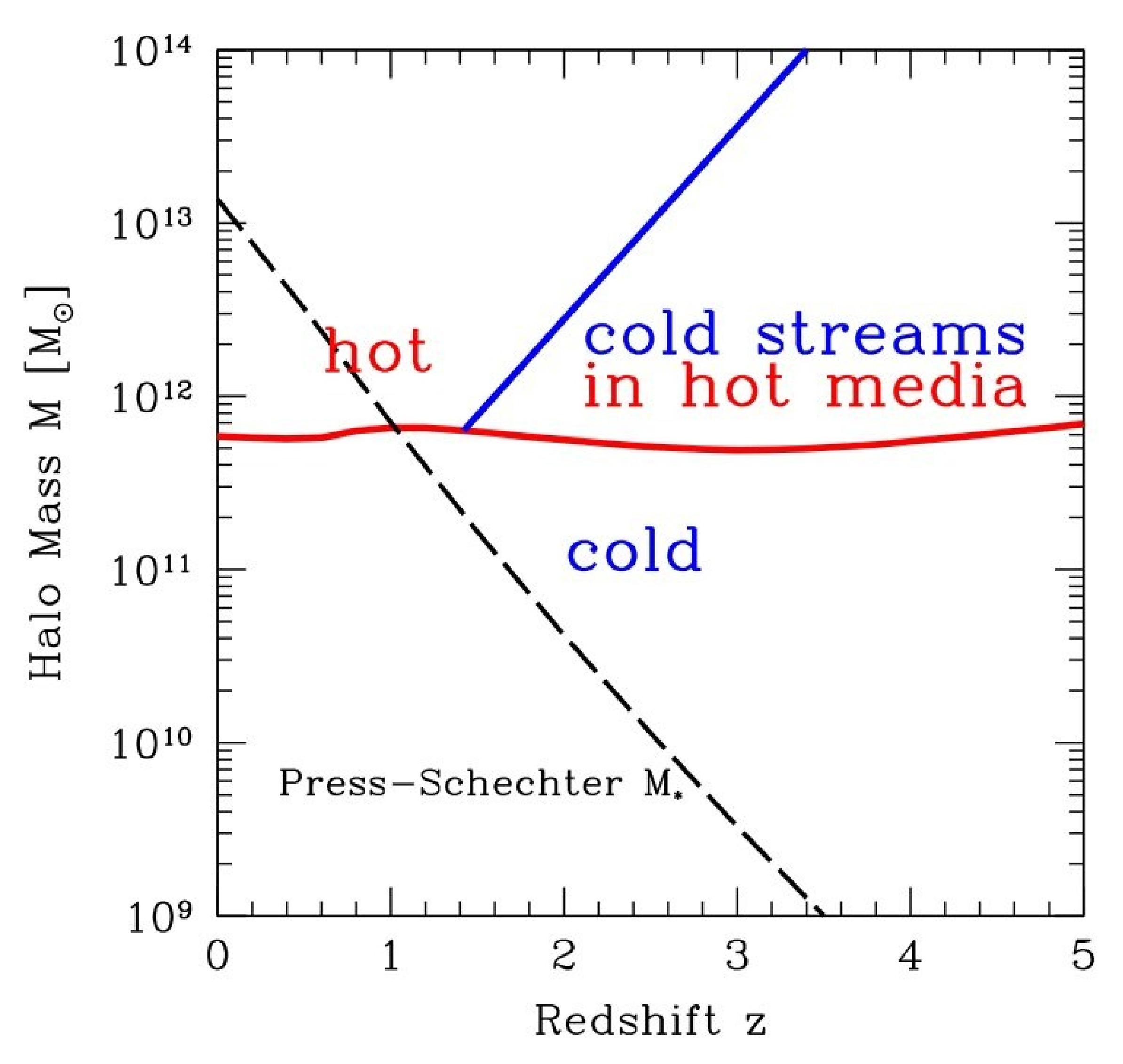
Horizon MareNostrum AMR simulation

$Z = 2.5$, $M_{vir} = 10^{12}\ M_O$



Shock stability analysis

- Spherical infall
- Threshold mass $\sim 10^{12}\ M_{\odot}$
- Stable shock
- Penetrating cold streams $z > z_{crit}$
- shut off of gas supply $z < z_{crit}$



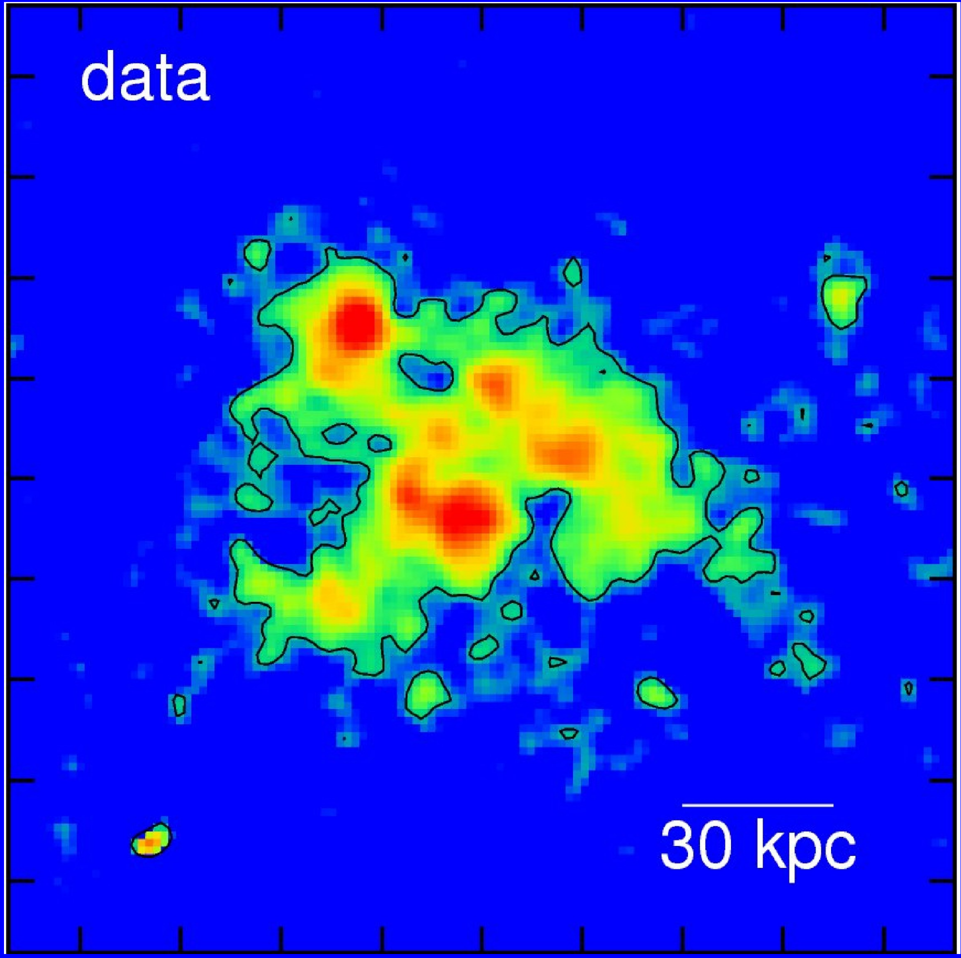
Cold streams

Lyman alpha blobs

First observed by Steidel et al. 2000

Redshift range z = 2 – 6.5

Observation by Matsuda et al. 2004



The AMR simulations

Horizon MareNostrum

Ramses by Romain Teyssier

UV background: Haardt & Madau 1996

Density dependent pressure floor:

$T_{floor} = 10^4\ (n/0.1)^{2/3}$K for $n>0.1\text{cm}^{-3}$

Ceverino, Dekel & Bournaud

Art by Andrey Kravtsov

UV background, mimics selfshielding

Gas can cool down to 100K

Computing Lyman alpha

Emissivity:

$$\epsilon = n_e \, n_{\mathrm{HI}} \, C_{\mathrm{L}\alpha}(T) + 0.68 \, h\nu_\alpha \, n_e \, n_{\mathrm{HII}} \, \alpha_{\mathrm{rec,B}}(T)$$

Collisional excitation coefficient:

$$C_{\mathrm{L}\alpha} = 3.7 \times 10^{-17} \, T^{-1/2} \, \exp\left(-\frac{h\nu_\alpha}{kT}\right) \, \mathrm{erg\, s^{-1}\, cm^3}$$

Case-B recombination coefficient:

$$\alpha_{\mathrm{rec,B}}(T) = 4.9 \times 10^{-6} T^{-1.5} \left(1 + \frac{115}{T^{0.41}}\right)^{-2.24} \mathrm{cm^3\, s^{-1}}$$

More computing

Number densities:

$$n_{\mathrm{HI}} = \frac{x_{\mathrm{HI}}\, X\, \rho}{m_{\mathrm{p}}} ,$$

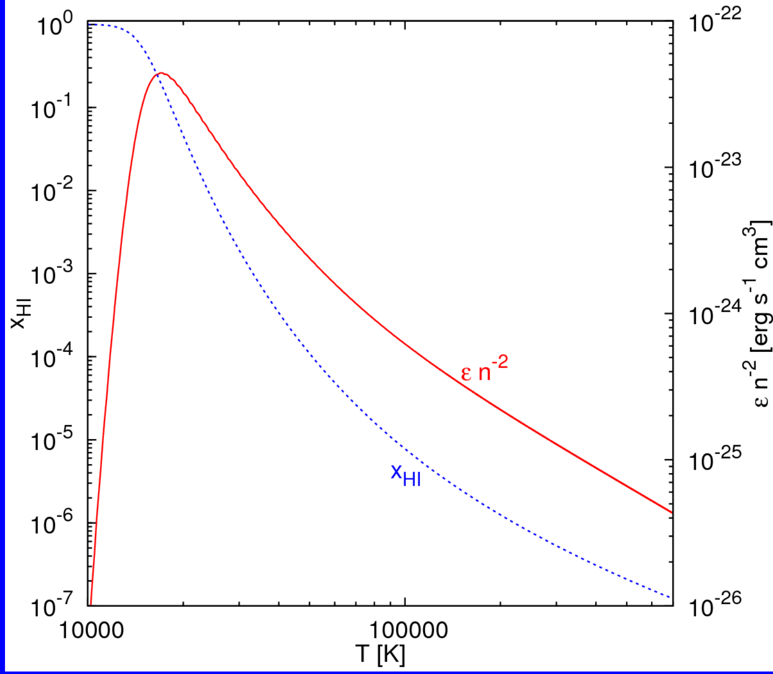
$$n_{\mathrm{HII}} = n_{\mathrm{e}} = \frac{(1 - x_{\mathrm{HI}})\, X\, \rho}{m_{\mathrm{p}}}$$

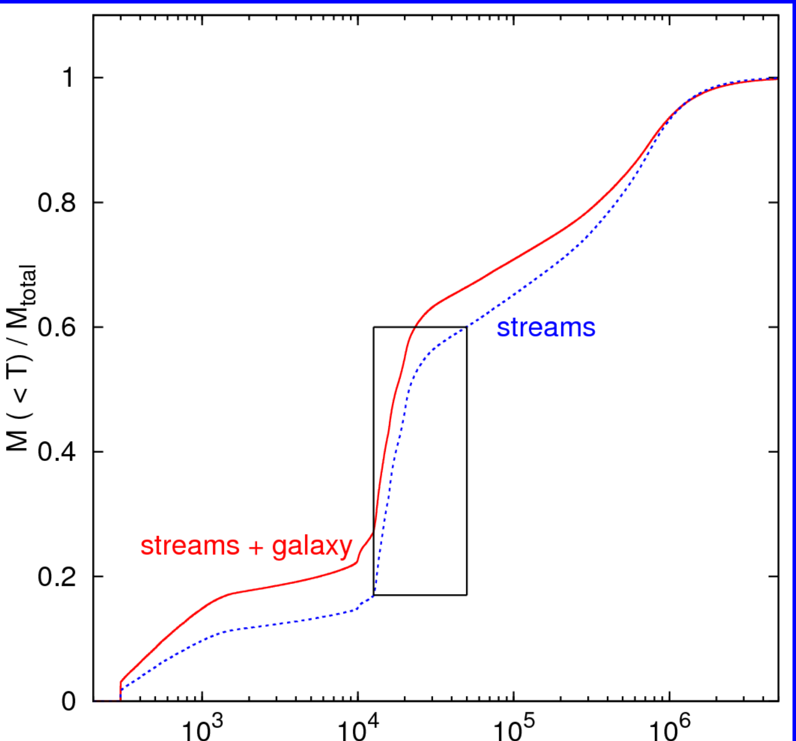
Neutral Hydrogen fraction:

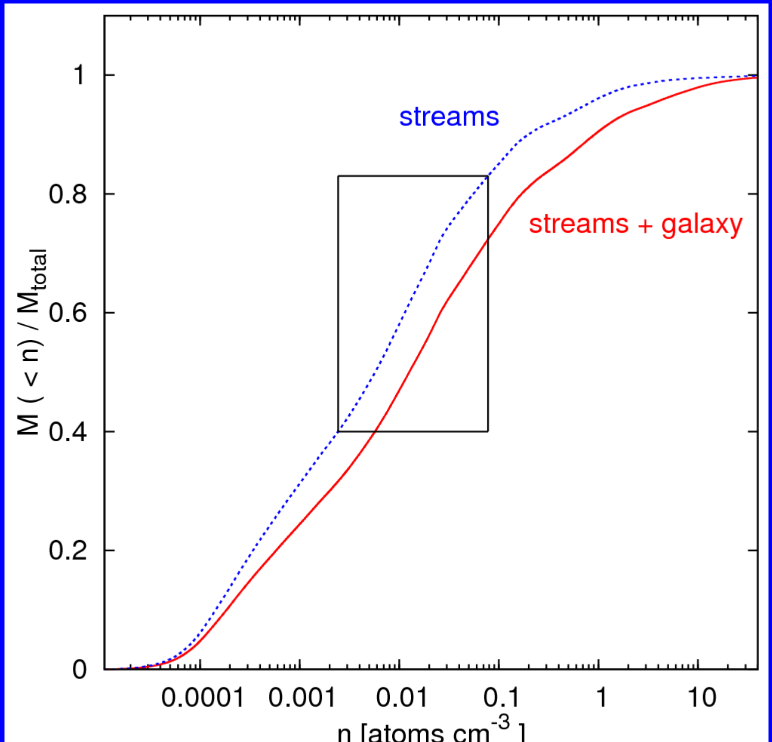
$$x_{\mathrm{HI}} = \frac{\alpha_{\mathrm{rec,B}}(T)}{\alpha_{\mathrm{rec,B}}(T) + C_{\mathrm{ion}}}$$

Lα emissivity:

50% of the gas emits Lα efficiently





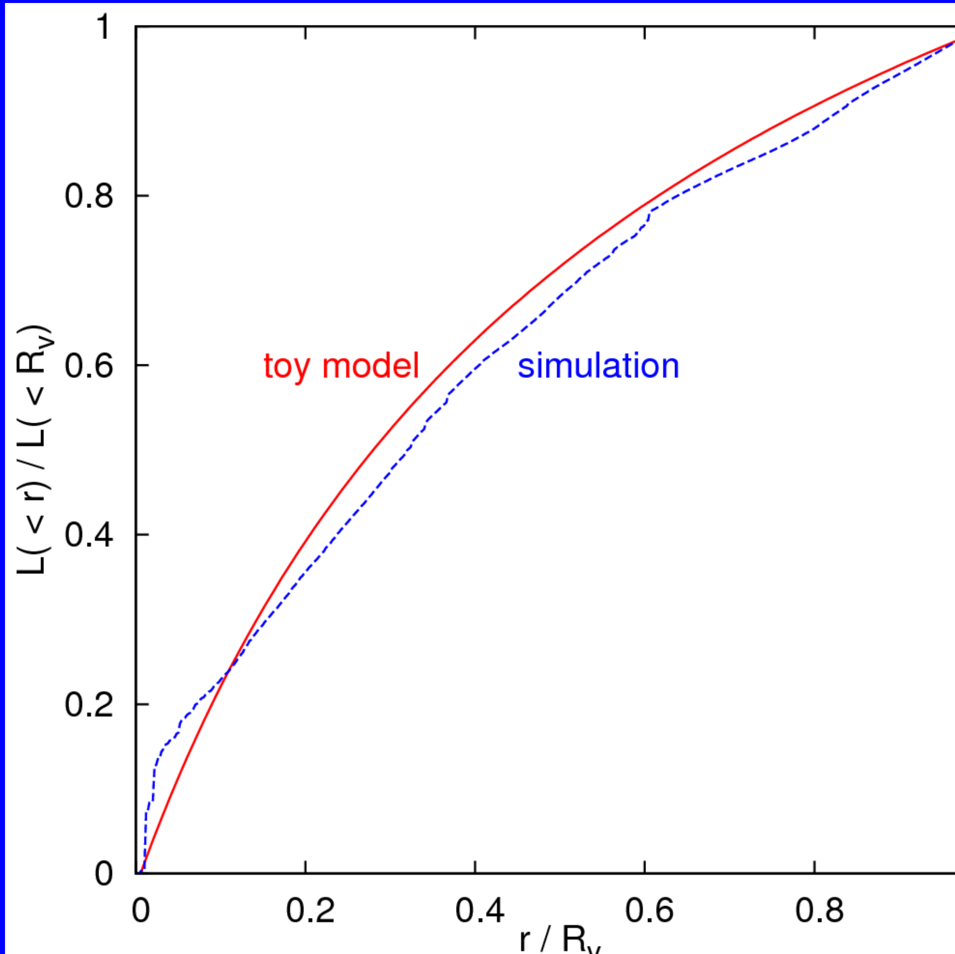


Toy model:

NFW profile

Neistein infall (EPS)

Constant infall velocity

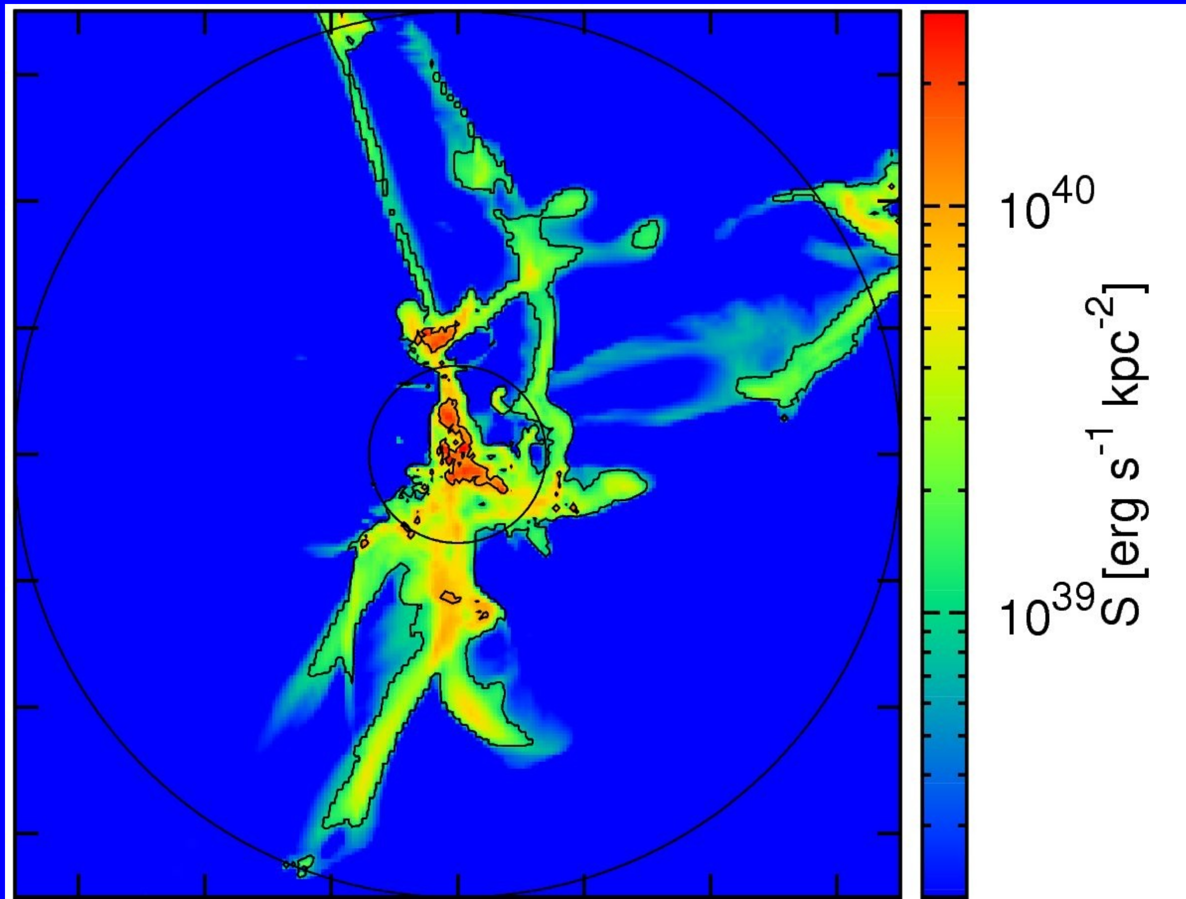


Resulting maps: Surface brightness

CDB simulation

Z = 3.09

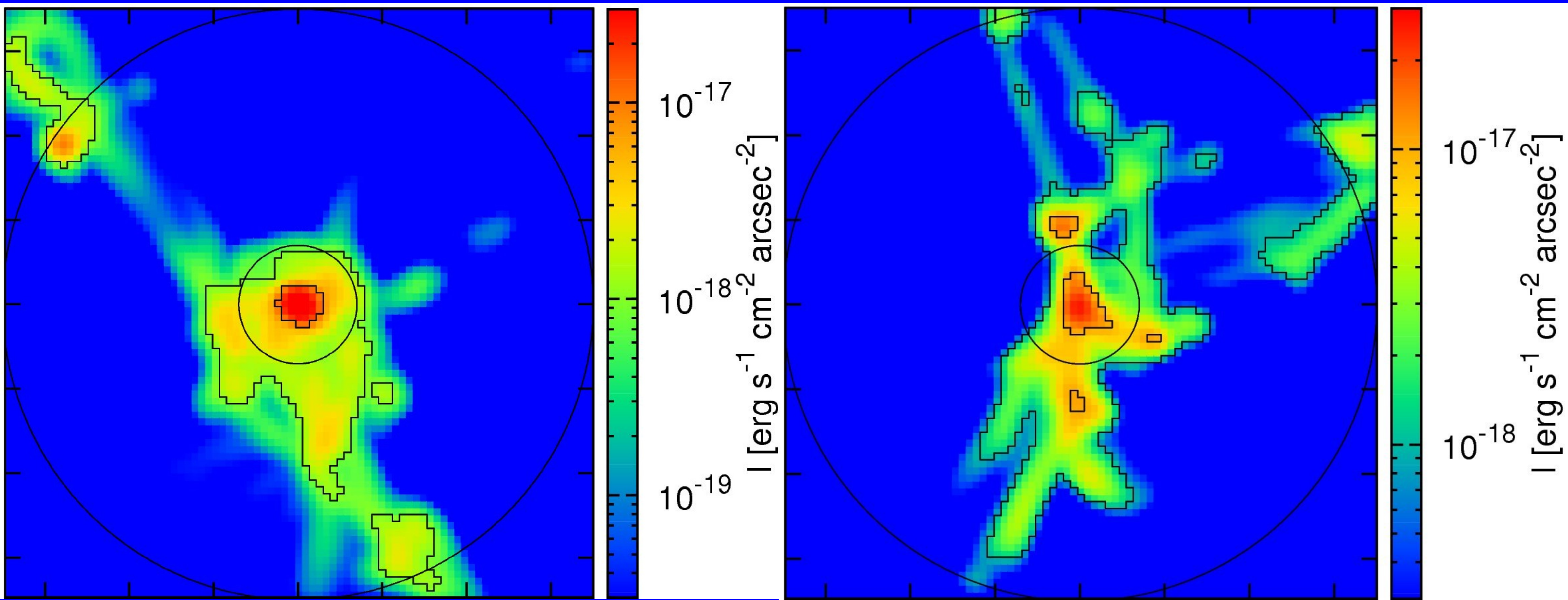
M_{vir} = 3.5e11M_O



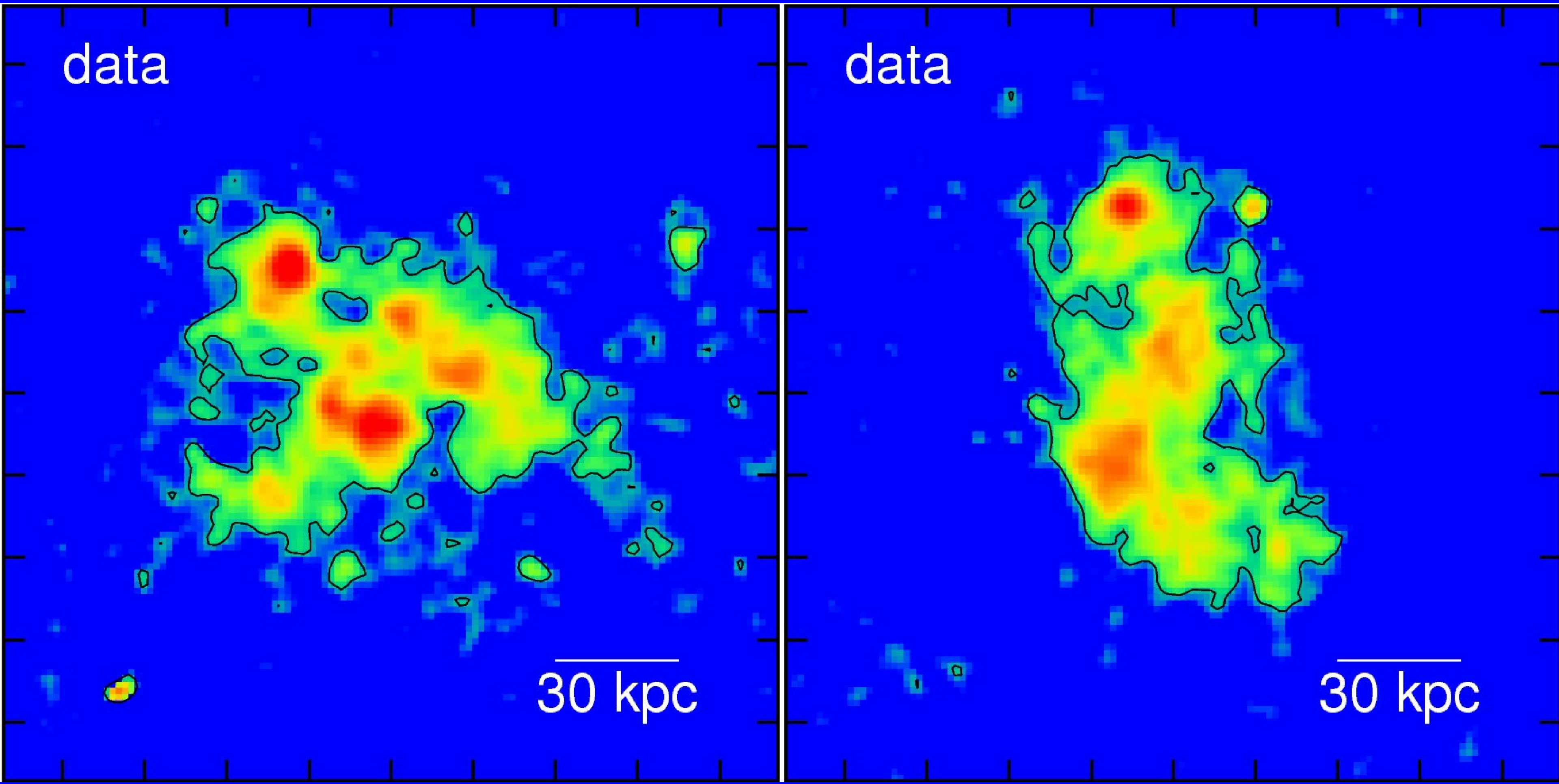
What an observer would see:

$I = S / [4 \pi (1+z)^4]$

0.6'' FWHM
Gaussian PSF



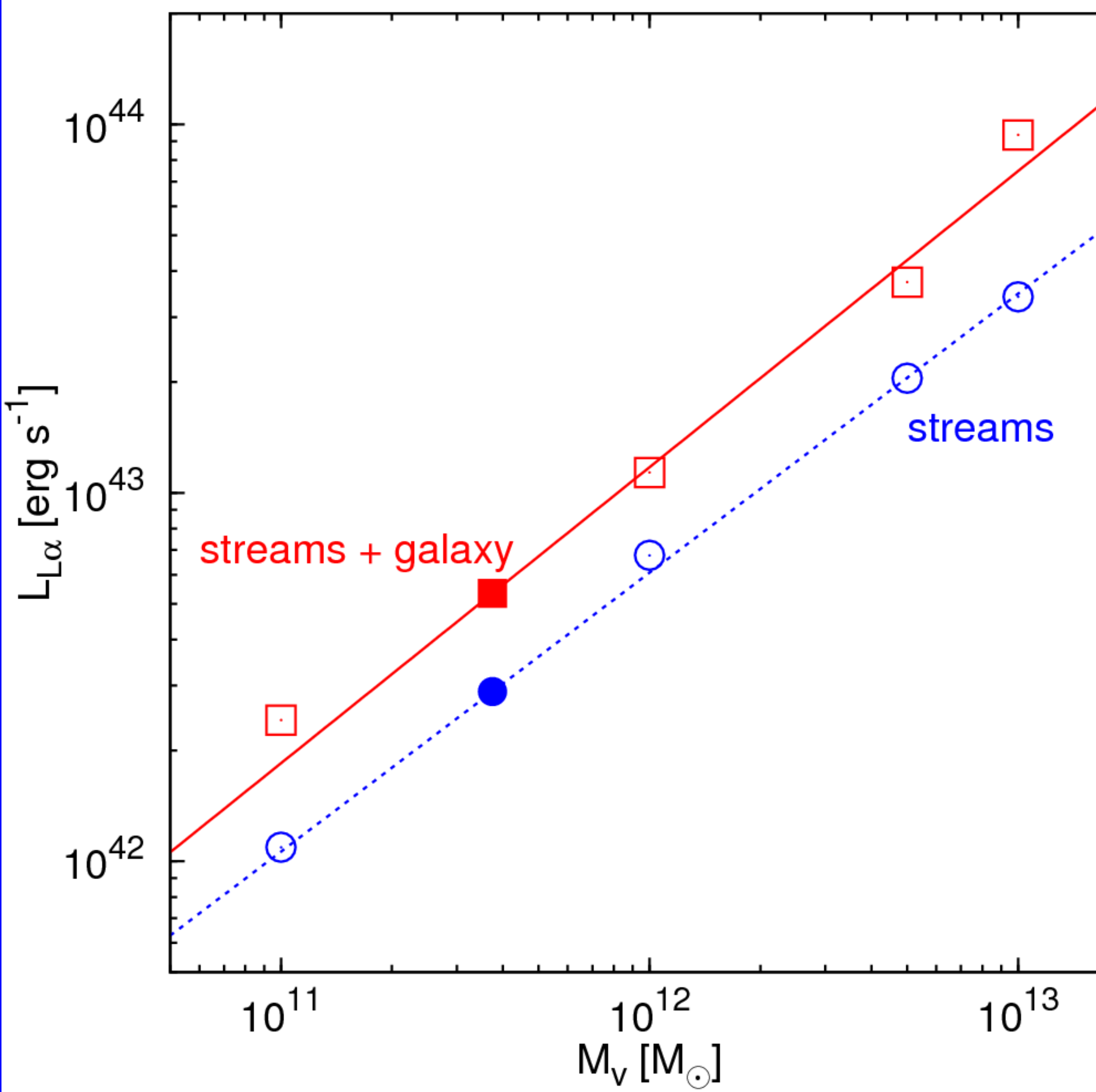
The data for comparison:



Lyman alpha vs halo mass

Several galaxies per data point

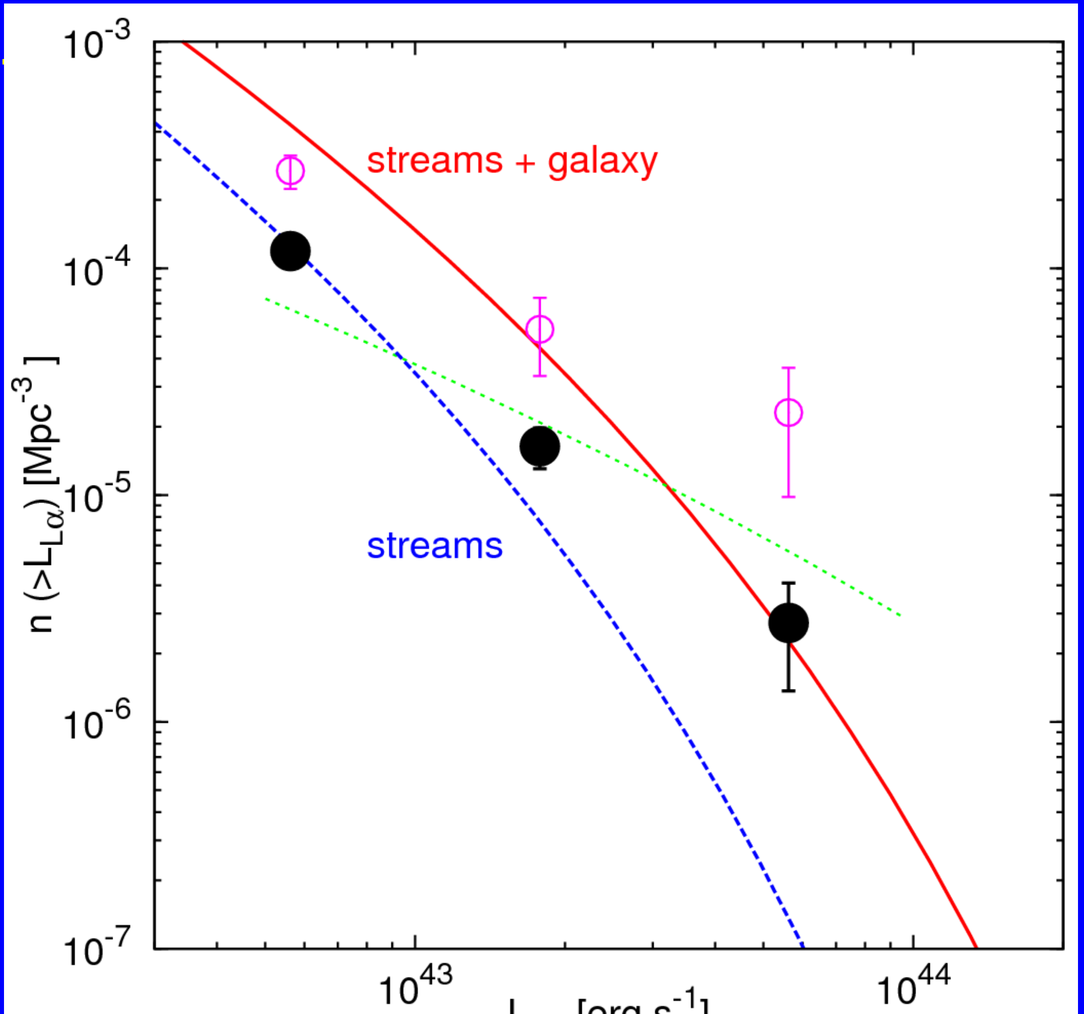
z = 3.09



Luminosity function

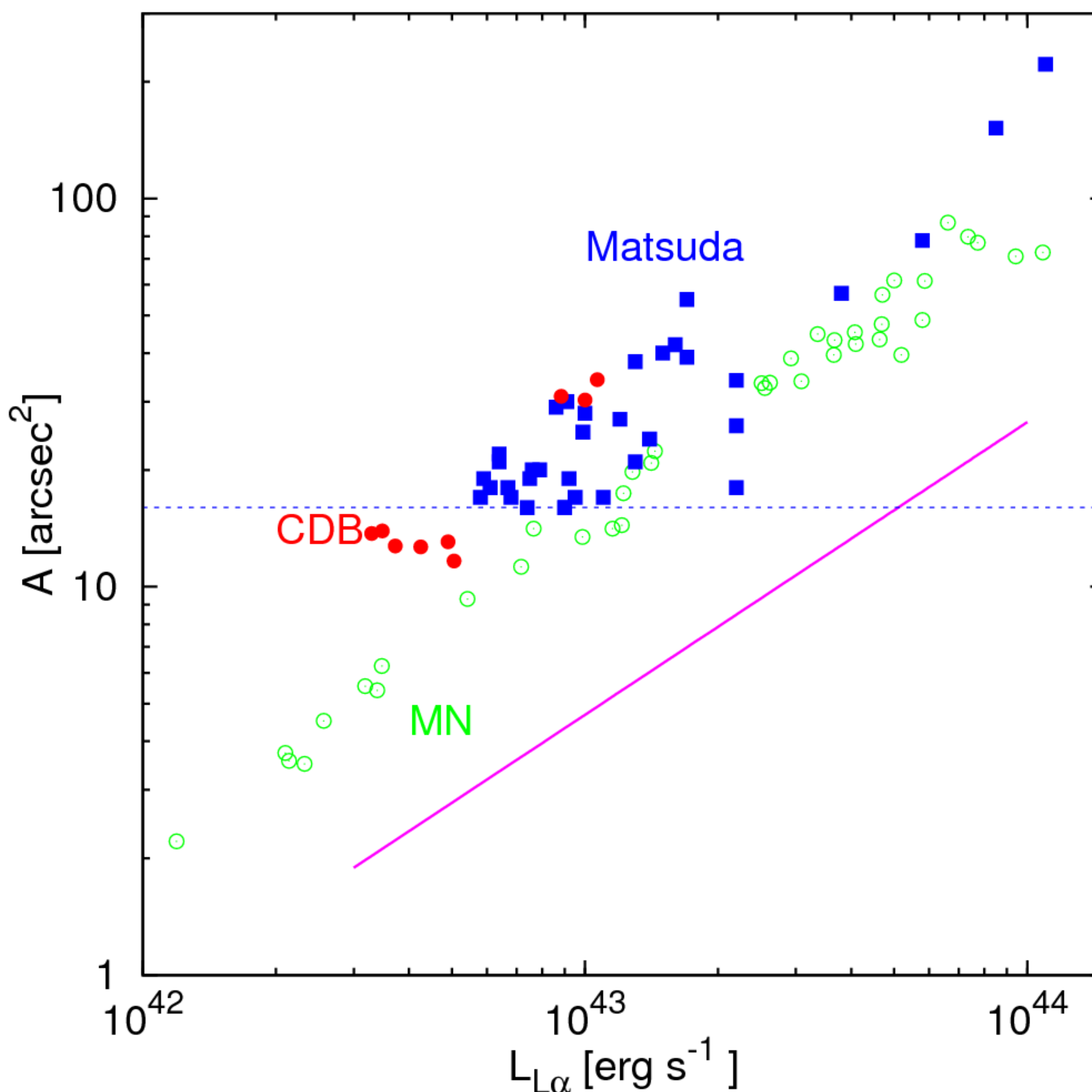
Correlation with Sheth Tormen mass function

Data from Matsuda et al. 2004



Area vs. Luminosity

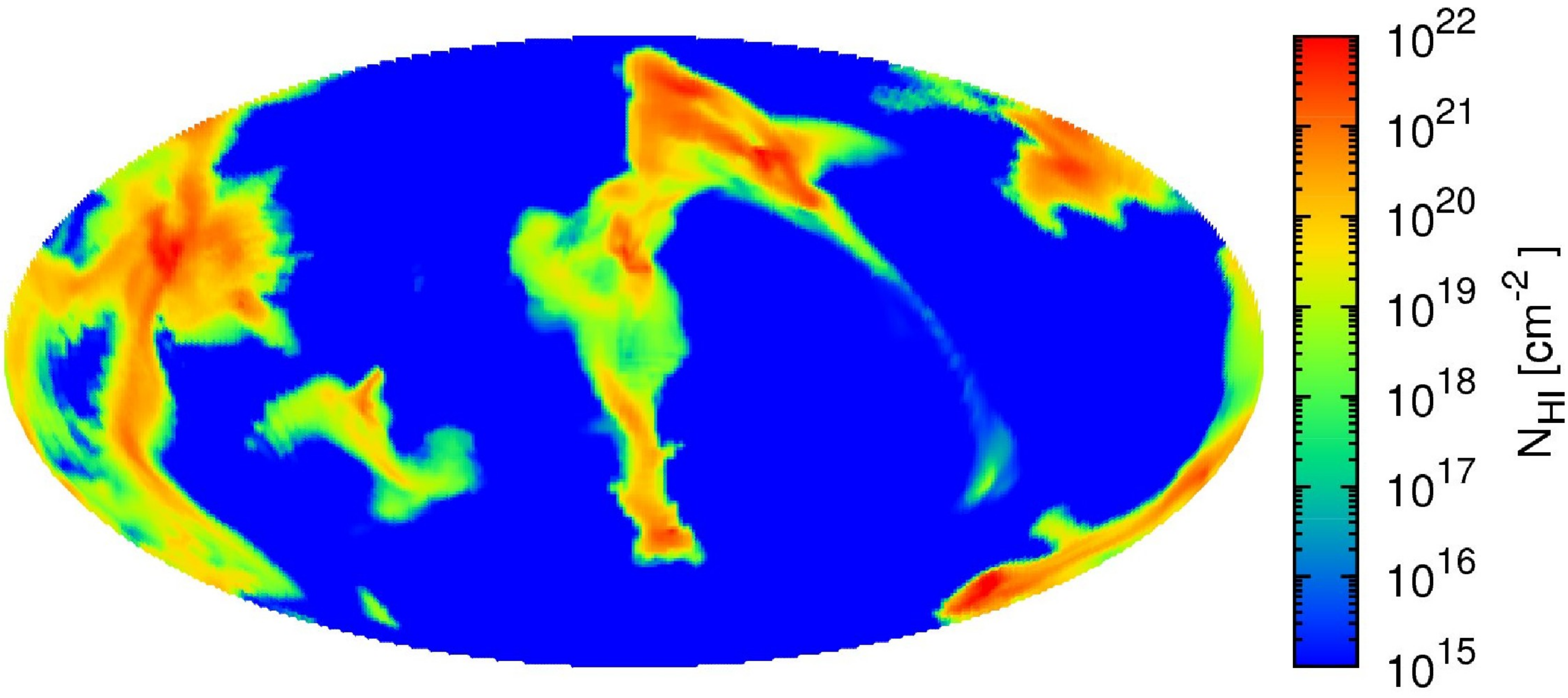
Isophotal area above 2.2e-18 erg s^{-1} cm^{-2} $arcsec^{-2}$ as a function of total luminosity



Detectability of absorption

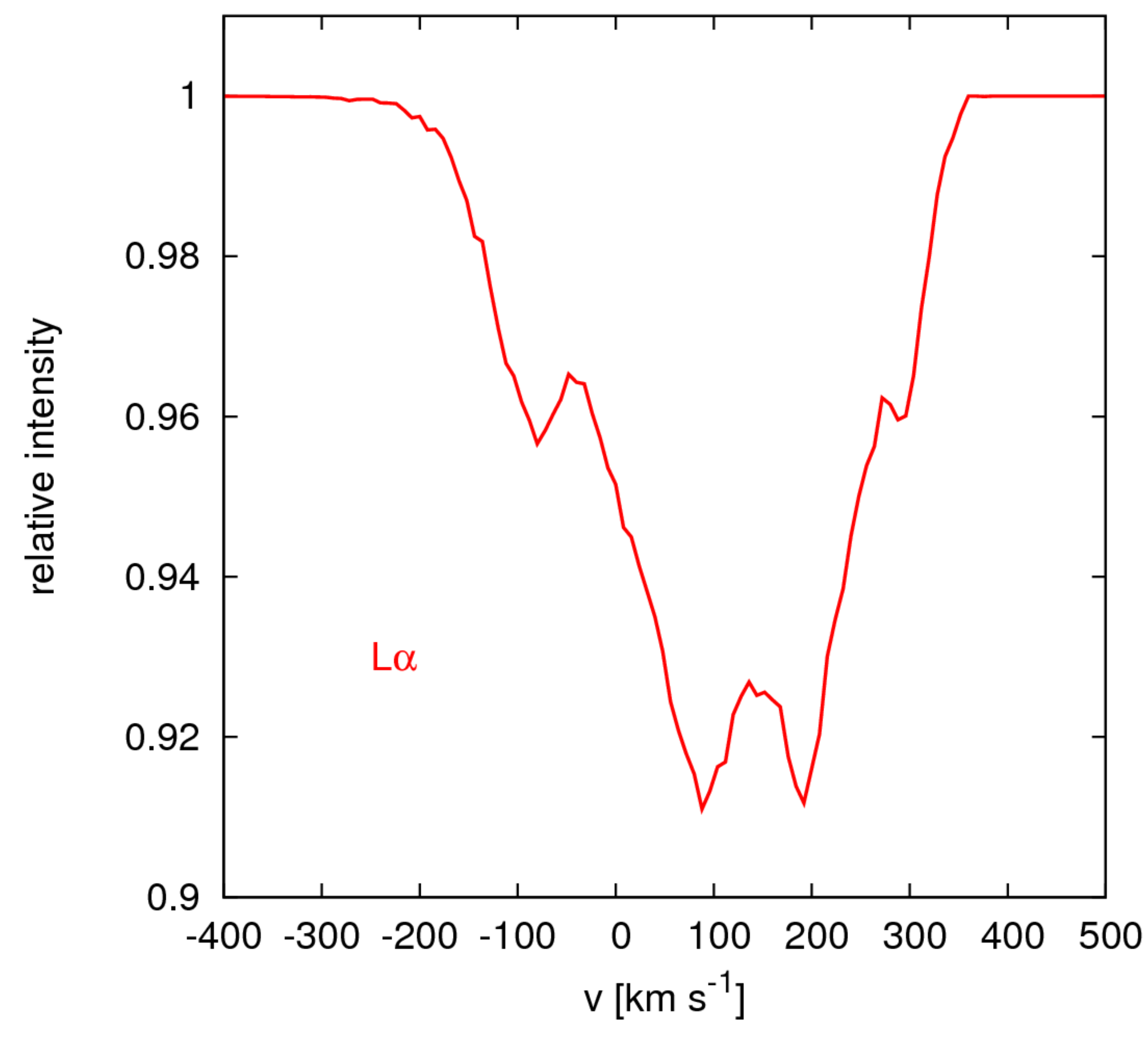
Low sky covering fraction → difficult

Low metallicity in streams → more difficult



Resulting line profiles

Lα: agreement with Steidel et al. 2010 Fig. 12



Summary

Cold streams loose pot. energy released as Lyman alpha photons

Simulation maps very similar to observations in extent, shape, luminosity

Luminosity function fits data

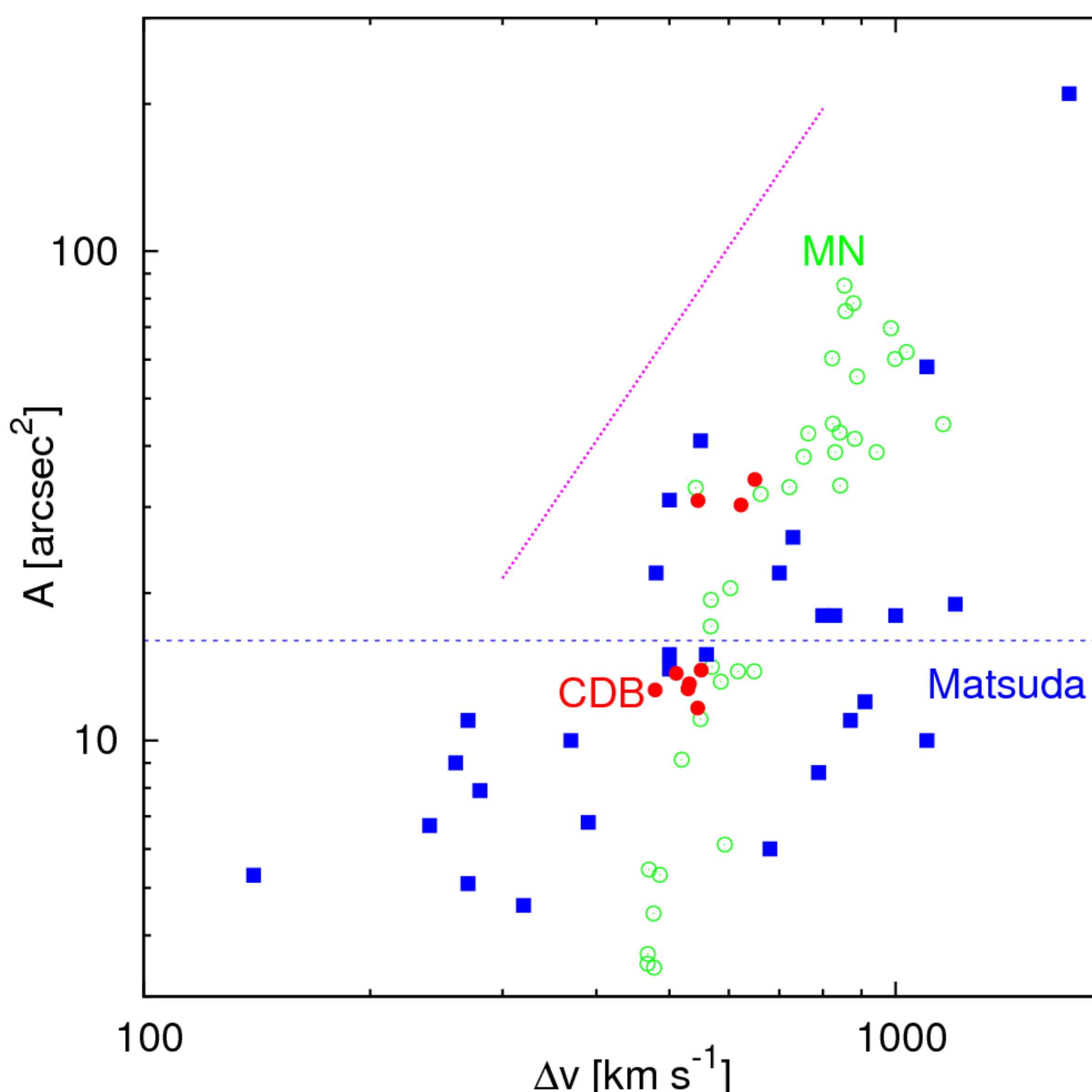
=> Cold streams can explain Lyman alpha blobs

=> First observational evidence for cold streams!

Thanks!

Kinematics

Area vs. velocity dispersion



Energy source: Gravitational heating vs. UV background

In the gas that contributes 80% o the luminosity more than 80% of the input energy is gravitational