Detectability of cold streams in absorption and emission

Tobias Goerdt

Universidad Autónoma de Madrid

Collaborators: Avishai Dekel, Amiel Sternberg, Daniel Ceverino, Romain Teyssier, Orly Gnat, Joel Primack

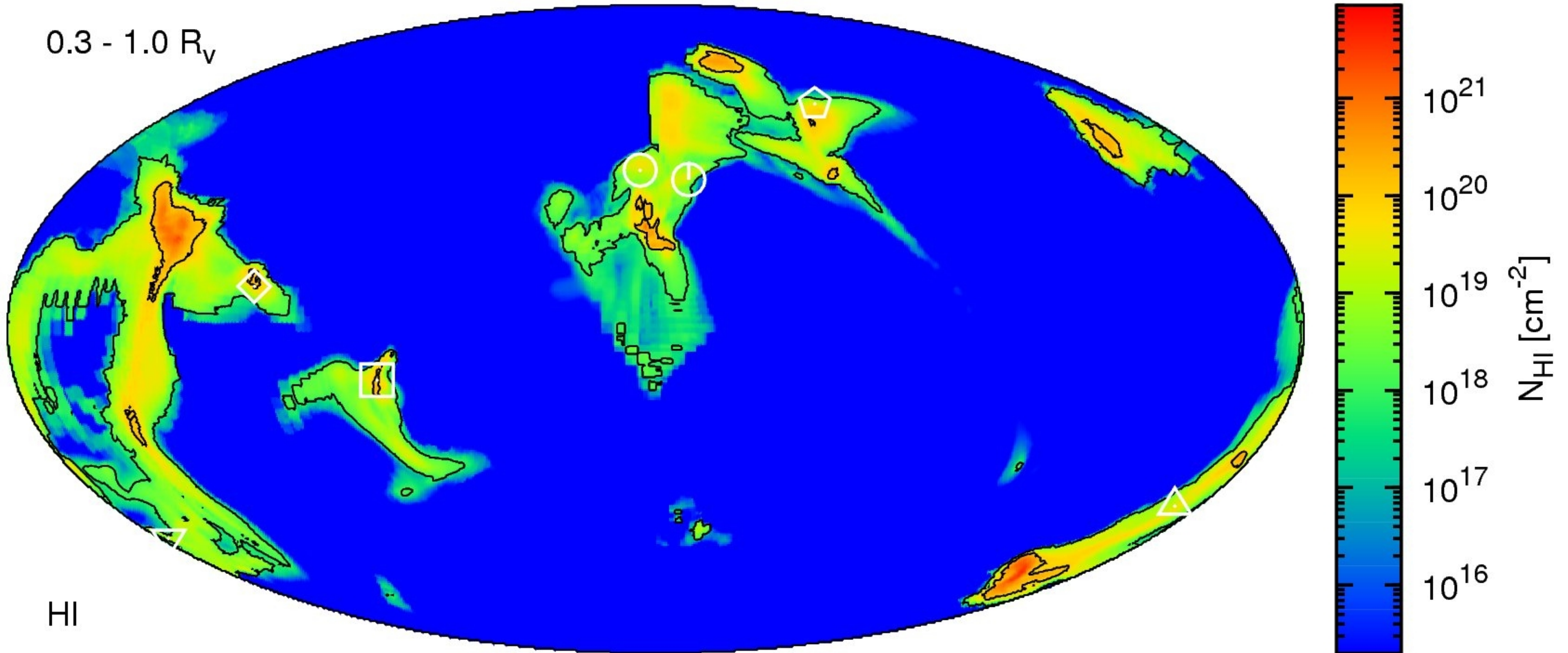
Cold streams

Steidel et al. 2010:

- Observes “Circum Galactic Medium”
- Absorption line profiles
- Stacks more than 100 spectra
- Detects massive outflows
- But: no sign of inflows
- Claim: Proof of absence of cold streams

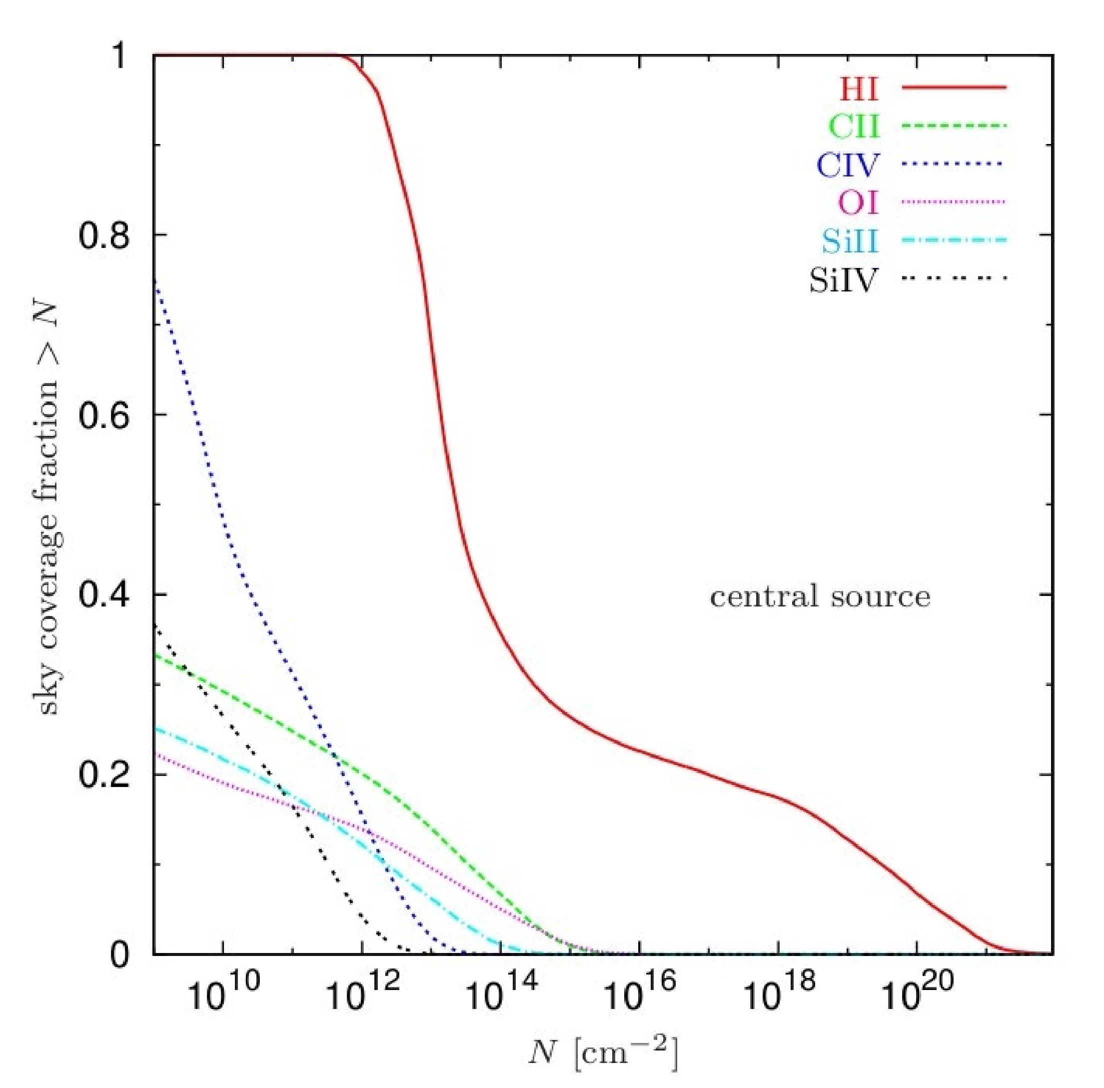
Central geometry

- Observes central galaxy through its own circum galactic medium
- AMR simulation, z = 2.5, $M_{vir} = 4 * 10^{11} M_O$



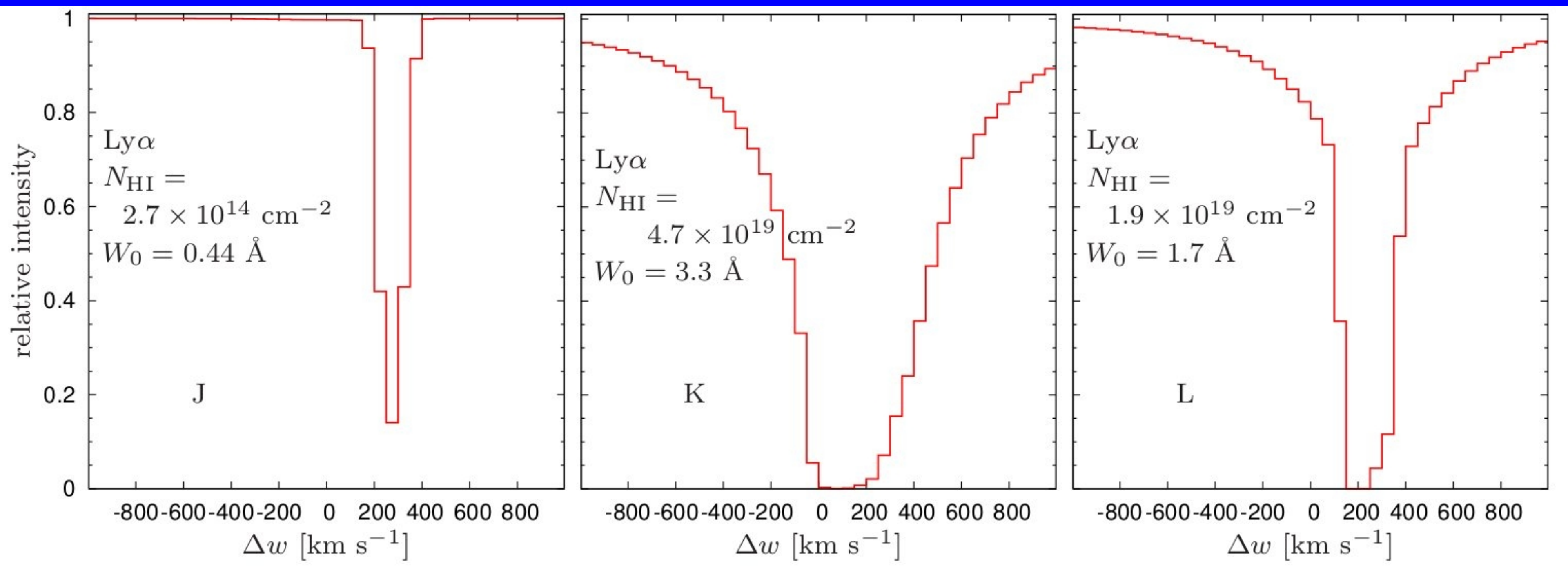
Sky covering fraction

- Very low sky covering fraction
- Low metallicity in streams



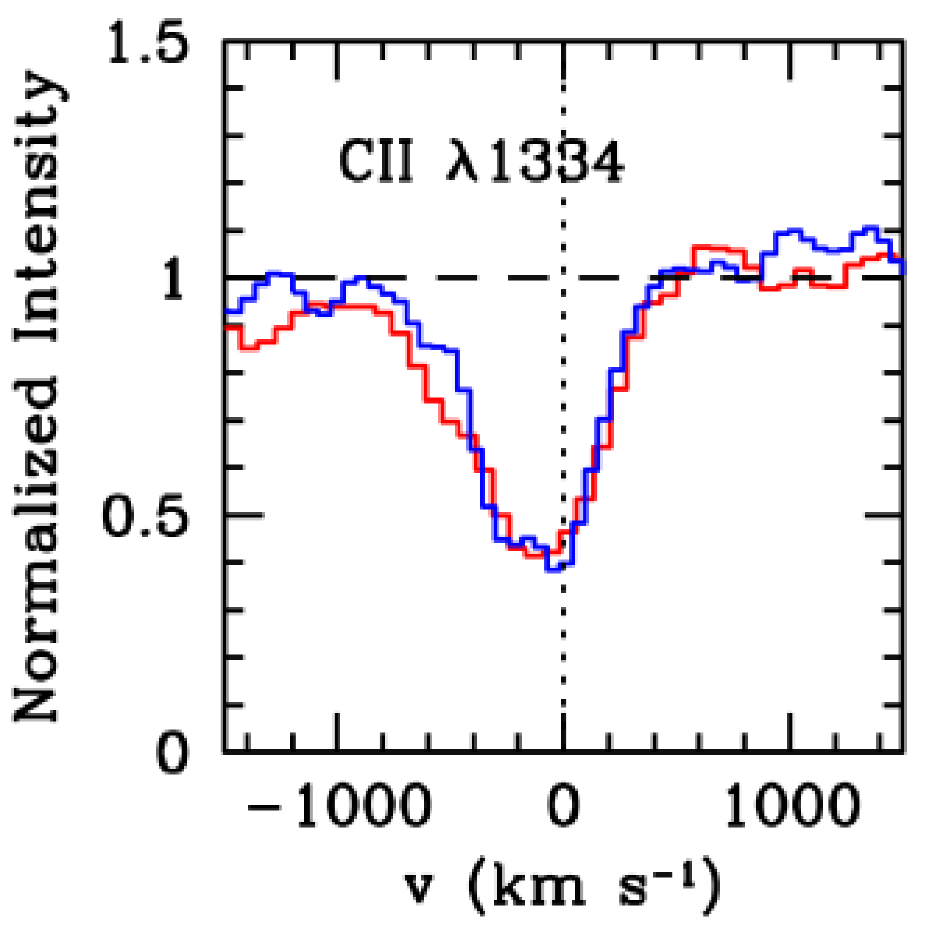
Example line profiles

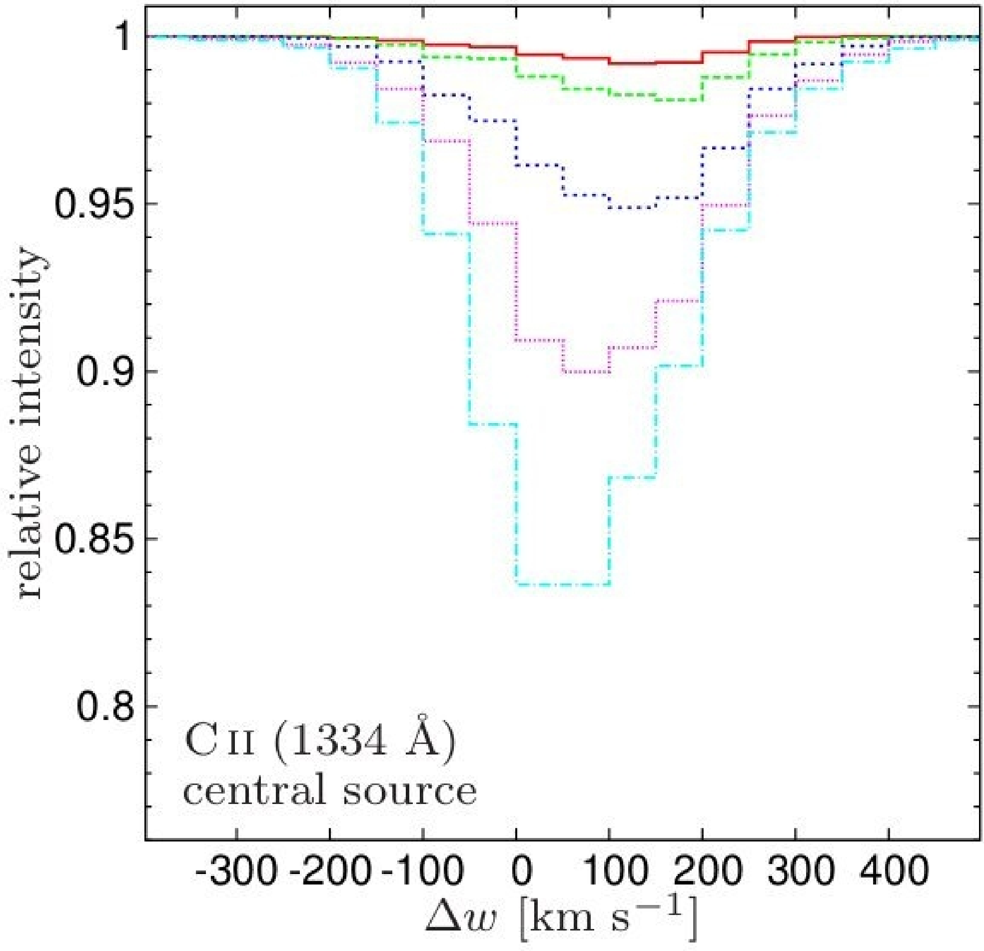
- Lyα
- Gaussian point spread function with 4kpc beam-size applied
- Velocity resolution degraded to 50 km s[-1]
- Observer convention: inflow positive (right)



Stacked line profile:

- Averaging over all available example line profiles (3 galaxies, all directions)



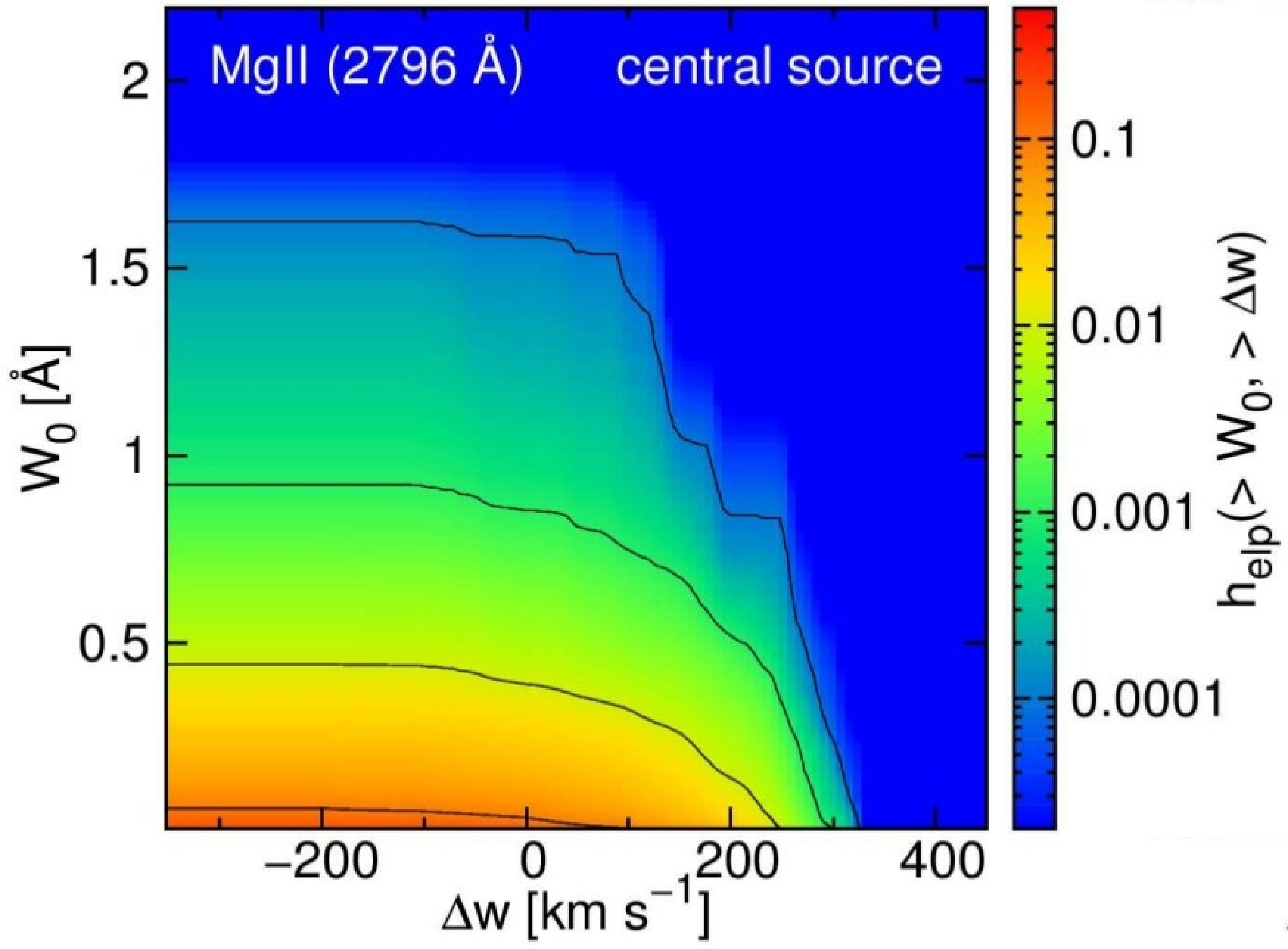


Stacking?

- Stacking washes out the cold filament absorption signal
- Cold filament absorption signal might still be visible in non stacked data

Statistics

- Mg II: inflow > 150 km s^{-1} with an EW > 0.2 Å in 1.3 % of all observations

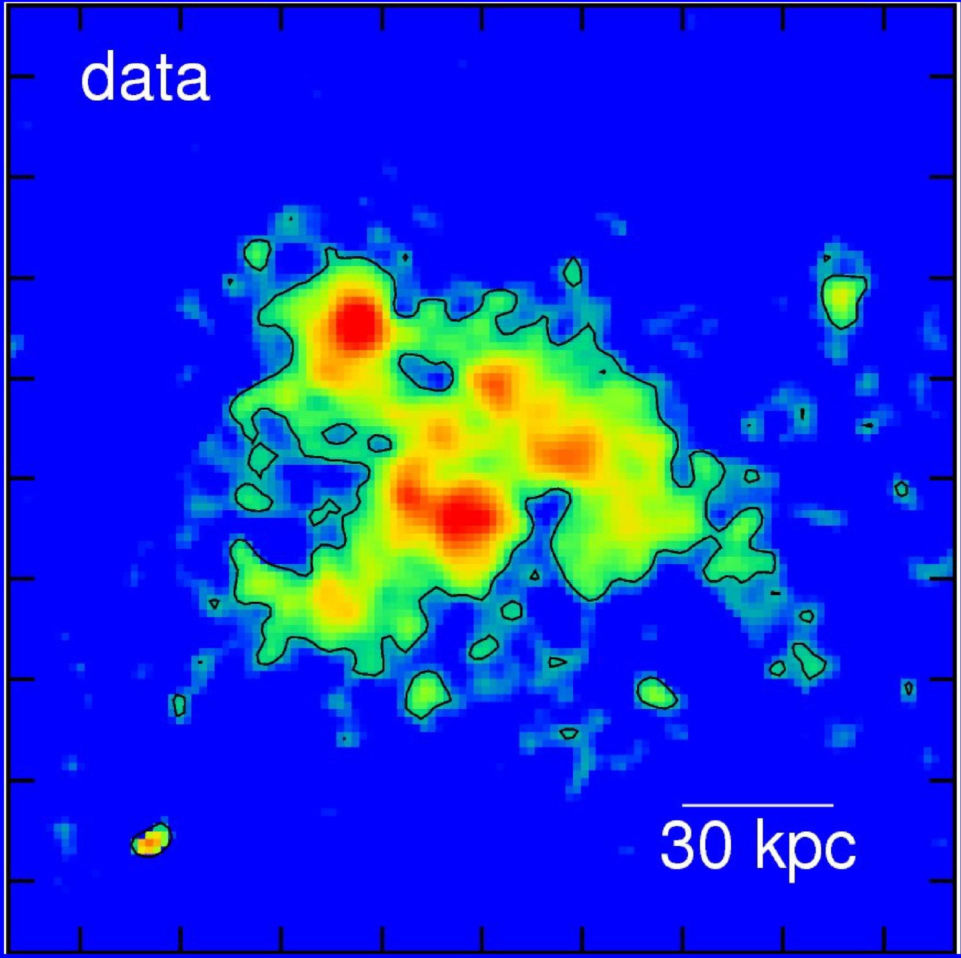


Absorption summary

- Observational features from cold streams extremely difficult to detect.
- Outflows are dominant.
- No falsification done.

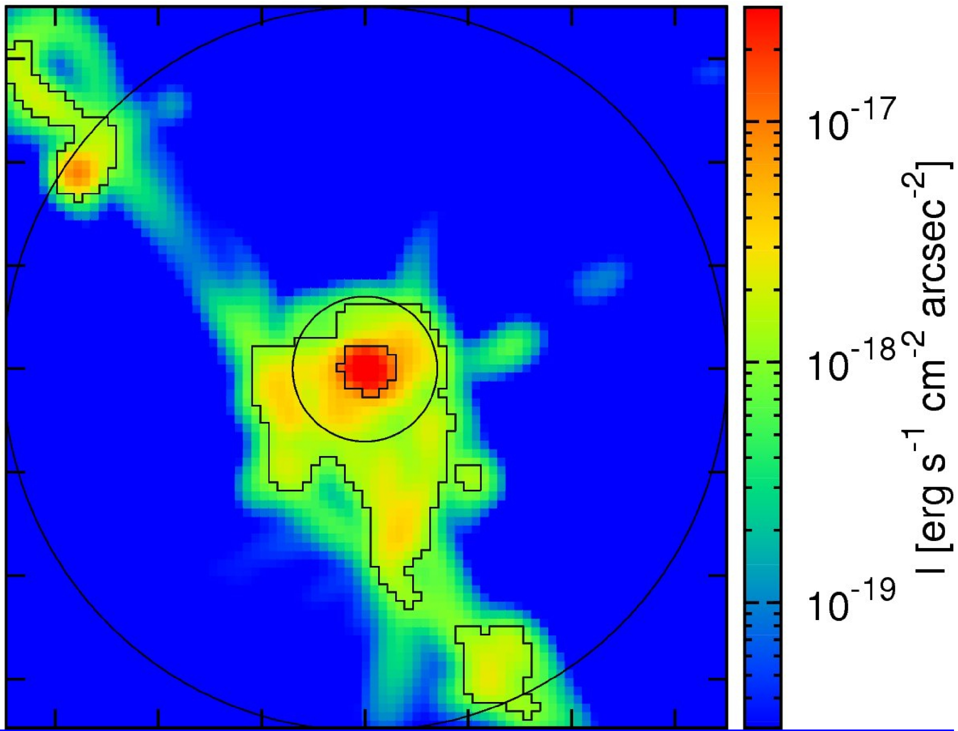
Lyman alpha blobs

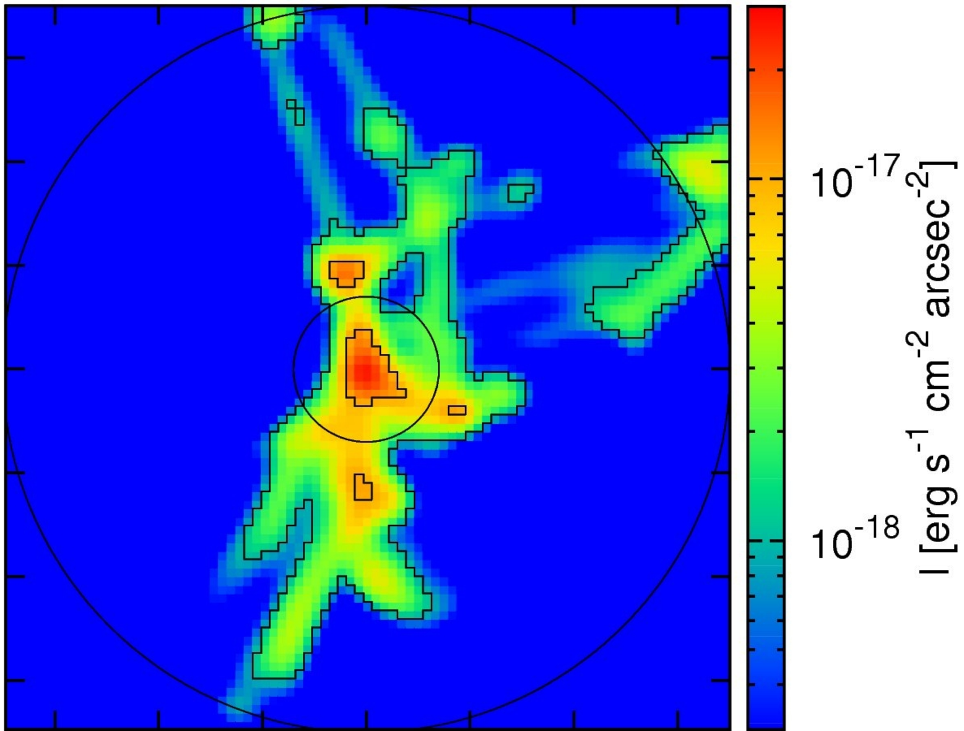
- First observed by Steidel et al. 2000
- Redshift range z = 2 – 6.5
- Observation by Matsuda et al. 2004



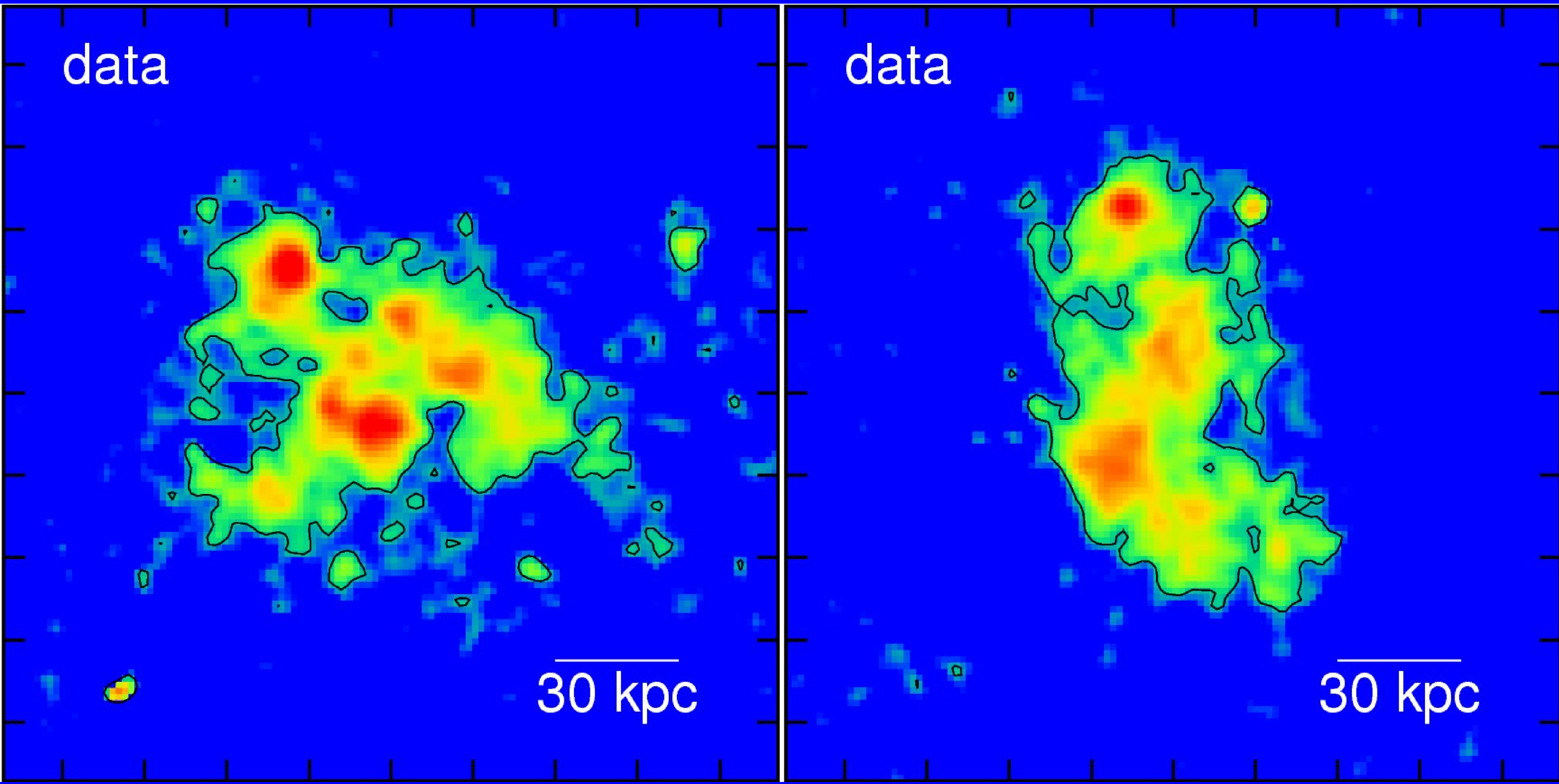
Simulated surface brightness maps:

- AMR simulation (CDB)
- Z = 3.09
- M_{vir} = 3.5e11M_O
- 0.6'' FWHM Gaussian PSF



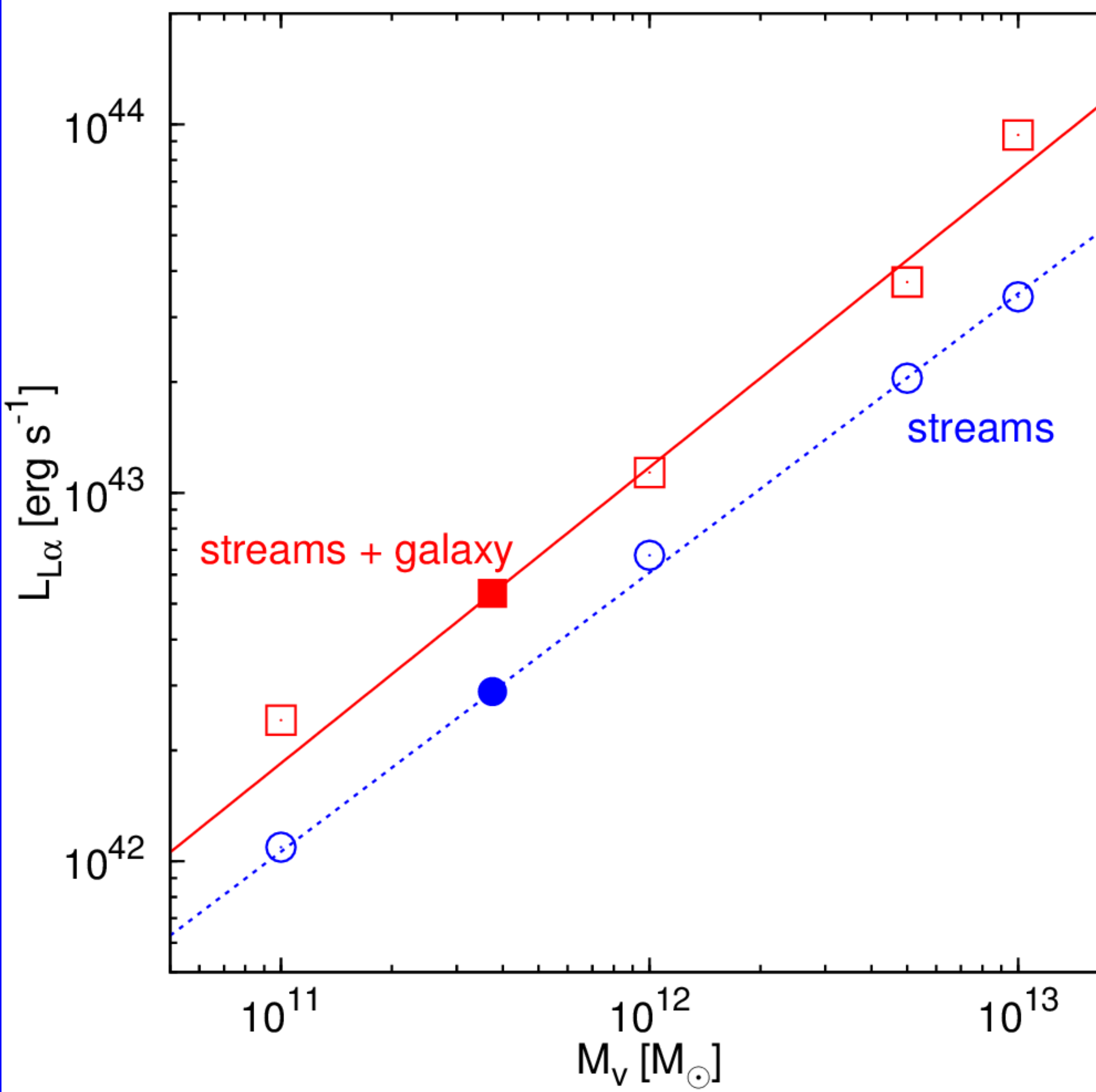


The observations for comparison:



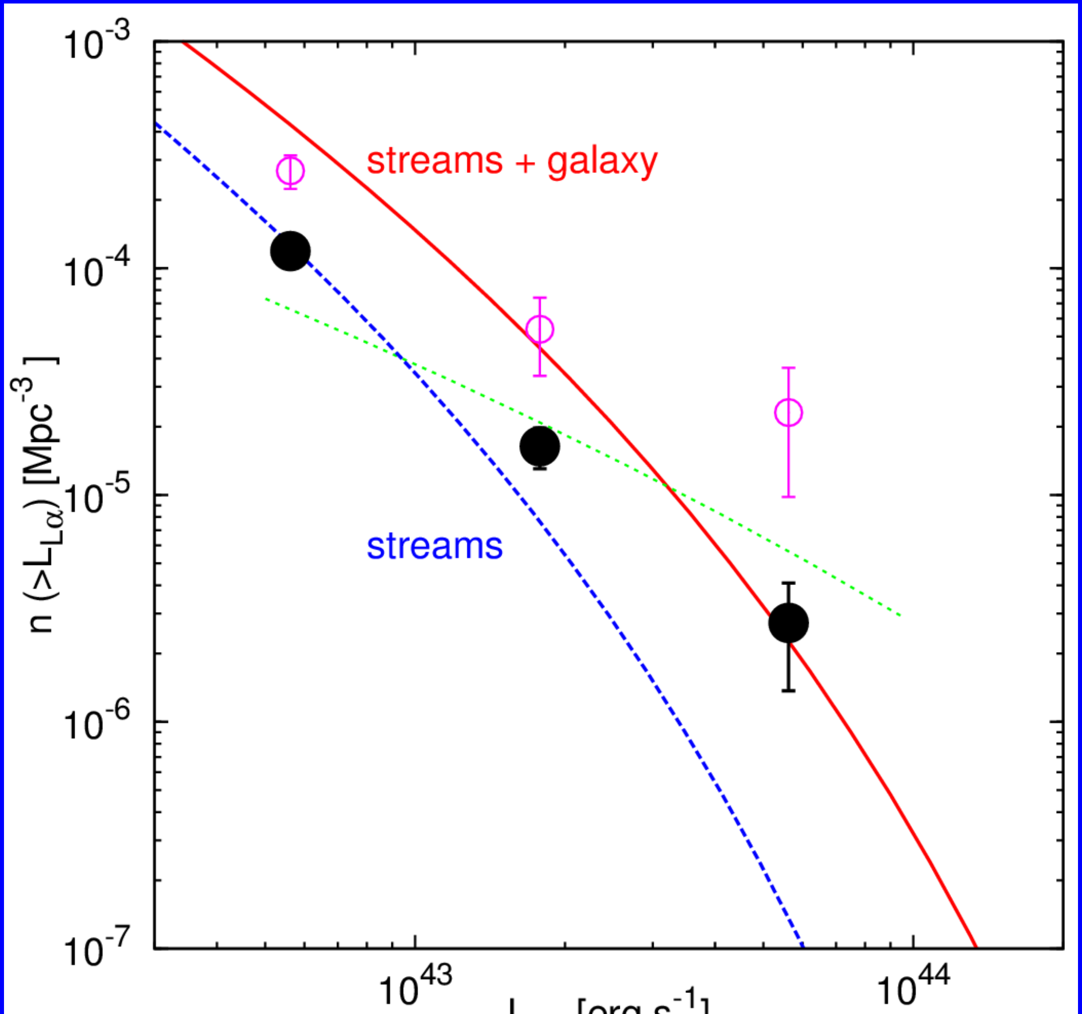
Lyman alpha vs halo mass

- AMR simulations
- Several galaxies per data point
- z = 3.09



Luminosity function

- Correlation with Sheth Tormen mass function
- Data from Matsuda et al. 2004



Emission 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

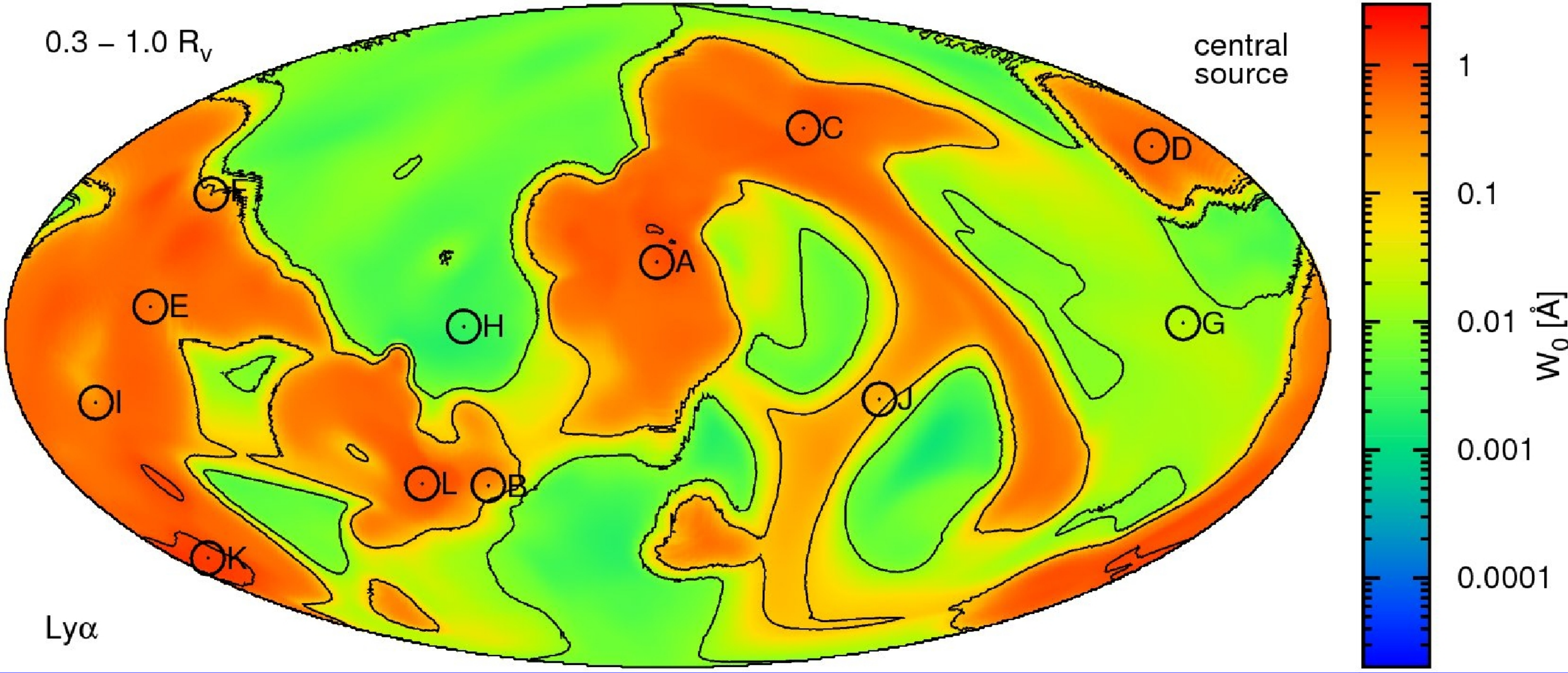
=> Cold streams can explain Lyman alpha blobs

=> First observational evidence for cold streams!

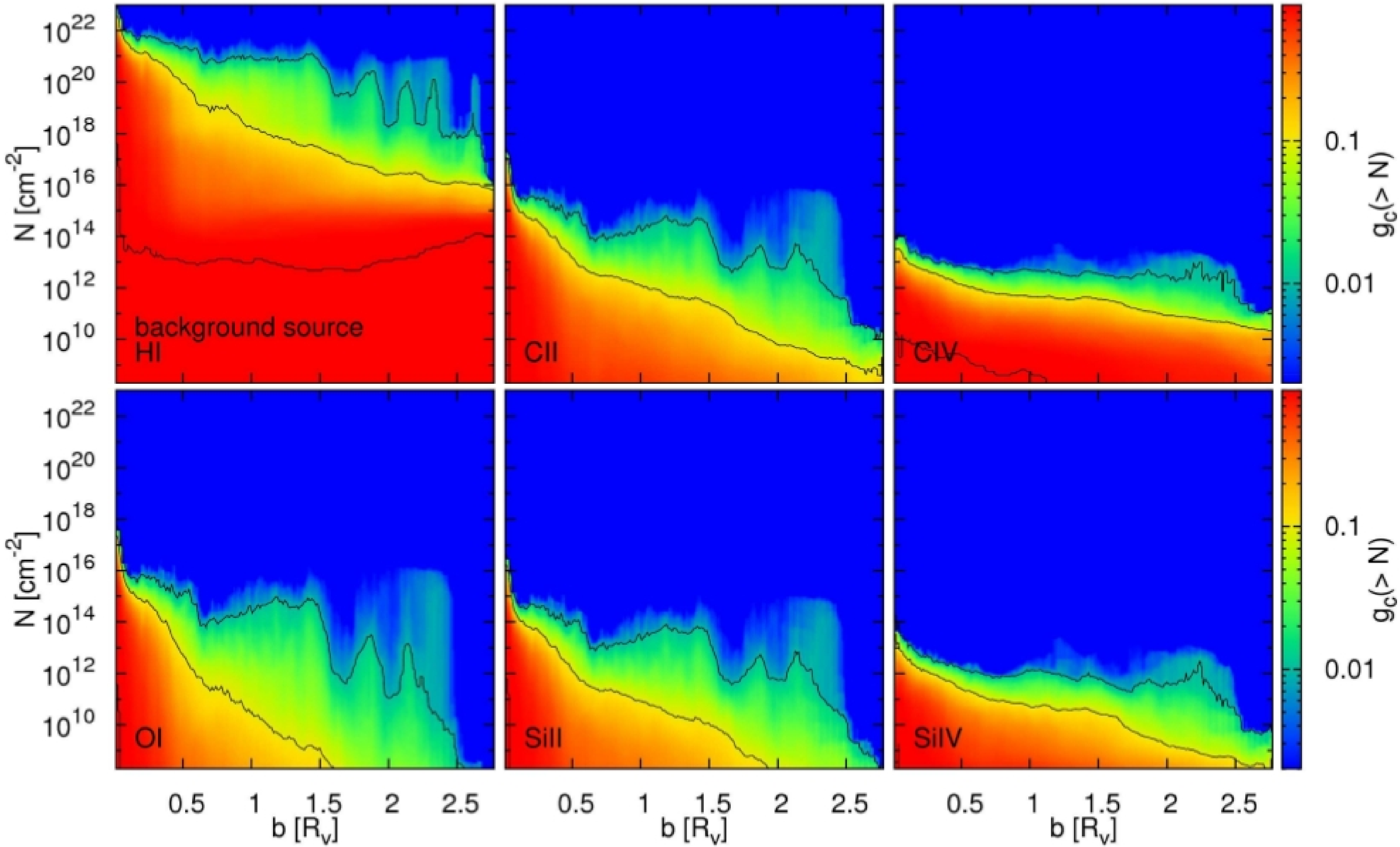
Thanks!

Equivalent width

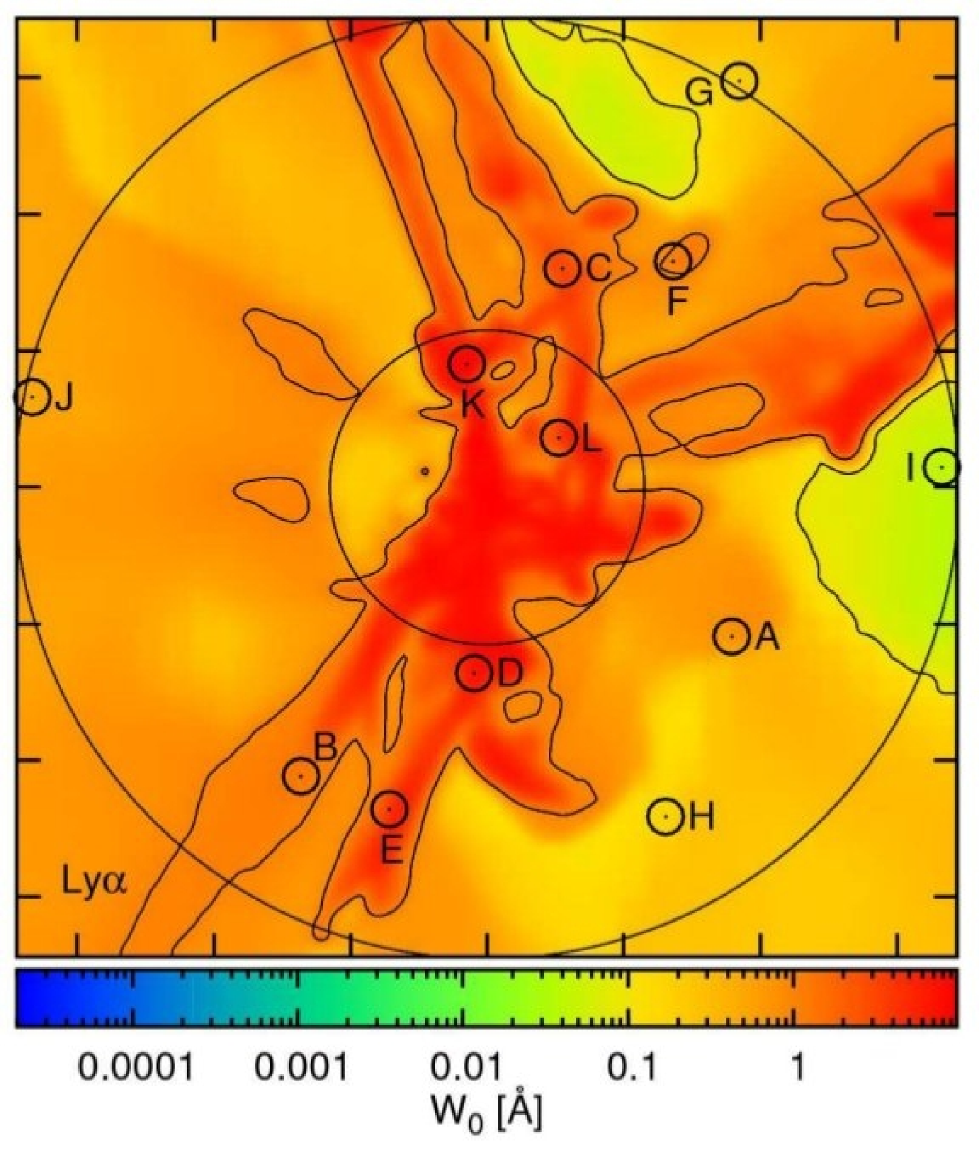
$$EW = \frac{\lambda^2}{c}\int_0^\infty [1 - \exp(-\tau_\nu)]\, \mathrm{d}\nu = \frac{\lambda^2}{c}\int_0^\infty g(\nu)\, \mathrm{d}\nu,$$



covering fraction vs impact parameter vs column density



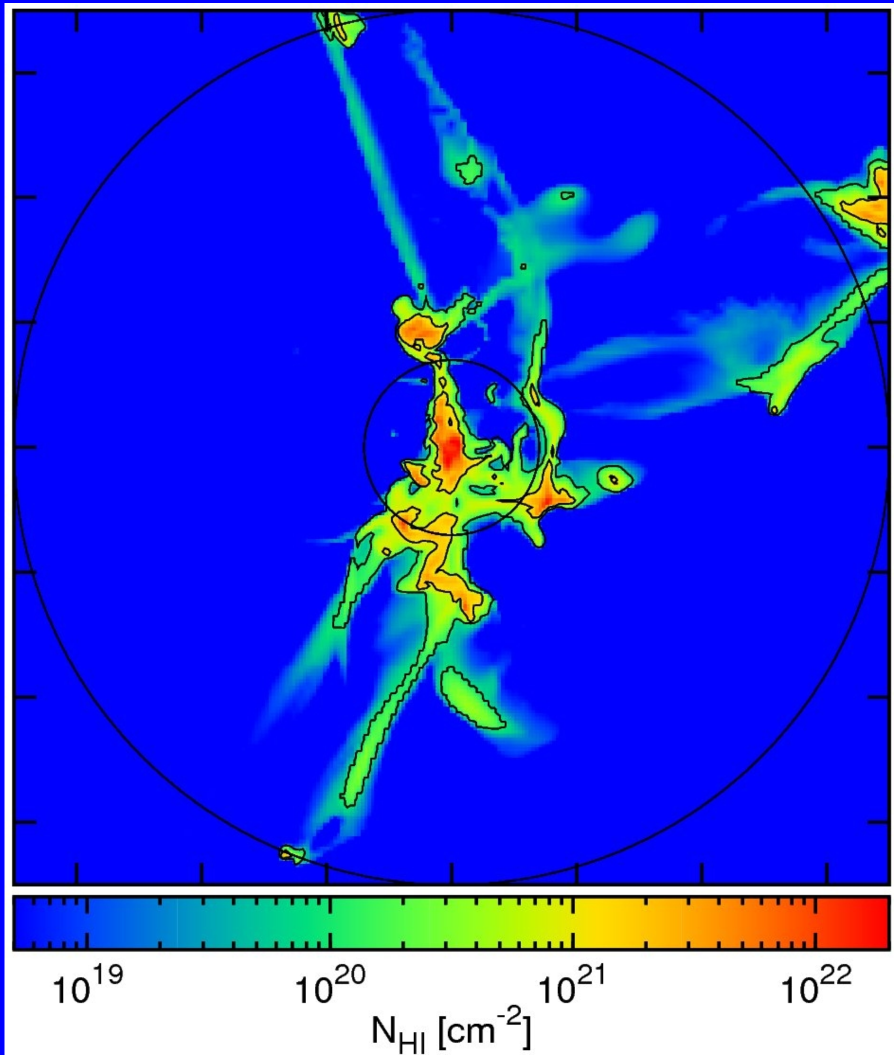
Equivalent width



Background geometry

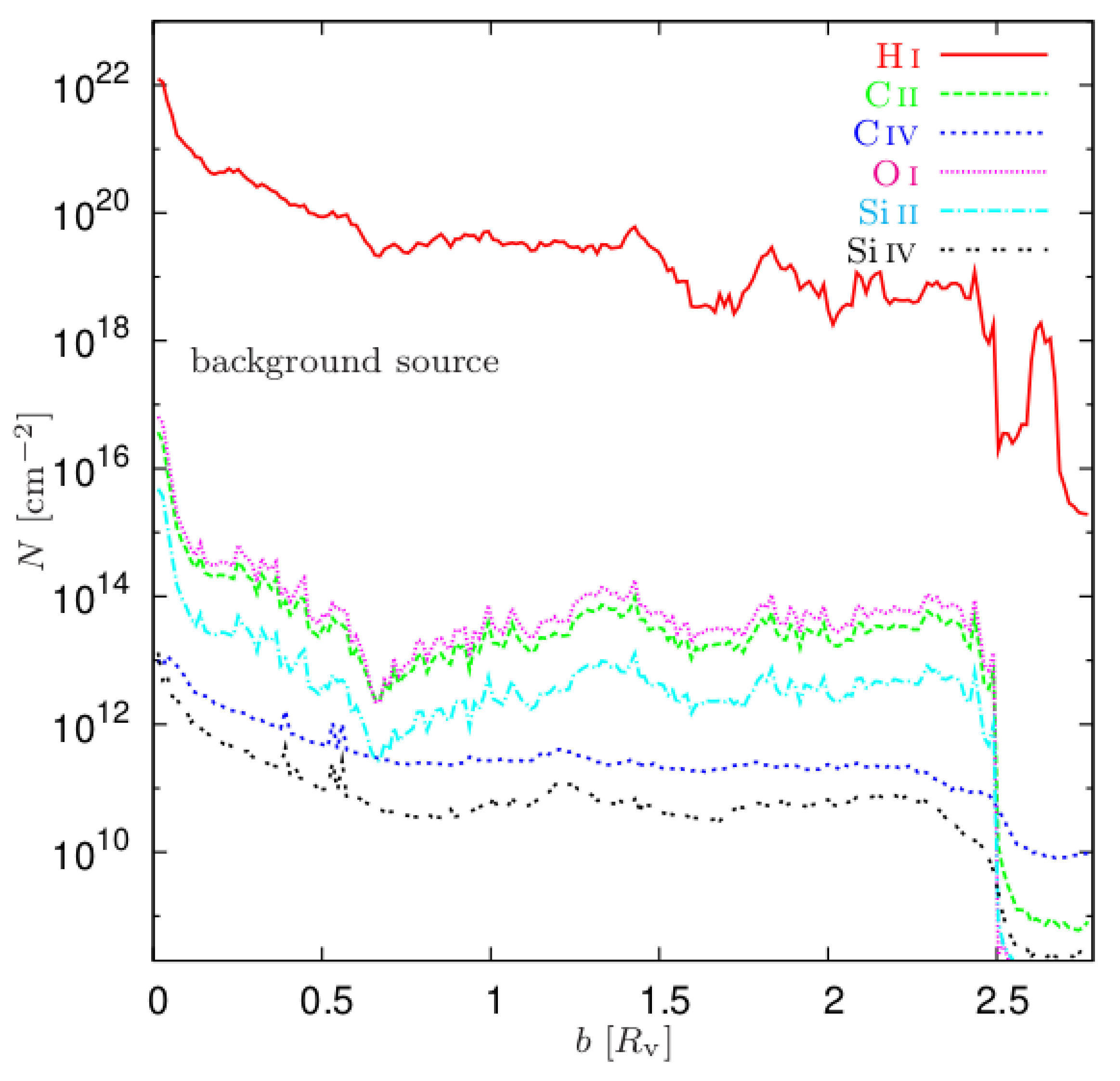
- Observes background galaxy through circum galactic medium of galaxy in question
- Additional parameter:

  Impact parameter b



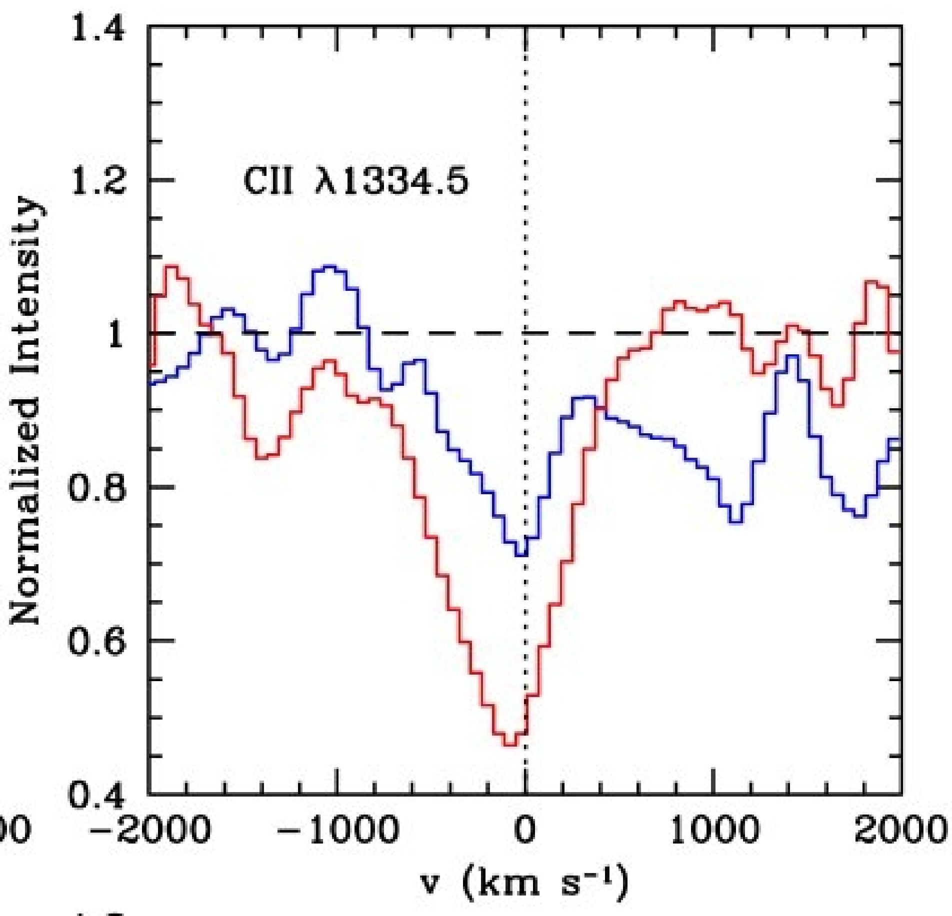
Column density vs impact parameter

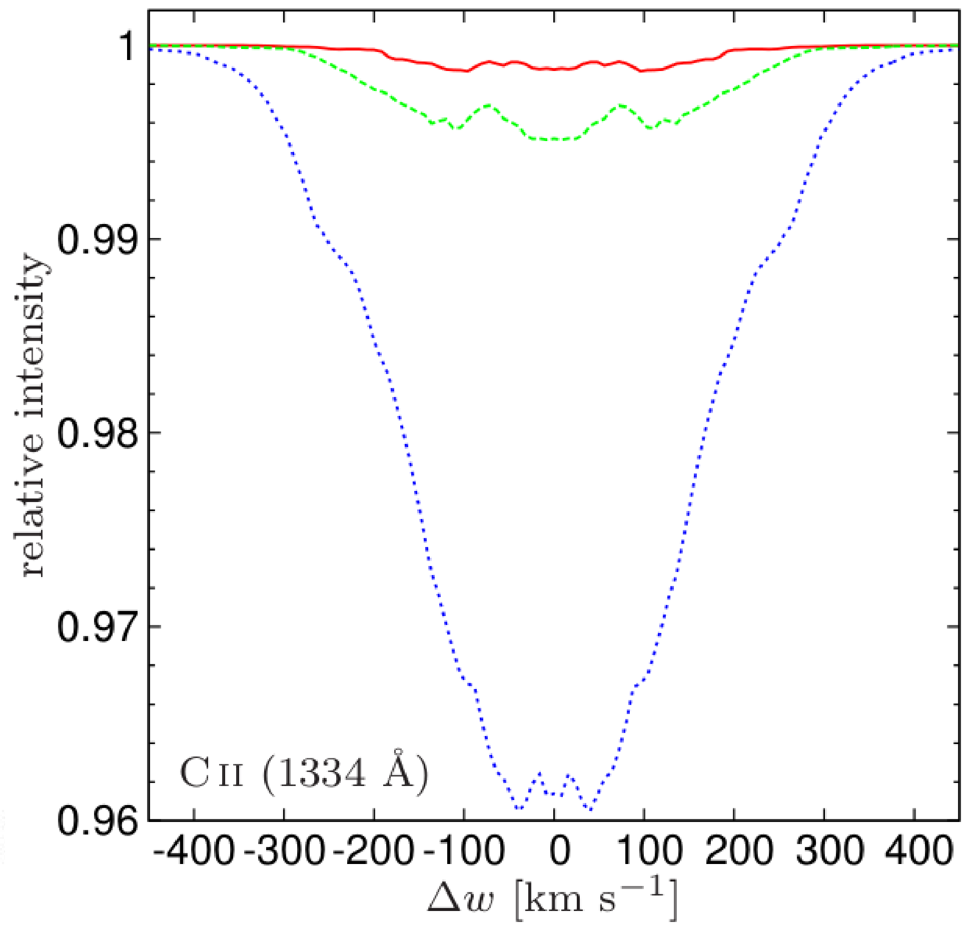
- All lines decreasing
- Ly alpha considerably higher than metals



Stacked line profile

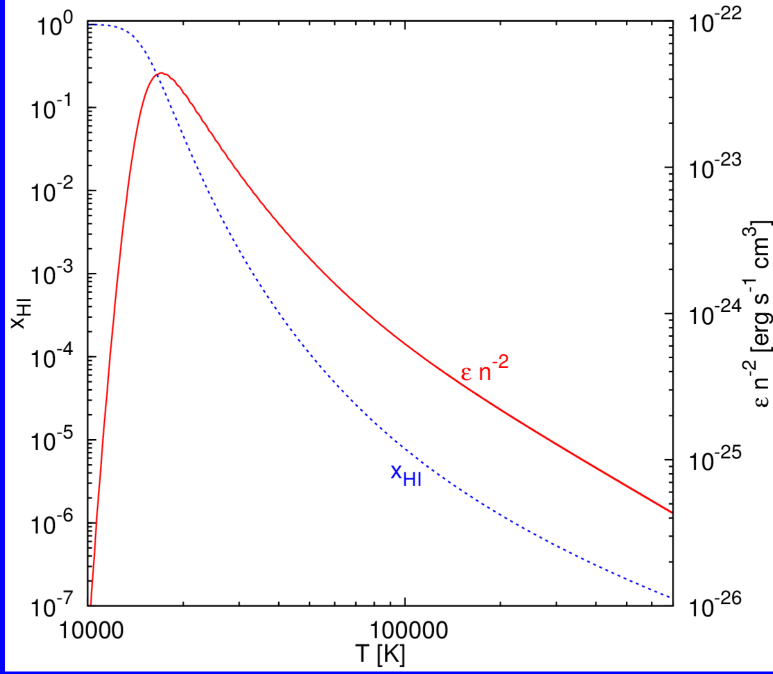
- Averaging over all available example line profiles (3 galaxies, 6 principal directions, all points in radiusrange)

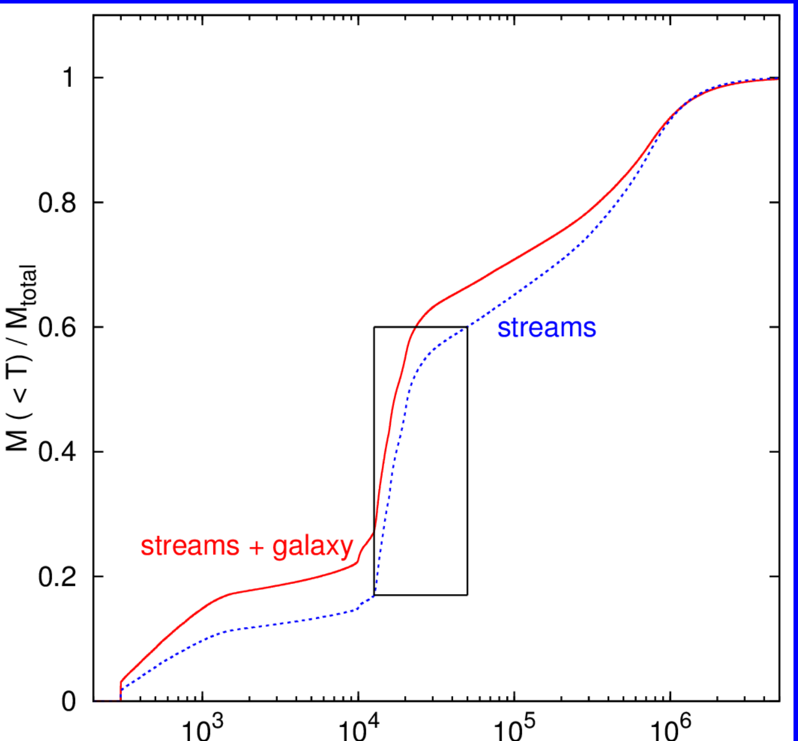


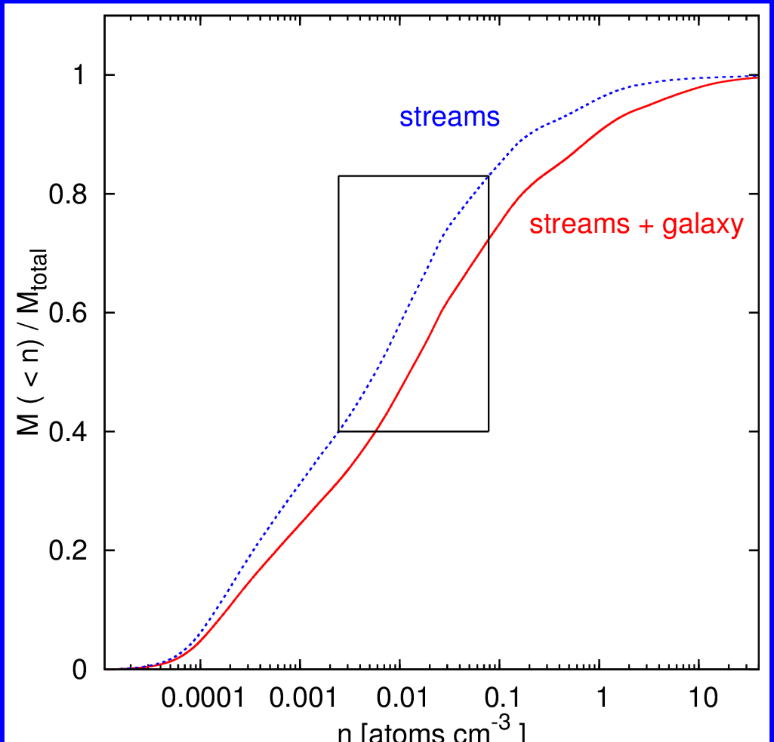


Lα emissivity:

- 50% of the gas emits Lα efficiently

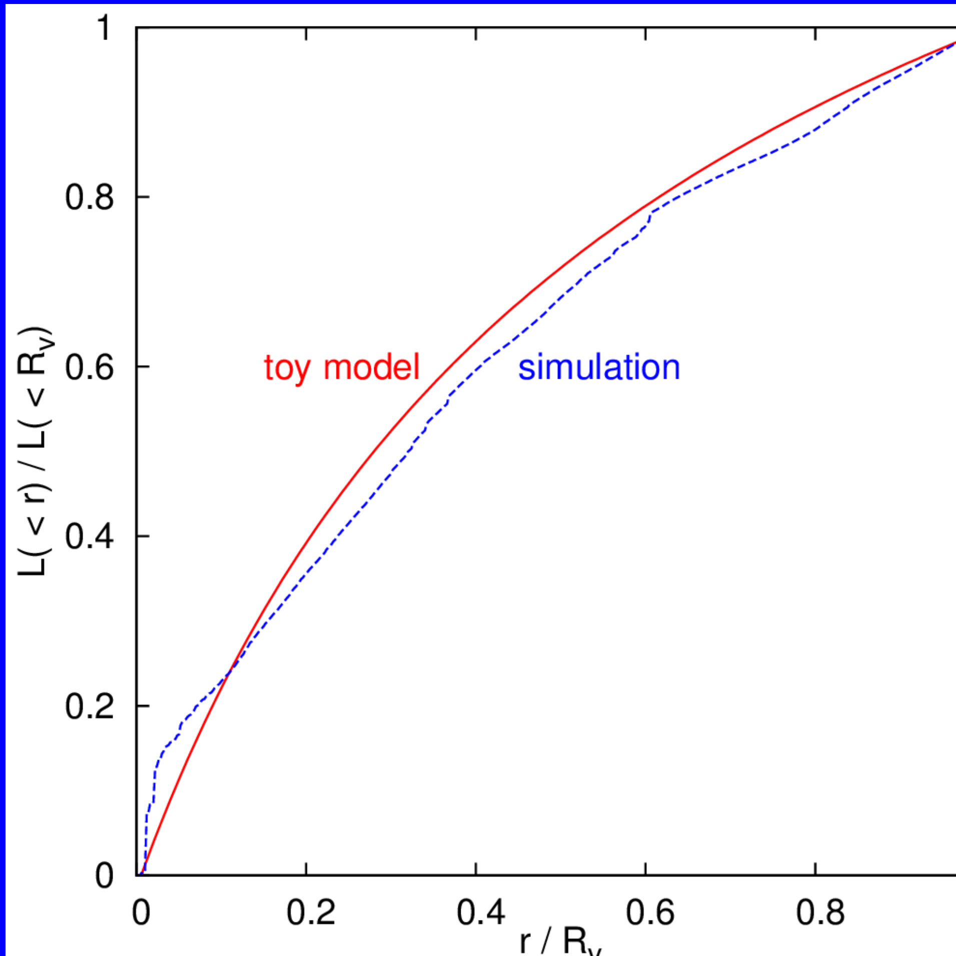






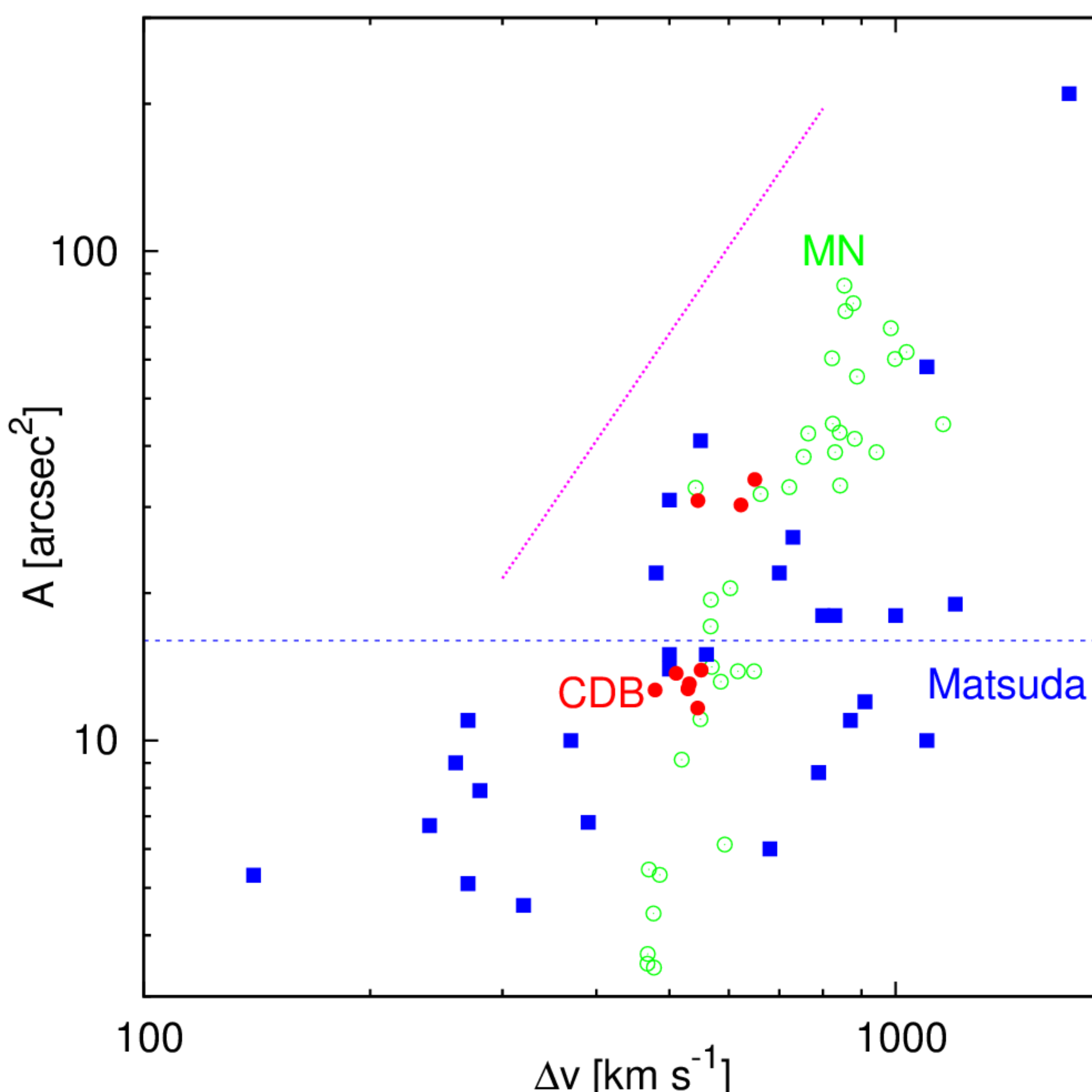
Toy model:

- NFW profile
- Neistein infall (EPS)
- Constant infall velocity



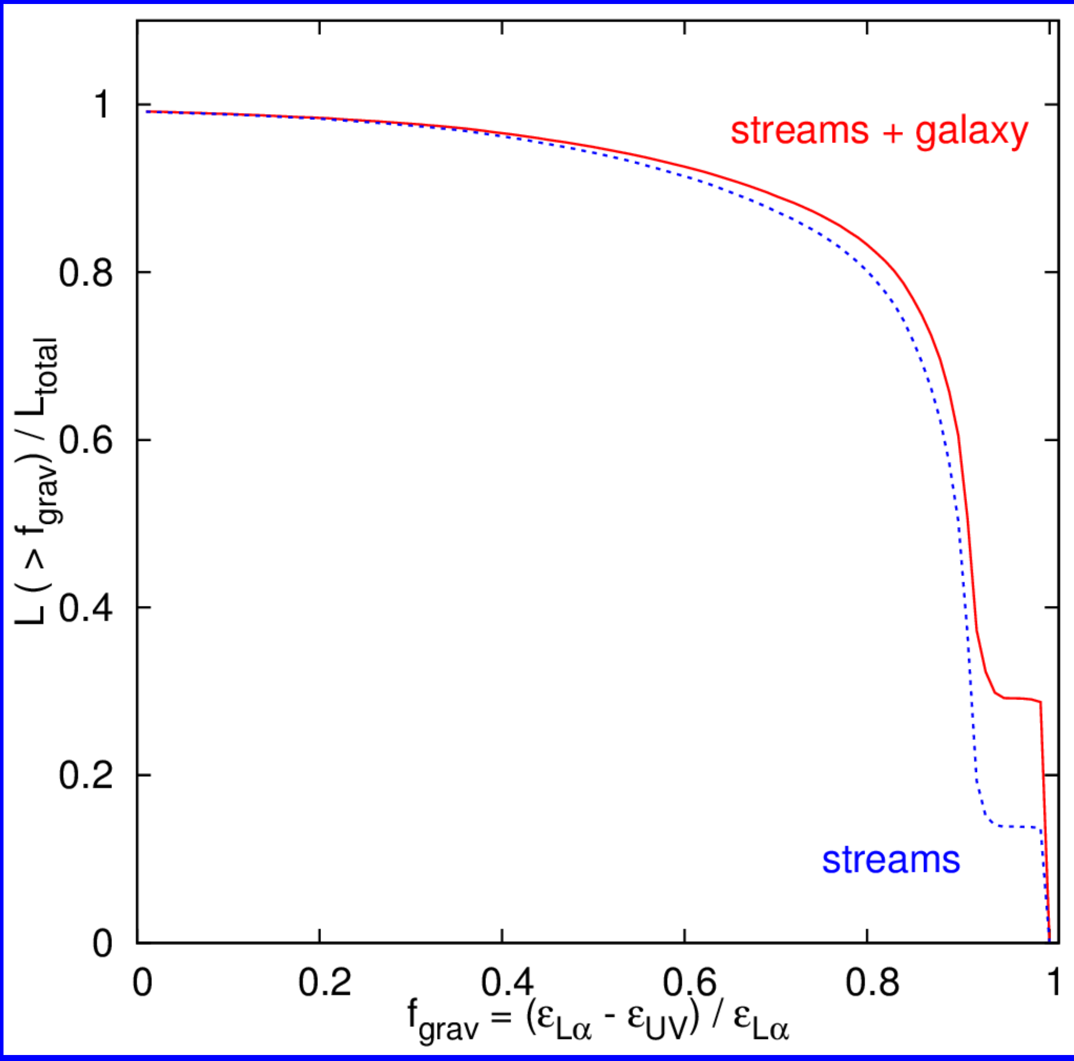
Kinematics

- Area vs. velocity dispersion



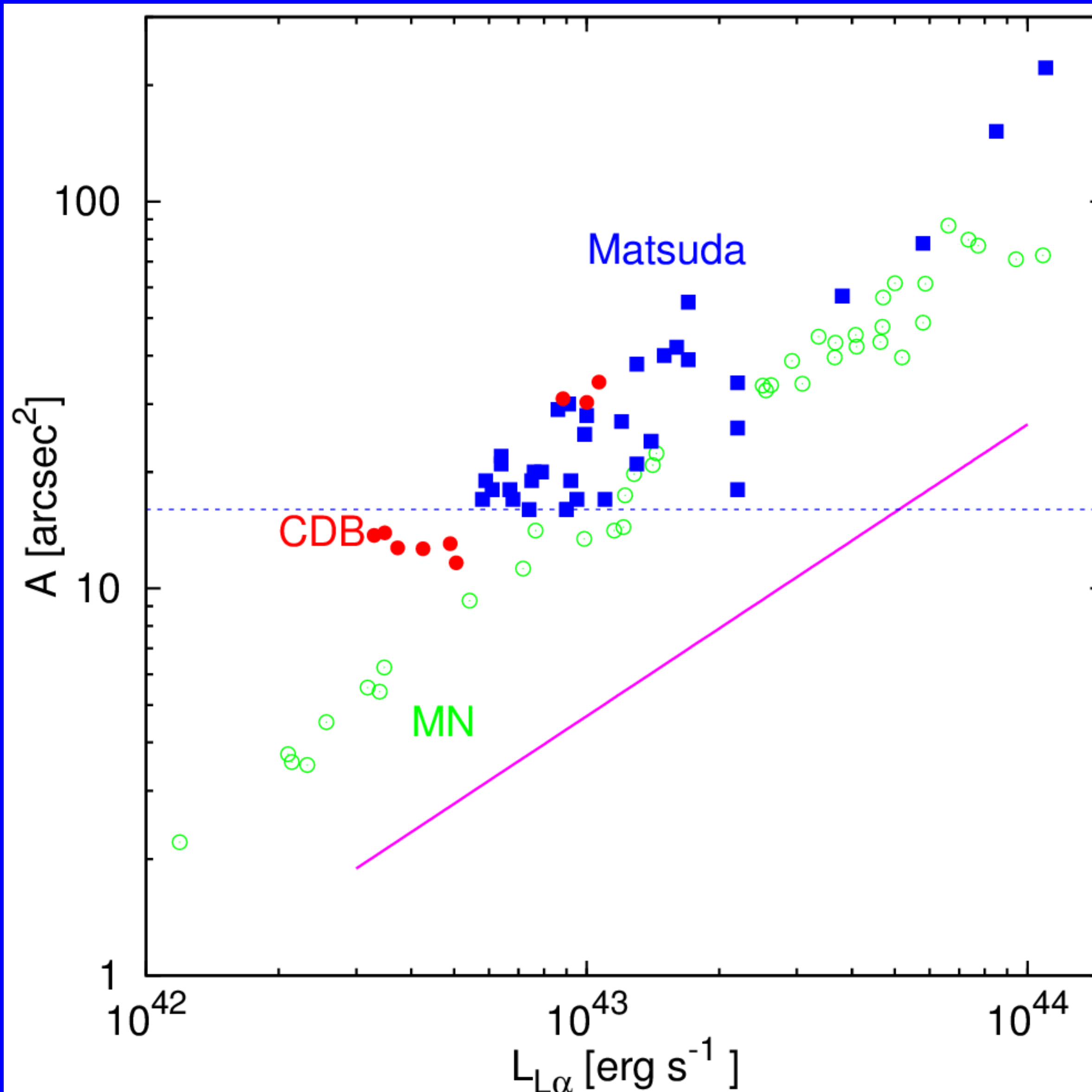
Energy source: Gravitational heating vs. UV background

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



Area vs. Luminosity

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



The AMR simulations

- Ceverino, Dekel & Bournaud
  - Art by Andrey Kravtsov
  - UV background, Haardt & Madau 1996
  - mimics self-shielding
  - Gas can cool down to 100K
  - 3 re-simulated galaxies
  - High resolution (70 pc physical)

Computing Lyman alpha

- Emissivity:

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

- Collisional excitation coefficient:

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

- Case-B recombination coefficient:

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

More computing

- Number densities:

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

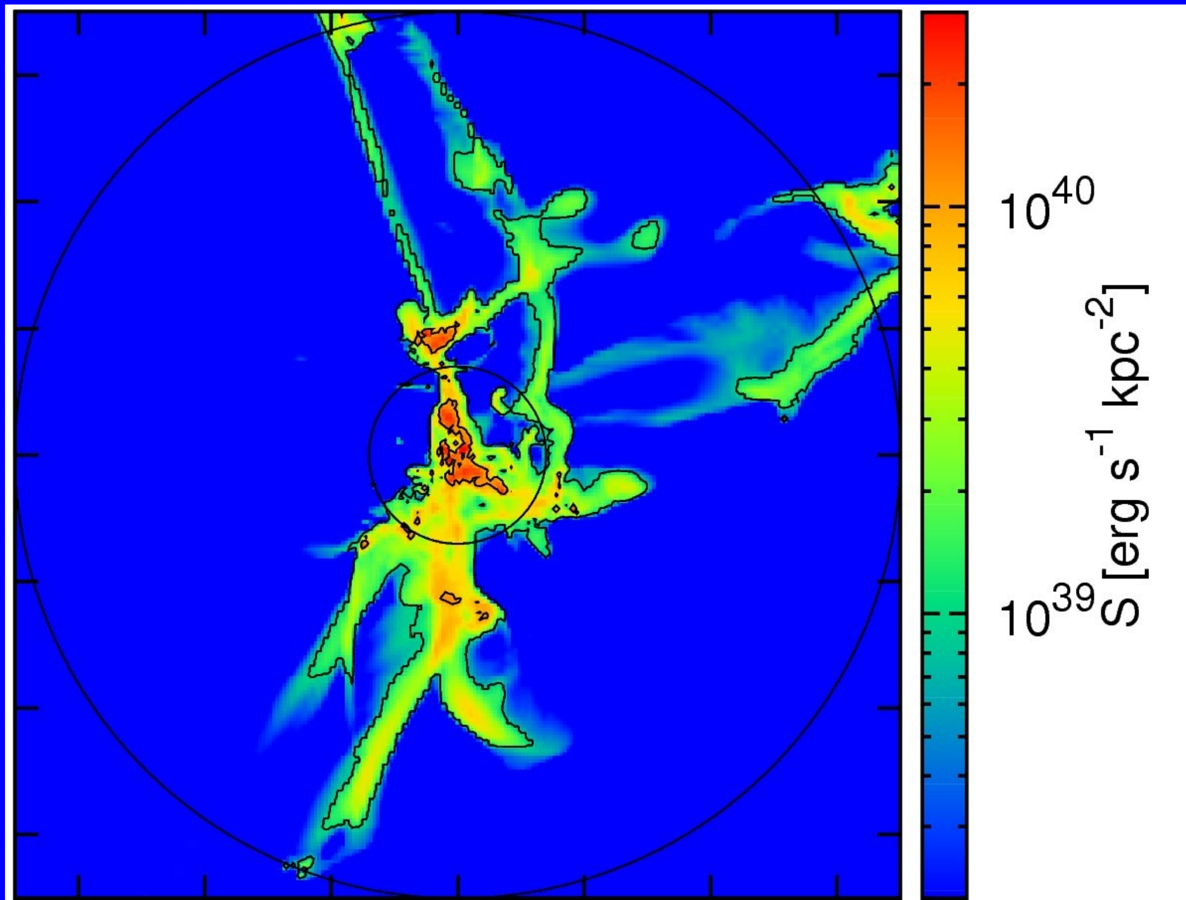
$$n_{\mathrm{HII}} = n_{\mathrm{e}} = \frac{(1 - x_{\mathrm{HI}})\, X\, \rho}{m_{\mathrm{p}}}$$

- Neutral Hydrogen fraction:

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

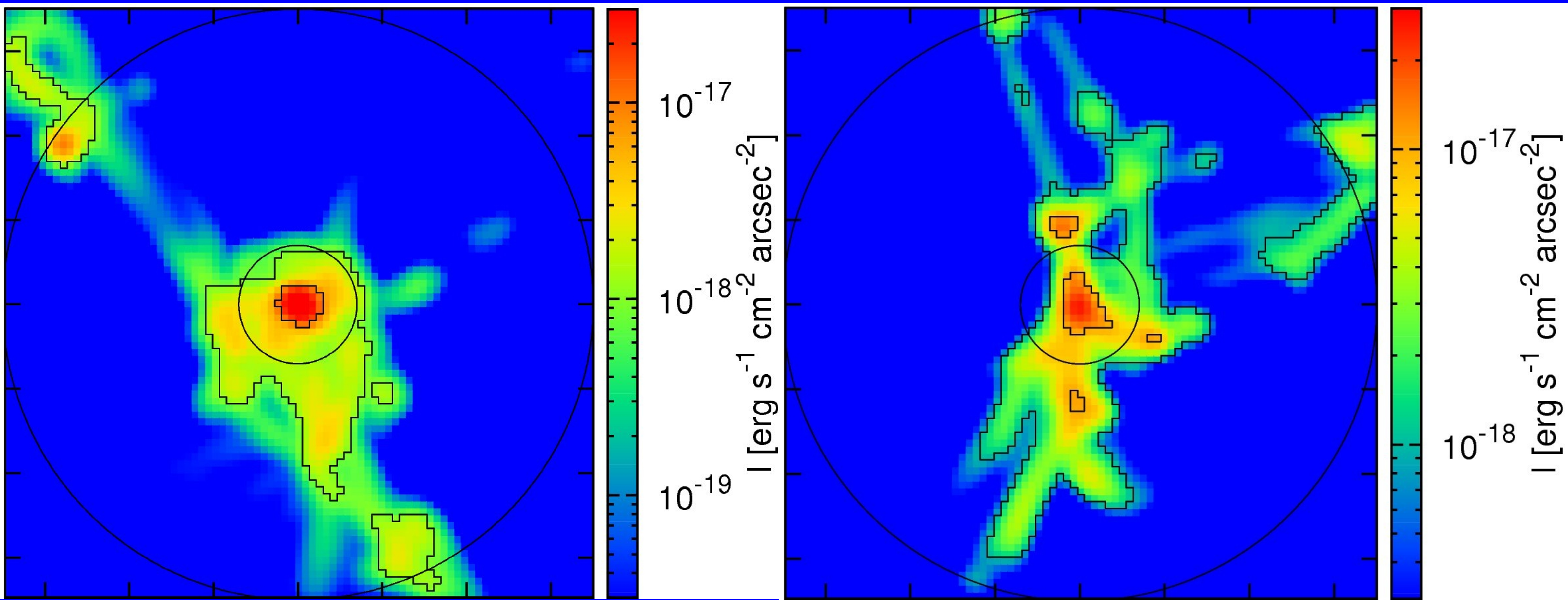
Resulting maps: Surface brightness

- CDB simulation
- Z = 3.09
- $M_{vir} = 3.5e11 M_O$



What an observer would see:

- $I = S / [4 \pi (1+z)^4]$
- 0.6" FWHM Gaussian PSF



Computing line profiles

- Doppler broadening

$$b = \sqrt{\frac{2\,k\,T}{m_{\mathrm{Y}}}},$$

- Optical depth τ

$$\tau_\nu(\phi, \theta, \Delta w) = \frac{\sqrt{\pi}\; e^2\; f_\lambda\; \lambda_0}{m_{\mathrm{e}}\; c} \int_{\mathrm{r_i}}^{R_{\mathrm{v}}} \frac{n_{\mathrm{Y}}(\vec{r})\; X_{\mathrm{XX}}(\vec{r})}{b(\vec{r})} \times H\left[\frac{\gamma_\lambda\; \lambda_0}{4\,\pi\; b(\vec{r})}, \frac{\Delta w - v(\vec{r})}{b(\vec{r})}\right]\; dr,$$

- Intensity I(Δw) = exp(−τ)

Additional 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 $n>0.1cm^{-3}$
  - Fully cosmological simulation
  - Fairly good resolution (1kpc physical)