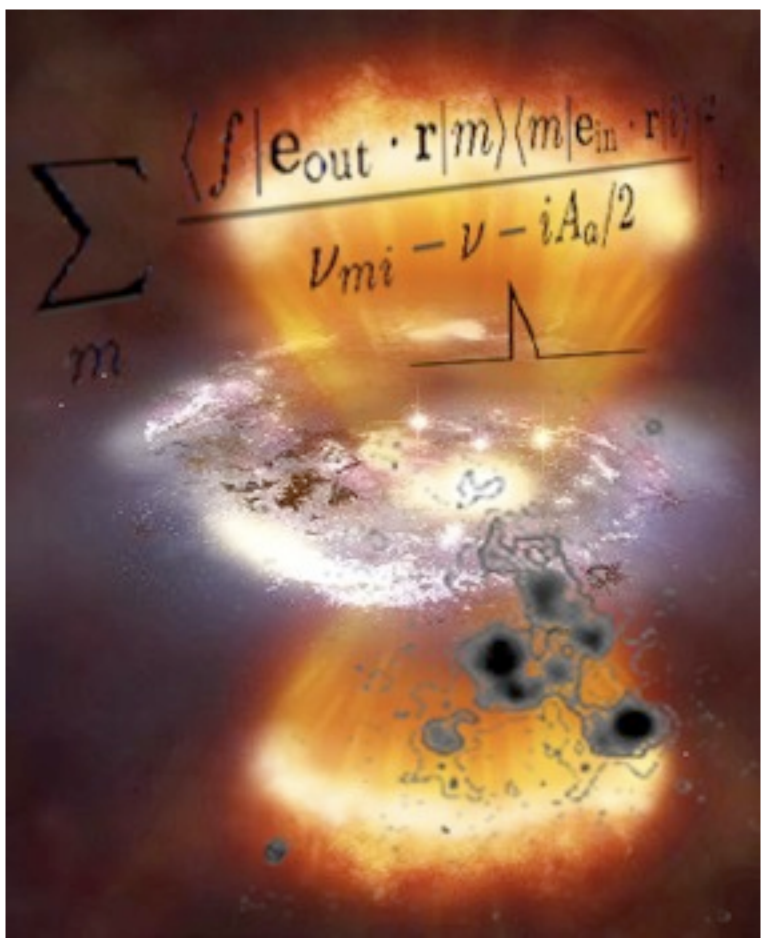
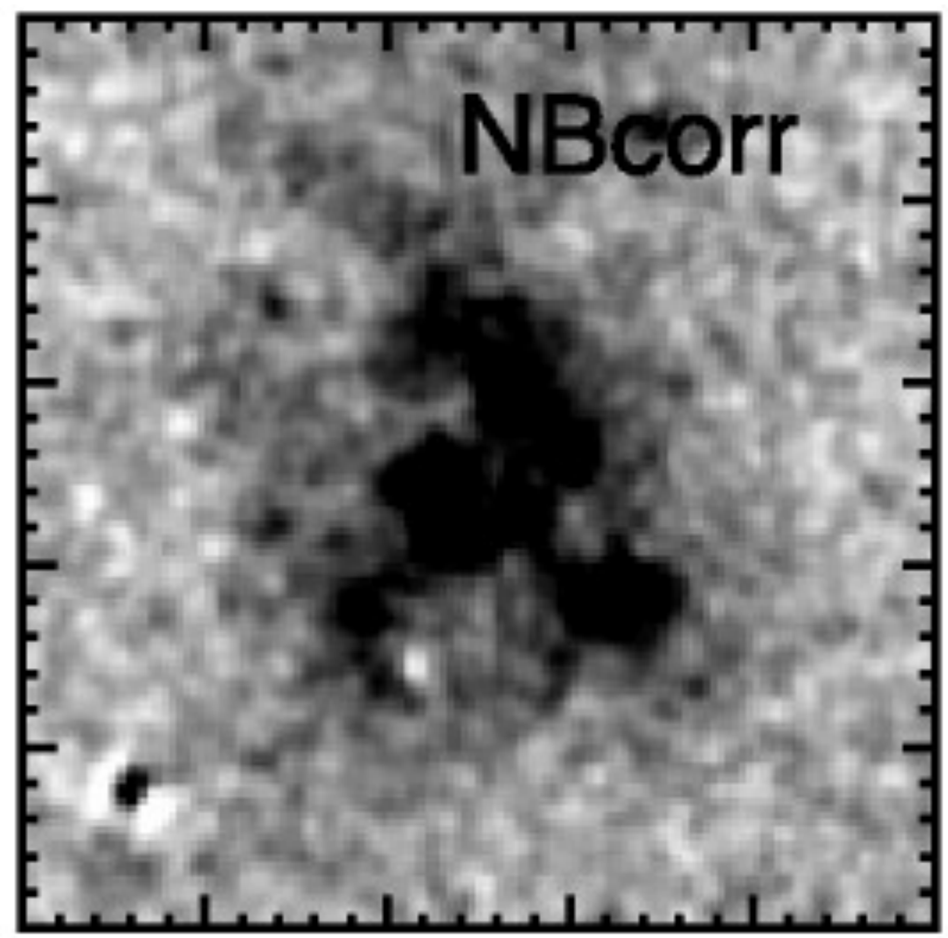
Spatially Extended Lyman α Emission from Cold Accretion Streams

Mark Dijkstra (MPA, Garching)





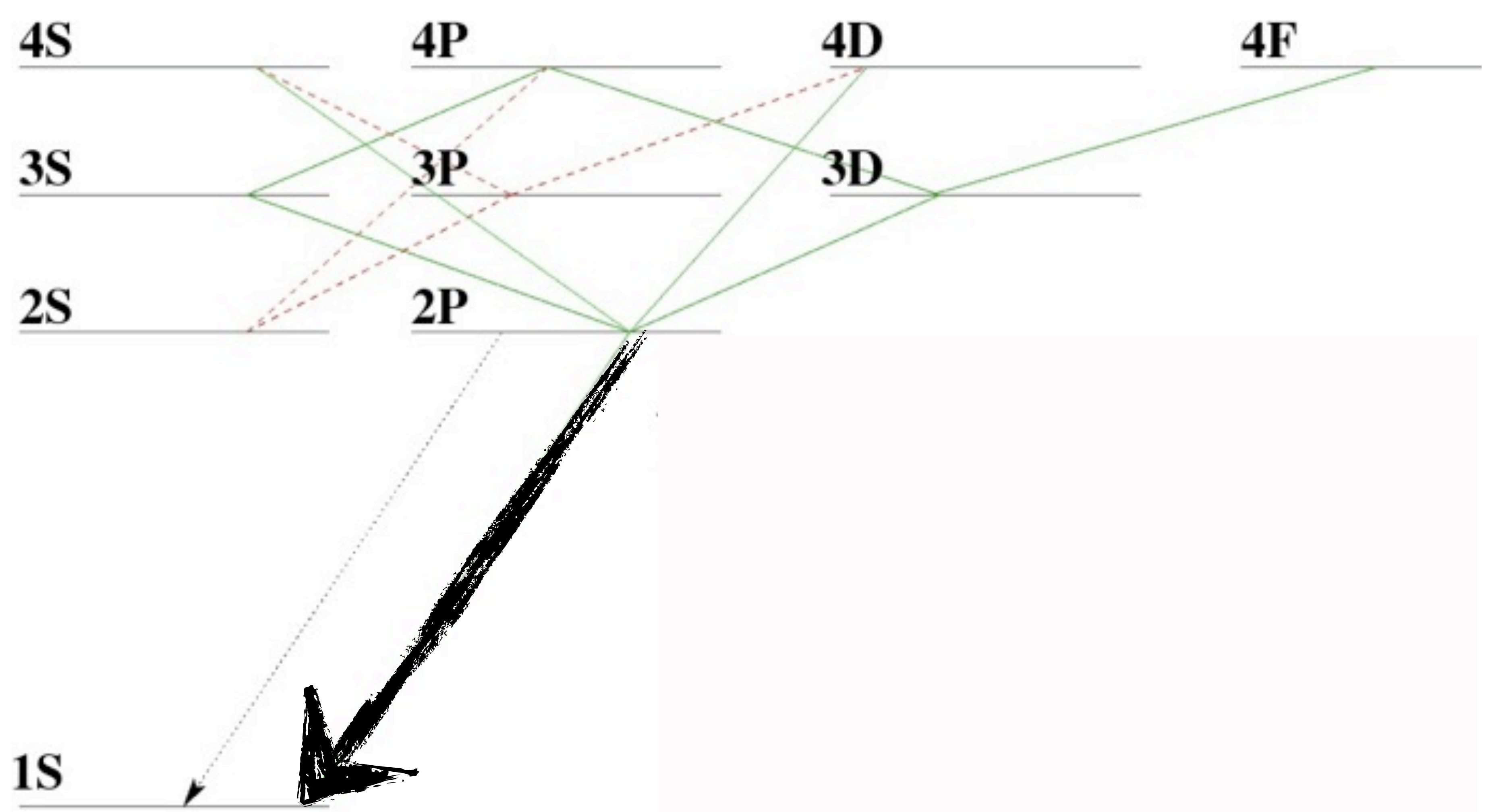
special thanks to: R. Kramer, A. Loeb, C.A. Faucher-Giguere, D. Keres

Outline

- Cold Accretion Streams play central role in Galaxy Formation & Evolution, but there's no direct observational evidence for them.
- Cold Streams are naturally Spatially Extended Lyα Sources.
- Observations of Spatially Extended Lyα Sources: Lyα halos around star forming galaxies & Lyα halos `blobs'.
- Cold Streams Model currently consistent with the majority of observations, but uncertainties exist on modeling side.
- Alternatives & Outlook.

The HI Lyα Transition.

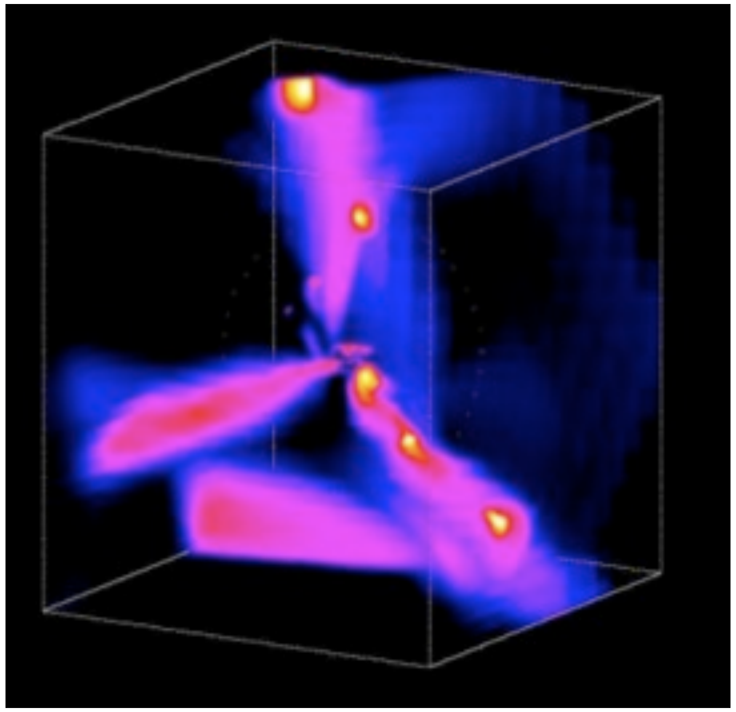
Lyα: 2p-> 1s transition of atomic hydrogen λ=1216 A; ΔE = 10.2 eV.

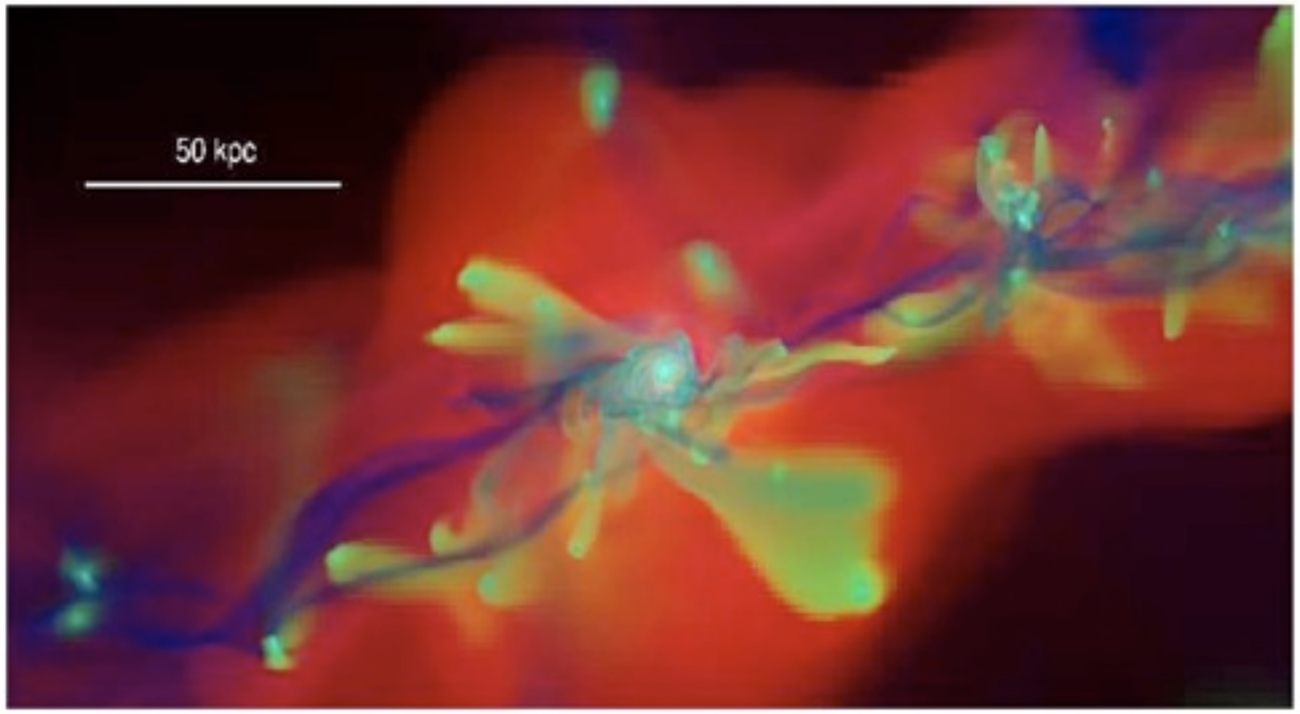


Gas with 1e4 K < T < 1e5 K is efficient source of Lya emission

Cold Accretion Streams around Galaxies.

- Simulations indicate that galaxies in massive DM halos at z>1 are fed by cold (1e4 K), continuous streams of gas in a hot gaseous halo.
- Geometry of spatially extended (hundreds of p-kpc), narrow streams.



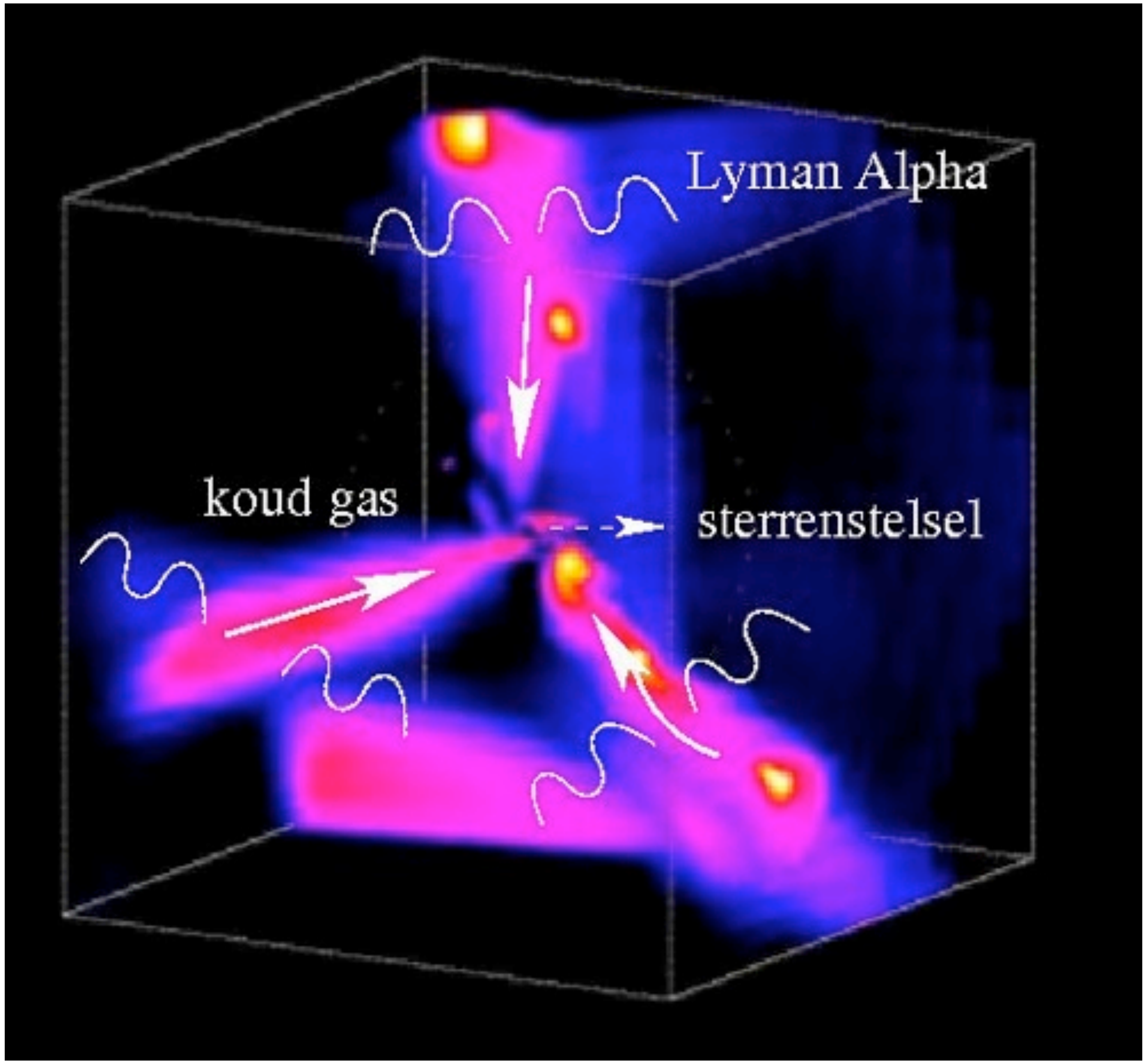


Dekel+09 Agertz+09

also see e.g. Keres+05, Dekel & Birnboim 06, Ocvirk+09, Keres+09

Spatially Extended Lyα Emission from Cold Streams around Galaxies.

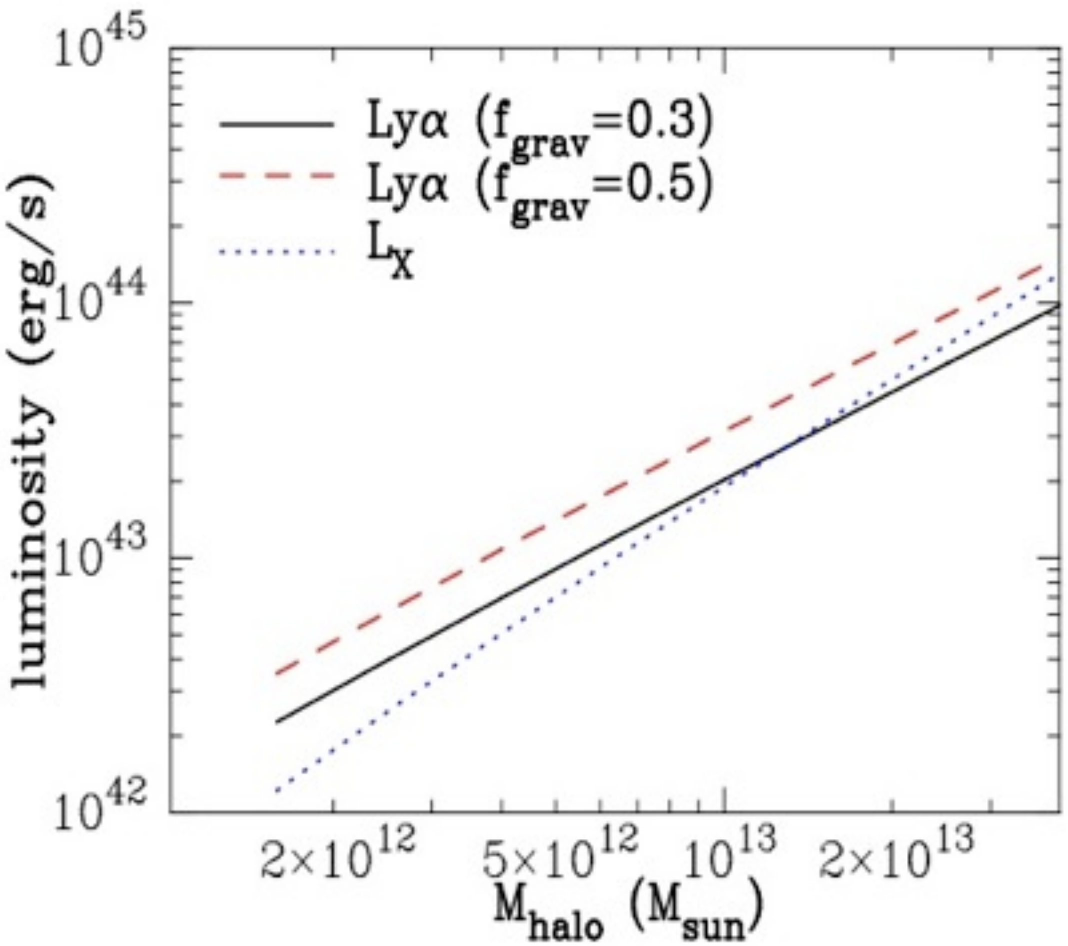
- For given simulation snapshot: thermal energy radiated away in 1e6-1e7 yrs.
- Cold flows visible in Lya for extremely short time, unless cold flow gas is heated!
- `Easiest' to estimate: gravitational heating (Haiman, Spaans & Quataert 2000)



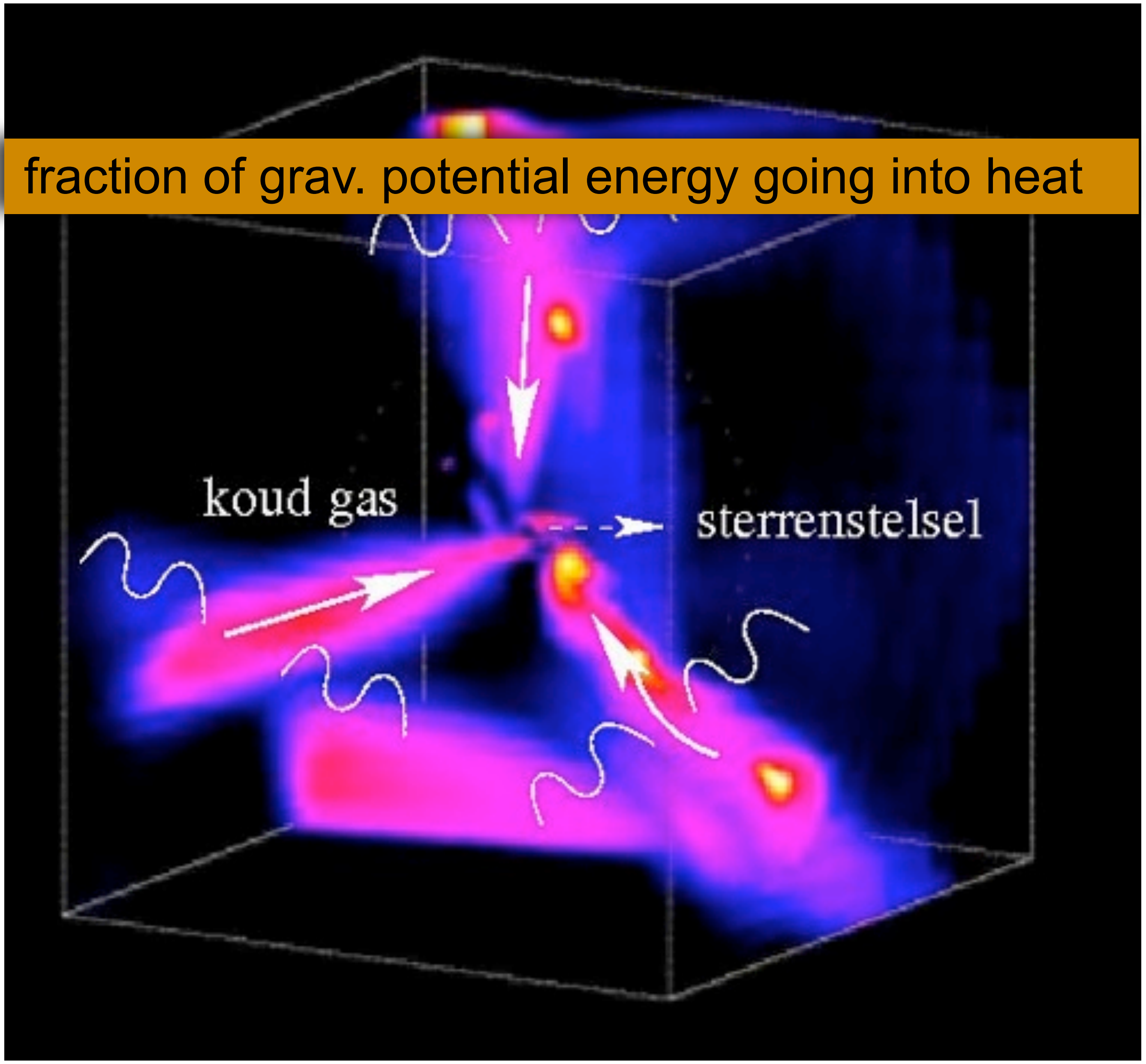
Spatially Extended Lyα Emission from Cold Streams around Galaxies.

$$L_{Ly\alpha}(M) \sim f_{grav} \times \Delta\Phi_{DM} \times \dot{M}_{gas}$$

MD & Loeb '09; Goerdt+10; Faucher-Giguere+10



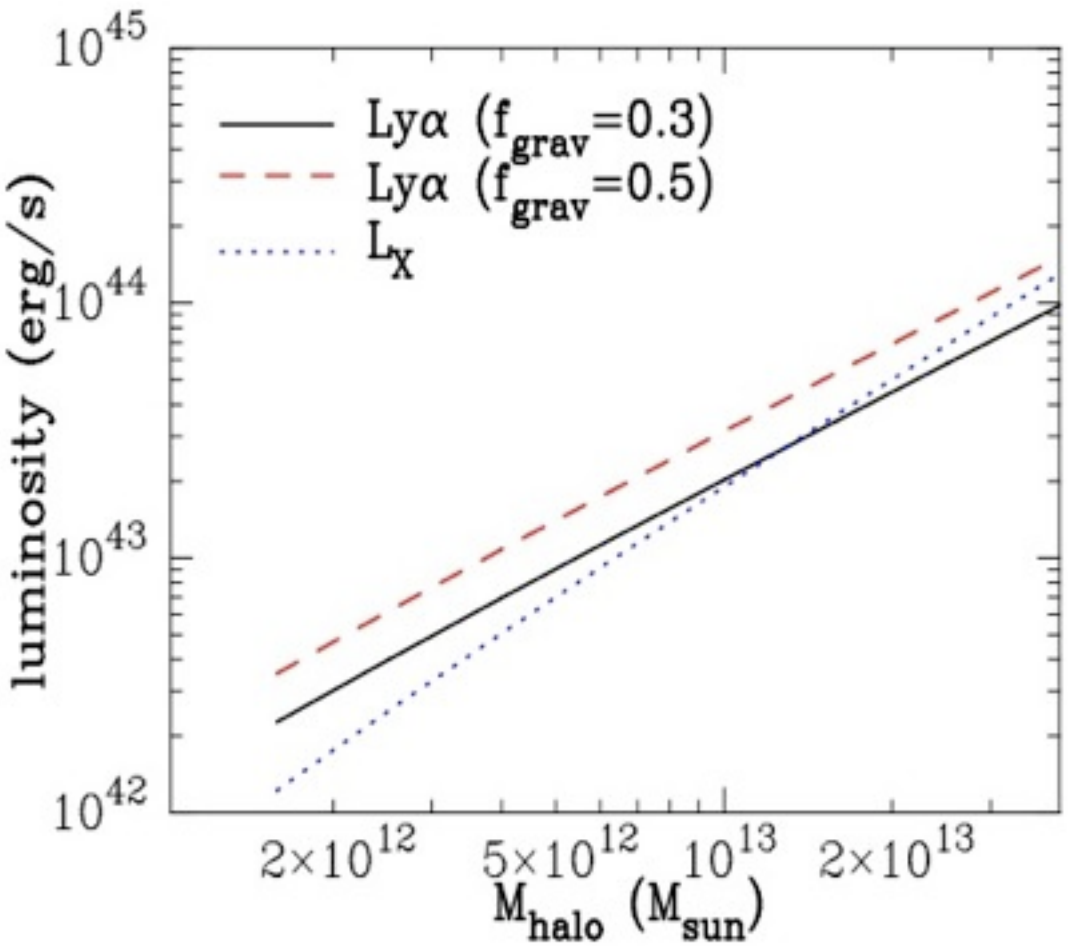
fraction of grav. potential energy going into heat



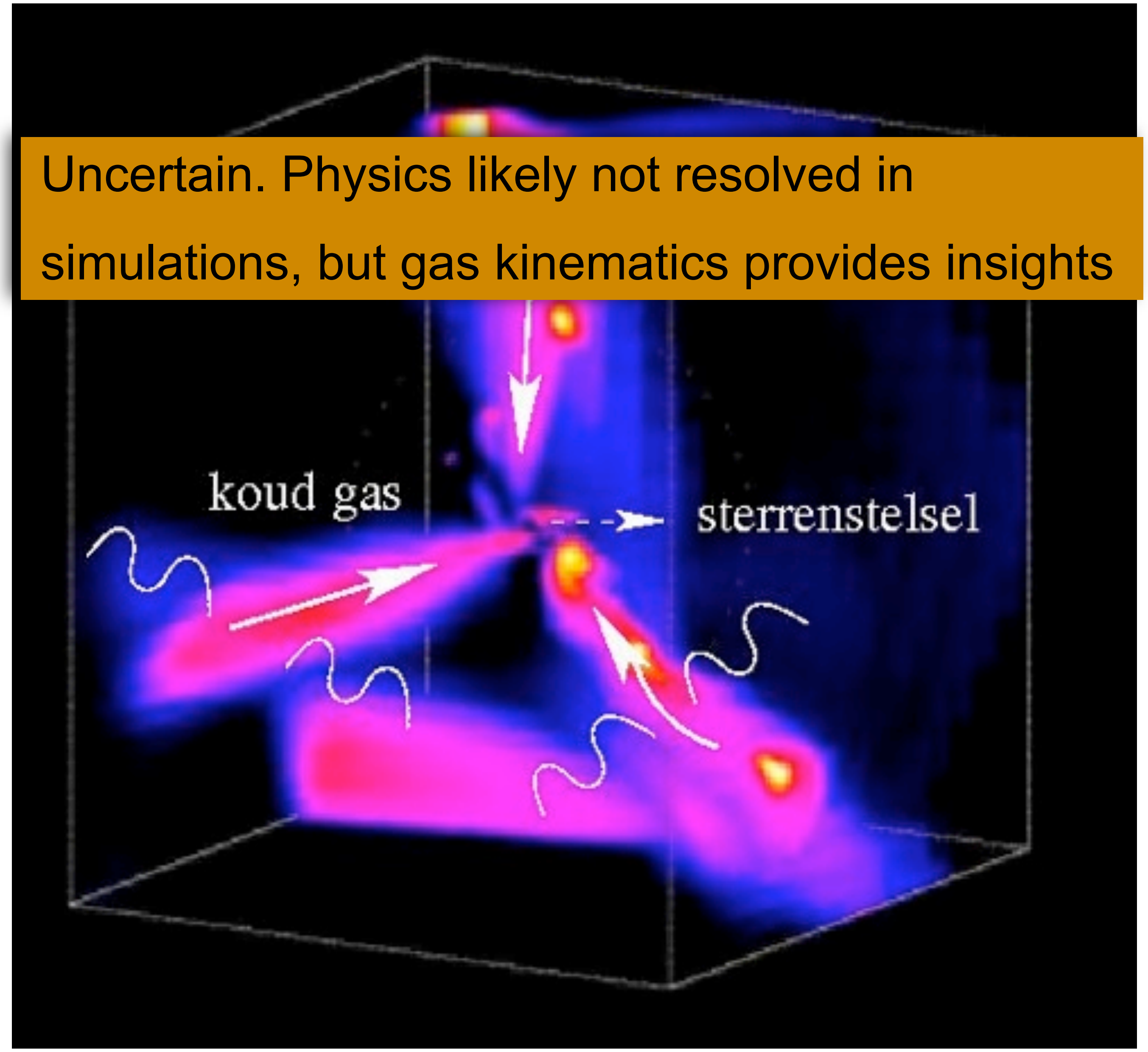
Spatially Extended Lyα Emission from Cold Streams around Galaxies.

$$L_{Ly\alpha}(M) \sim f_{grav} \times \Delta\Phi_{DM} \times \dot{M}_{gas}$$

MD & Loeb '09; Goerdt+10; Faucher-Giguere+10



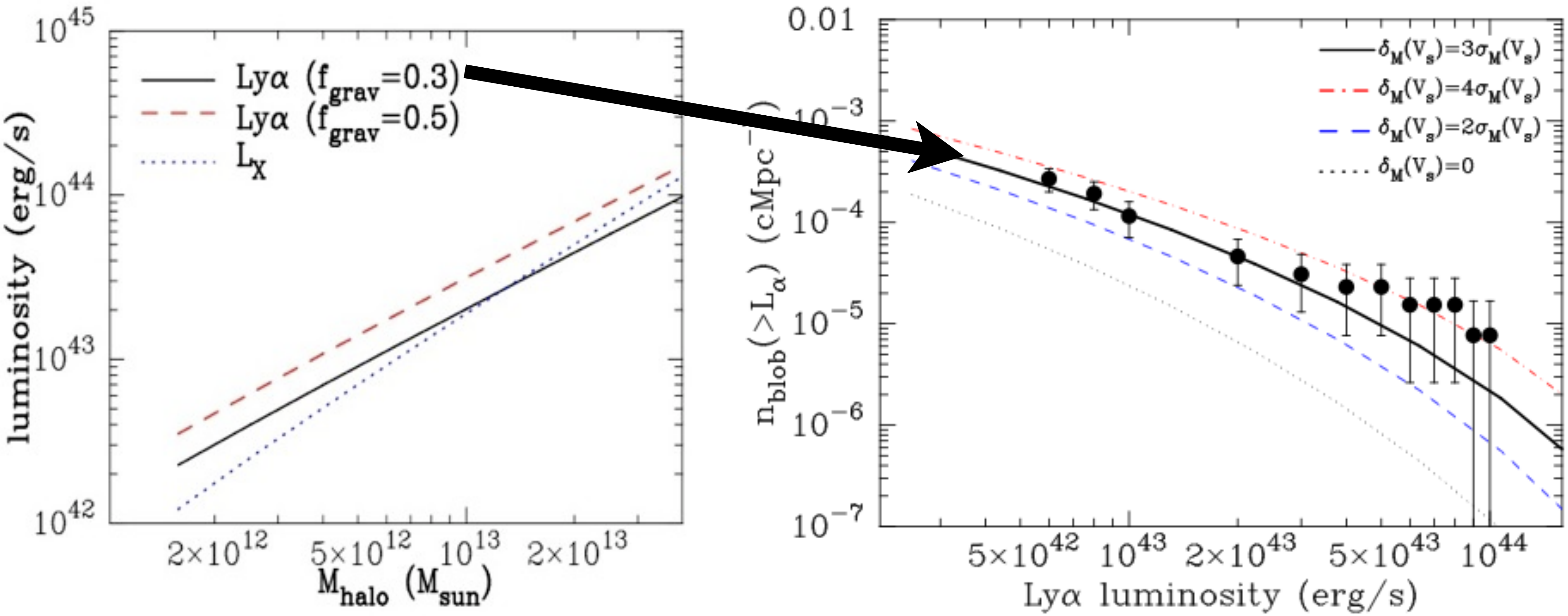
Uncertain. Physics likely not resolved in simulations, but gas kinematics provides insights



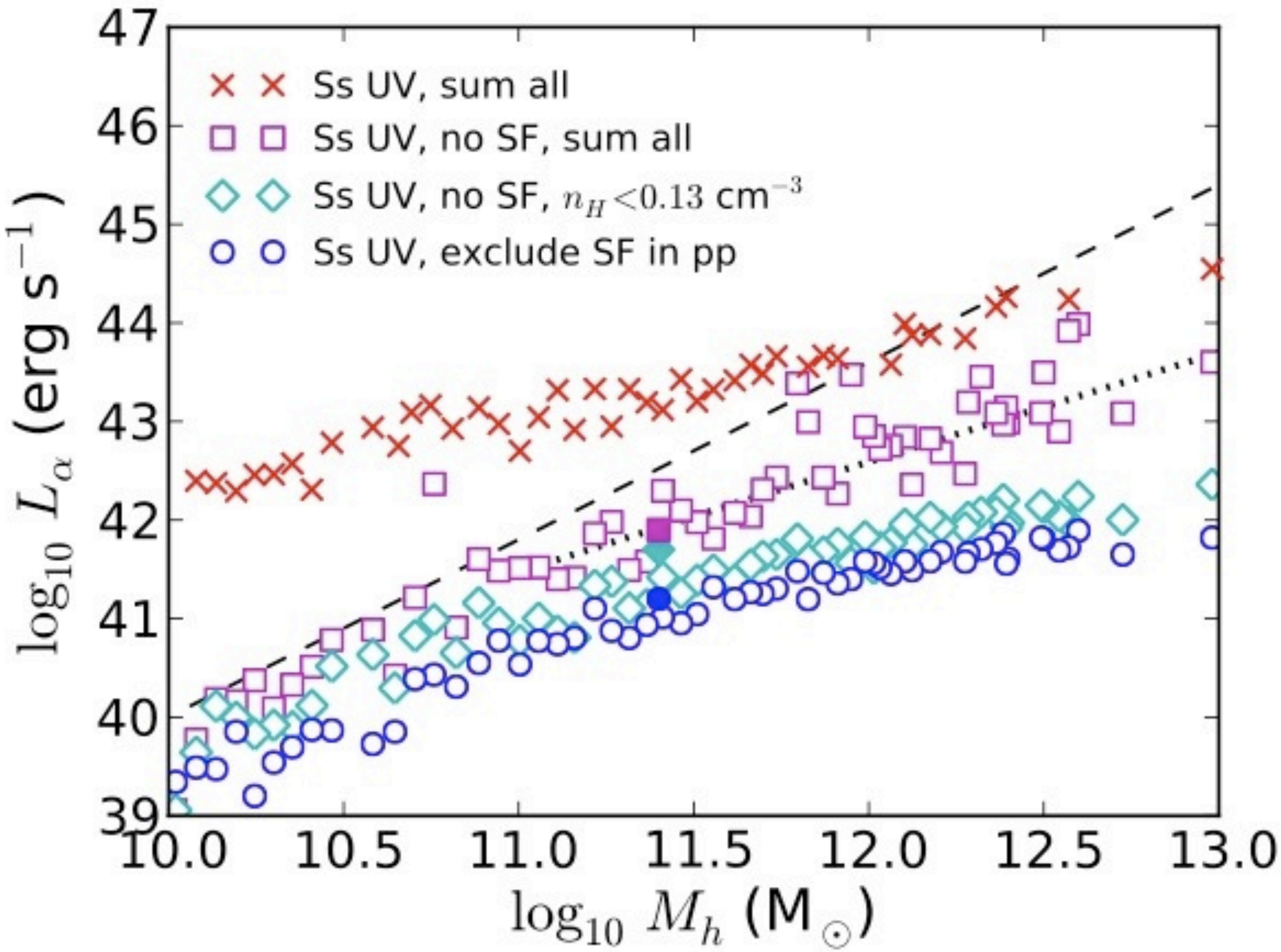
Spatially Extended Lyα Emission from Cold Streams around Galaxies.

$$L_{Ly\alpha}(M) \sim f_{grav} \times \Delta\Phi_{DM} \times \dot{M}_{gas}$$

MD & Loeb '09; Goerdt+10; Faucher-Giguere+10

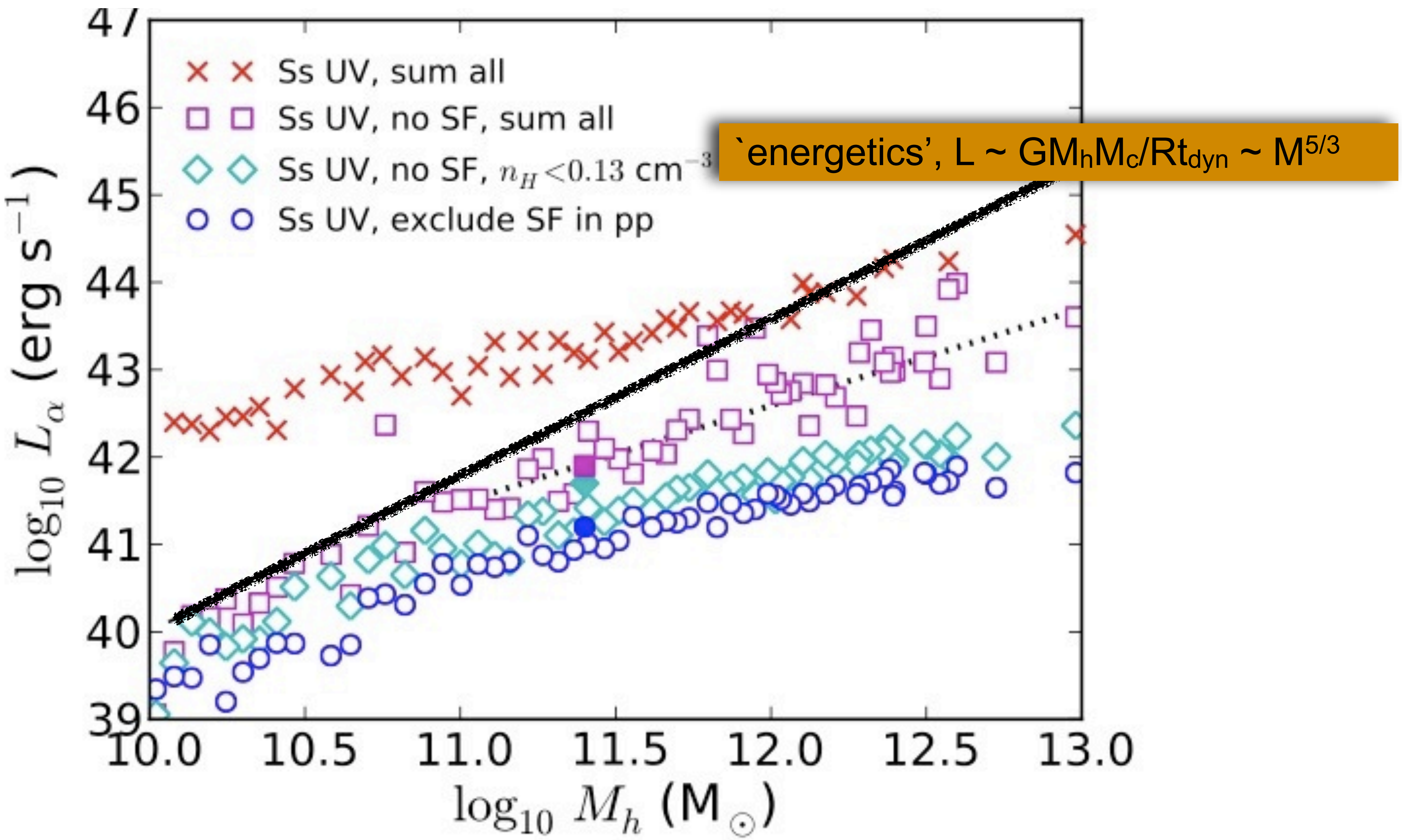


Spatially Extended Lyα Emission from Cold Streams around Galaxies.



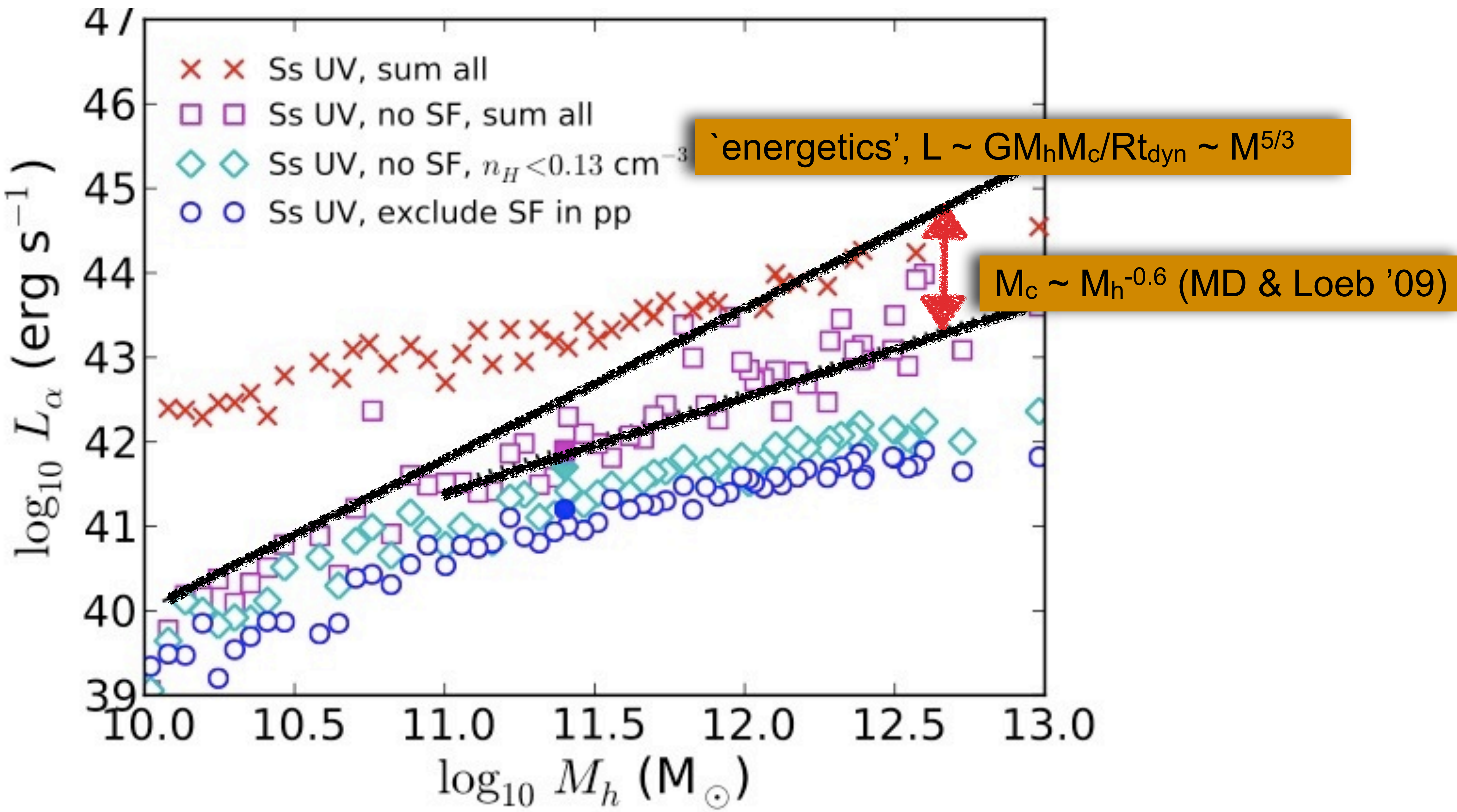
Faucher-Giguere+10

Spatially Extended Lyα Emission from Cold Streams around Galaxies.



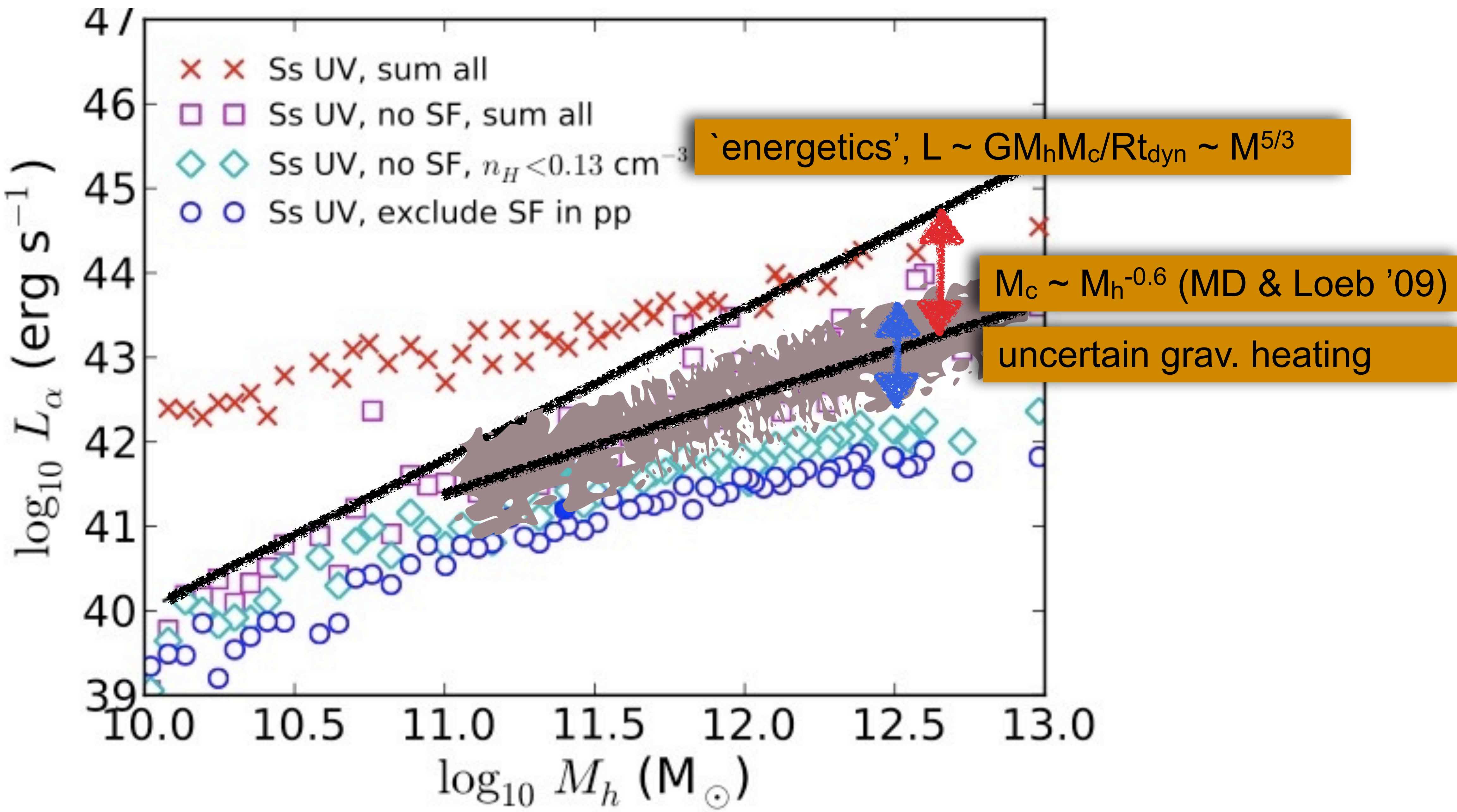
Faucher-Giguere+10

Spatially Extended Lyα Emission from Cold Streams around Galaxies.



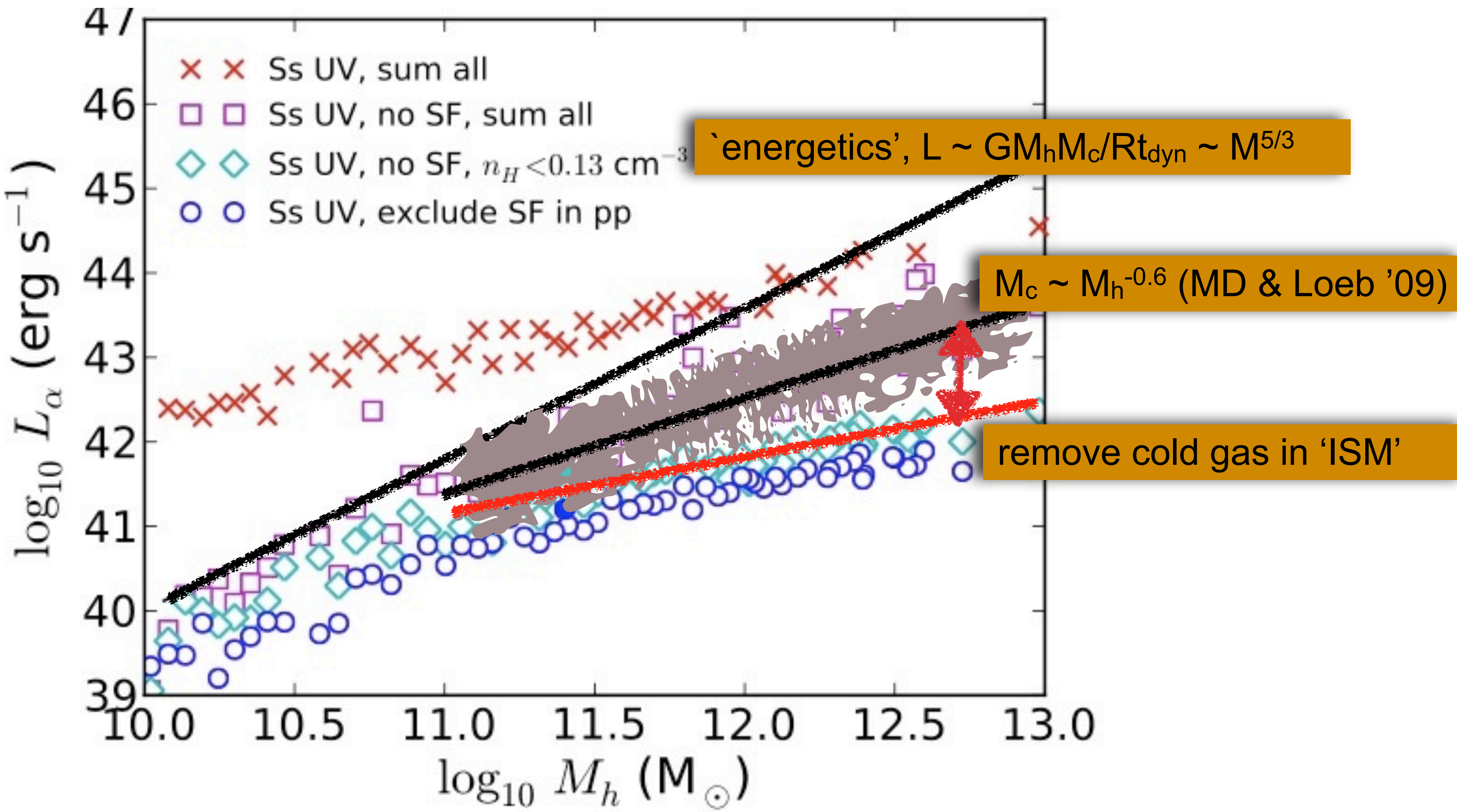
Faucher-Giguere+10

Spatially Extended Lyα Emission from Cold Streams around Galaxies.



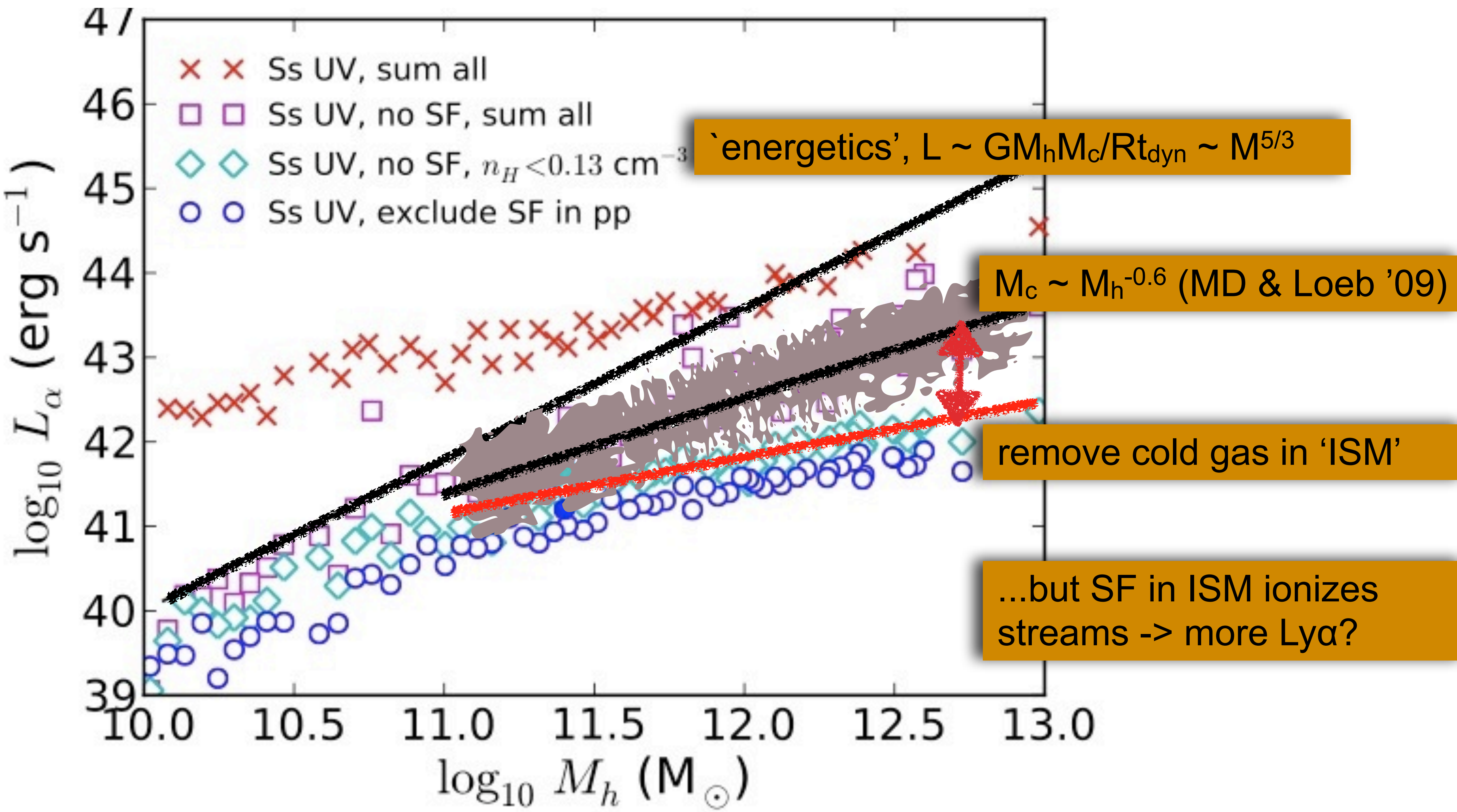
Faucher-Giguere+10

Spatially Extended Lyα Emission from Cold Streams around Galaxies.



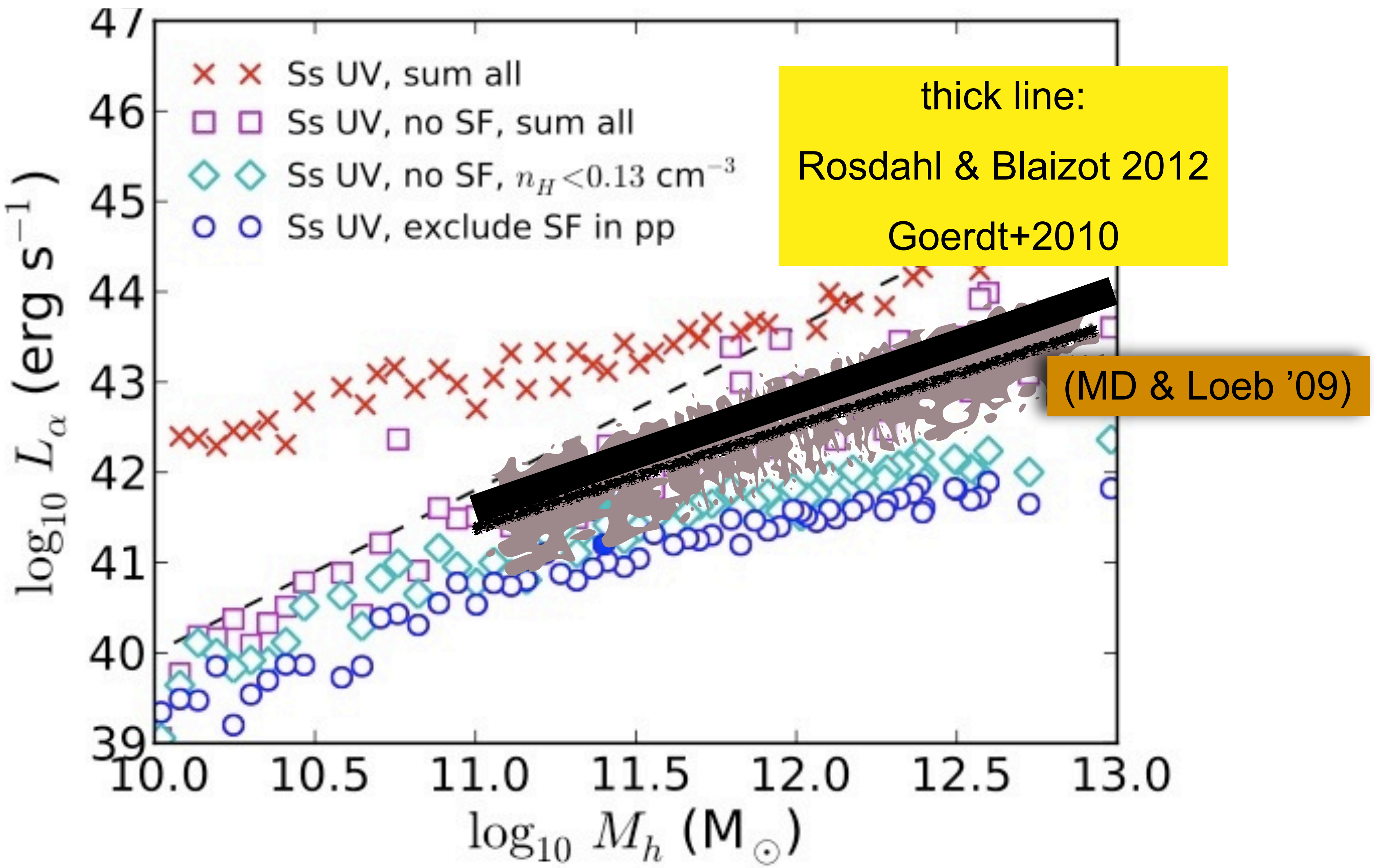
Faucher-Giguere+10

Spatially Extended Lyα Emission from Cold Streams around Galaxies.



Faucher-Giguere+10

Spatially Extended Lyα Emission from Cold Streams around Galaxies.

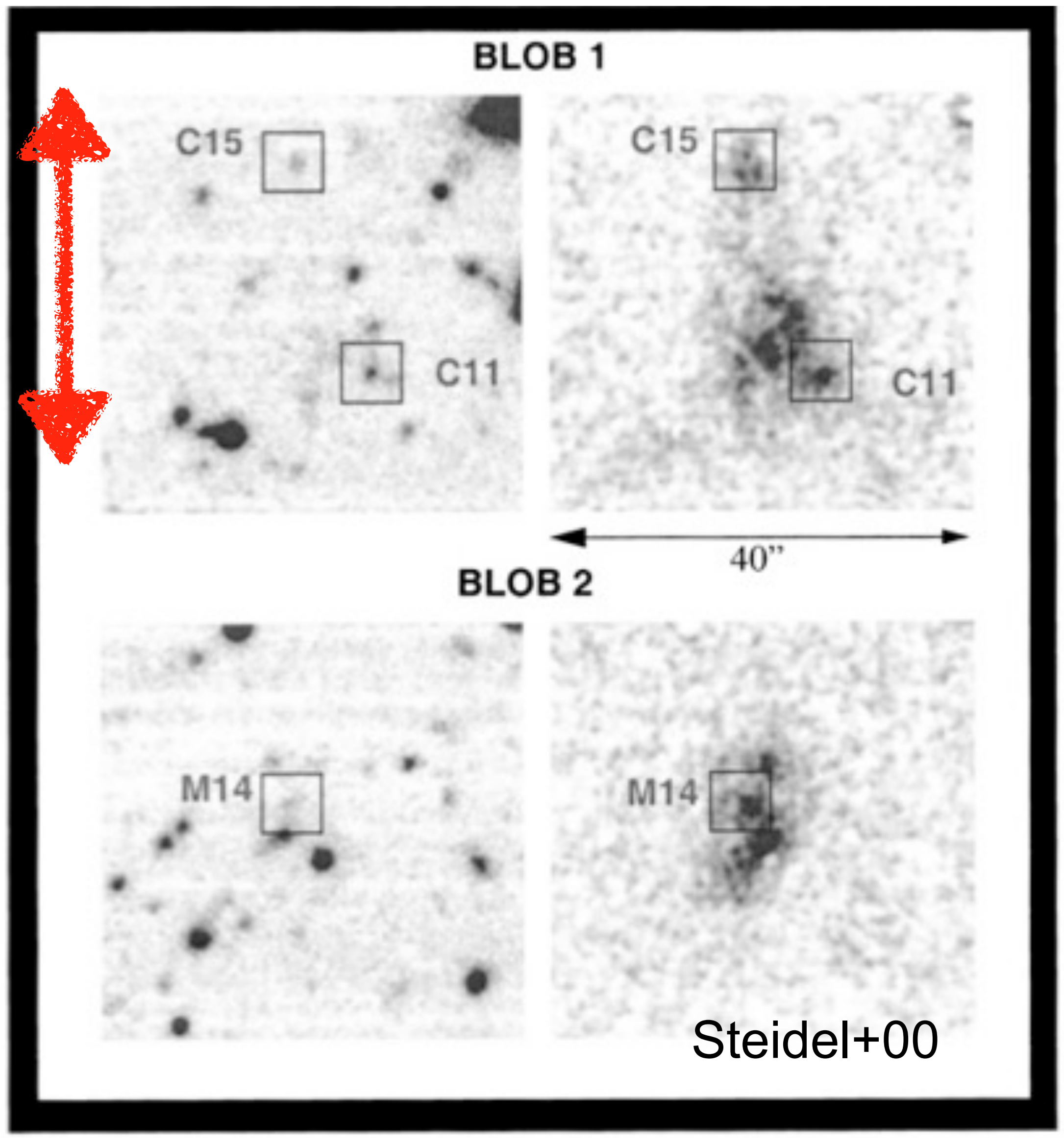


Faucher-Giguere+10

Observations.

Observations: Lyα `Blobs' (LABs)

~300 pkpc



Observations: Lyα `Blobs’ (LABs)

A (Selective) Summary of Blob Knowledge.

- Strongly clustered (e.g. Steidel+00,Matsuda+05,Yang+08)

- Lya Luminosity 5e42-1e44 erg/s (Matsuda+04).

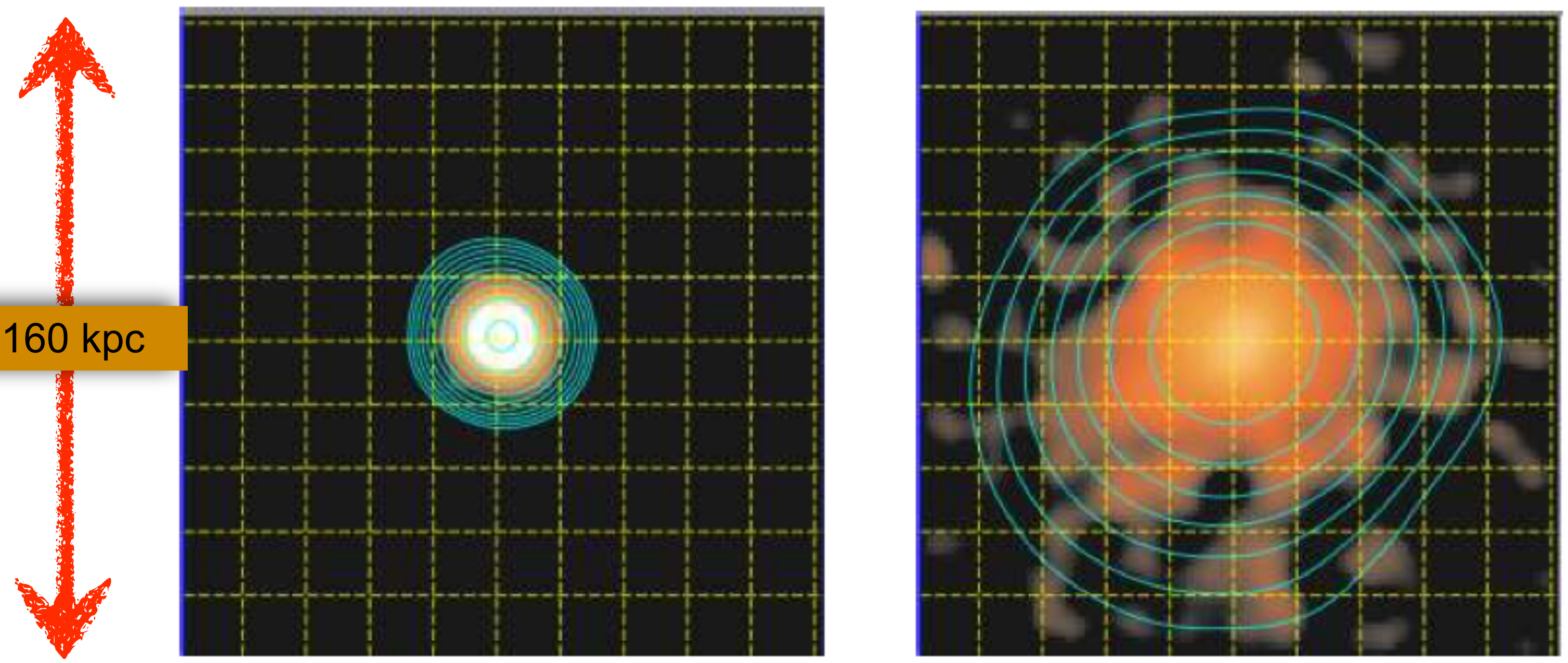
- Physical sizes up to 150 kpc (Steidel+00)

- Associated with all kinds of sources: submm (Chapman+01,Geach+05), type 1/2 AGN (Bunker+03,Basu-zych+04,Geach+07), regular LBGs (Matsuda+04), no association at all (Nilsson+06,Smith08).

- Lya ‘properties’ unrelated to central source properties (Geach+07,Yang+08)

Observations: Lyα Halos around z=2 `LBGs’

Steidel+ `11



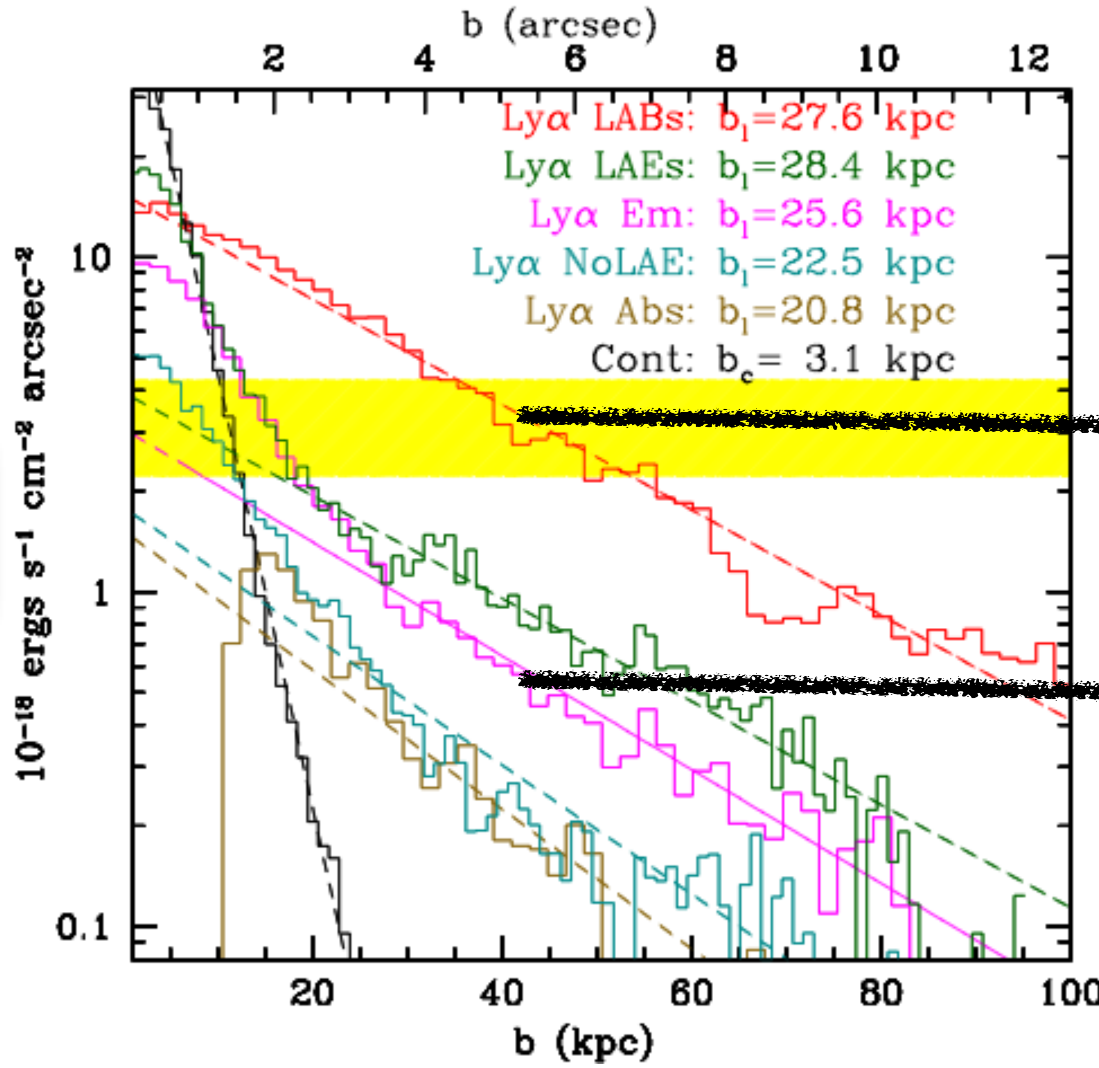
UV-continuum | Lyman Alpha

Lya halos around LBGs have $L_{Ly\alpha} \sim$ 1e43 erg/s.

Spatially Extended Lyα Halos around LBGs

Steidel+ `11

Surface brightness



Lya blobs in sample

<Lya halos> around LBGs

In Steidel+11's sample, Lya blobs have practically identical SB profiles.–> same physical mechanism powering emission?

Observations in the Context of Cold Stream Model.

Observations: Lyα `Blobs' (LABs)

Comparing to Cold Stream Model.

- Strongly clustered (e.g. Steidel+00,Matsuda+05,Yang+08)

In model Lya blobs are associated with cold inflows in massive galactic halos

- Lya Luminosity 5e42-1e44 erg/s (Matsuda+04).

Depending on grav. heating efficiency, this range can be fully covered.

- Physical sizes up to 150 kpc (Steidel+00)

Cold streams extend out to even larger scales .

- Associated with all kinds of sources: submm (Chapman+01,Geach+05), type 1/2 AGN (Bunker+03,Basu-zych+04,Geach+07), regular LBGs (Matsuda+04), no association at all (Nilsson+06,Smith08).

All aspects of galaxy formation in massive halos, where cold stream 'duty cycle' is 1, and,,,

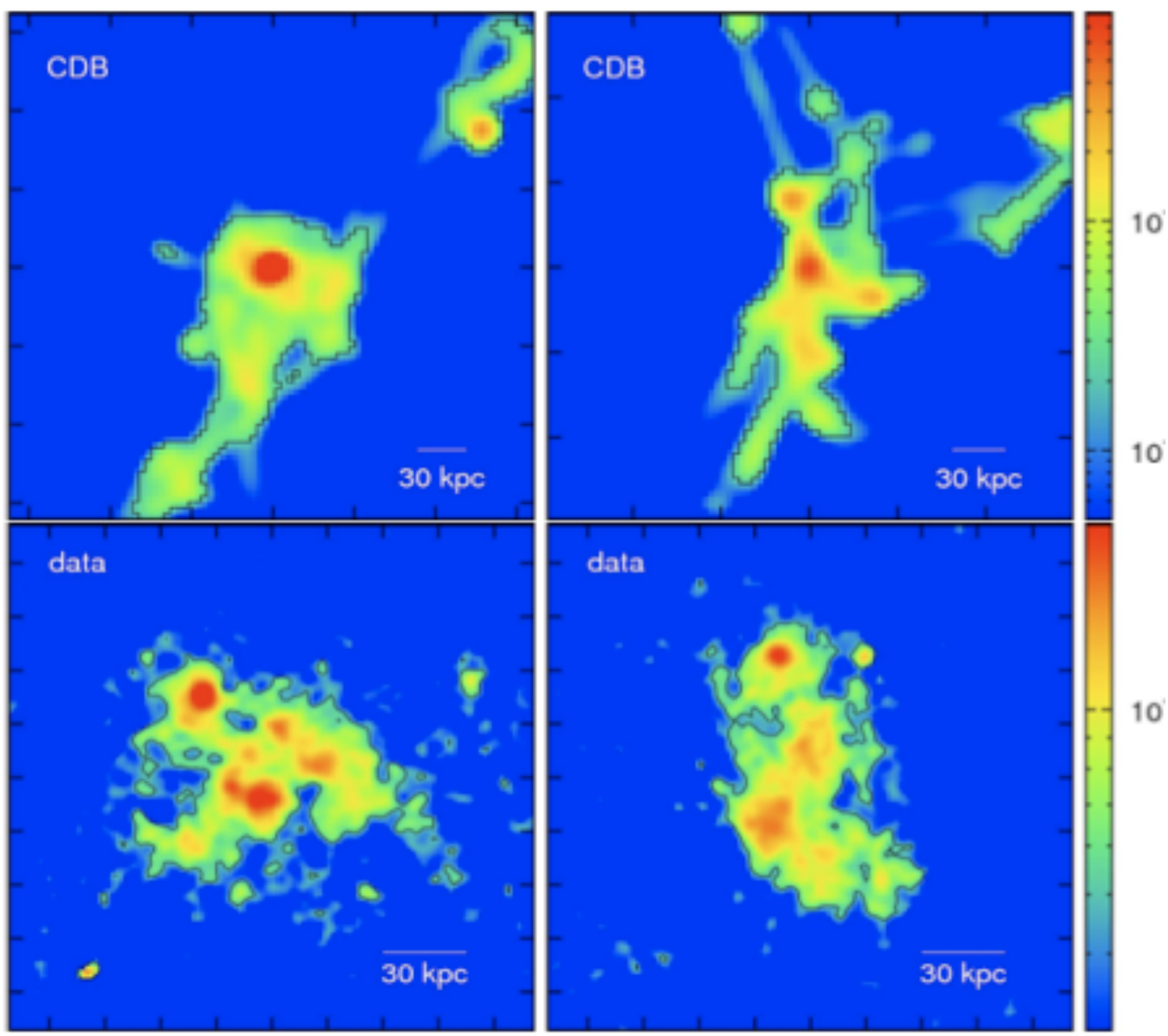
- Lya 'properties' unrelated to central source properties (Geach+07,Yang+08)

central sources are not powering Lya emission,

Observations: Lyα `Blobs' (LABs)

Comparing to Cold Stream Model

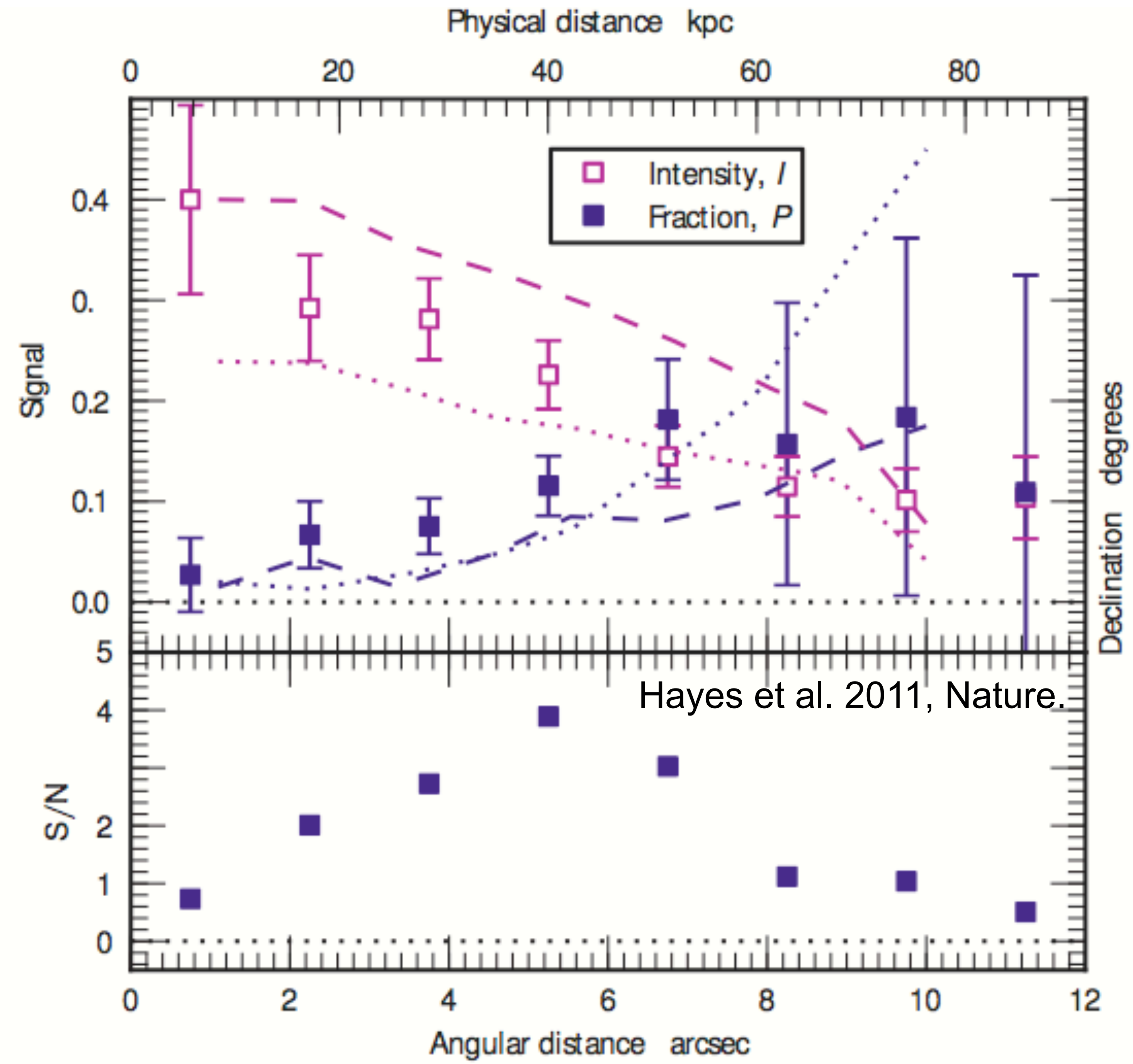
Morphologically similar.



Goerdt+10

Problems with Cold Stream Model.

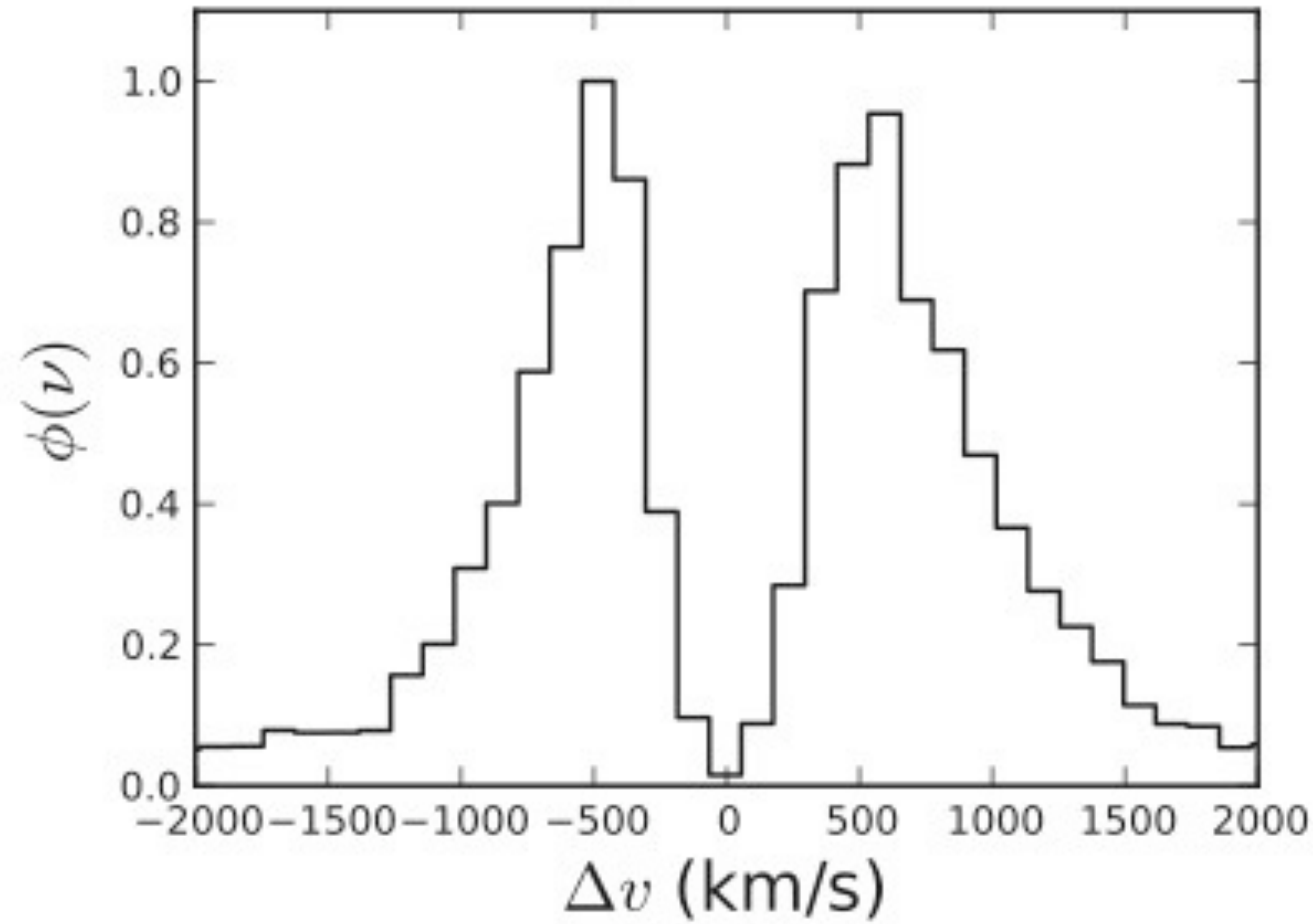
Polarization Detected in One Blob.



Polarization indicative of scattering origin of fraction of blobs.

`Predicted' Lya Spectrum with Lya RT.

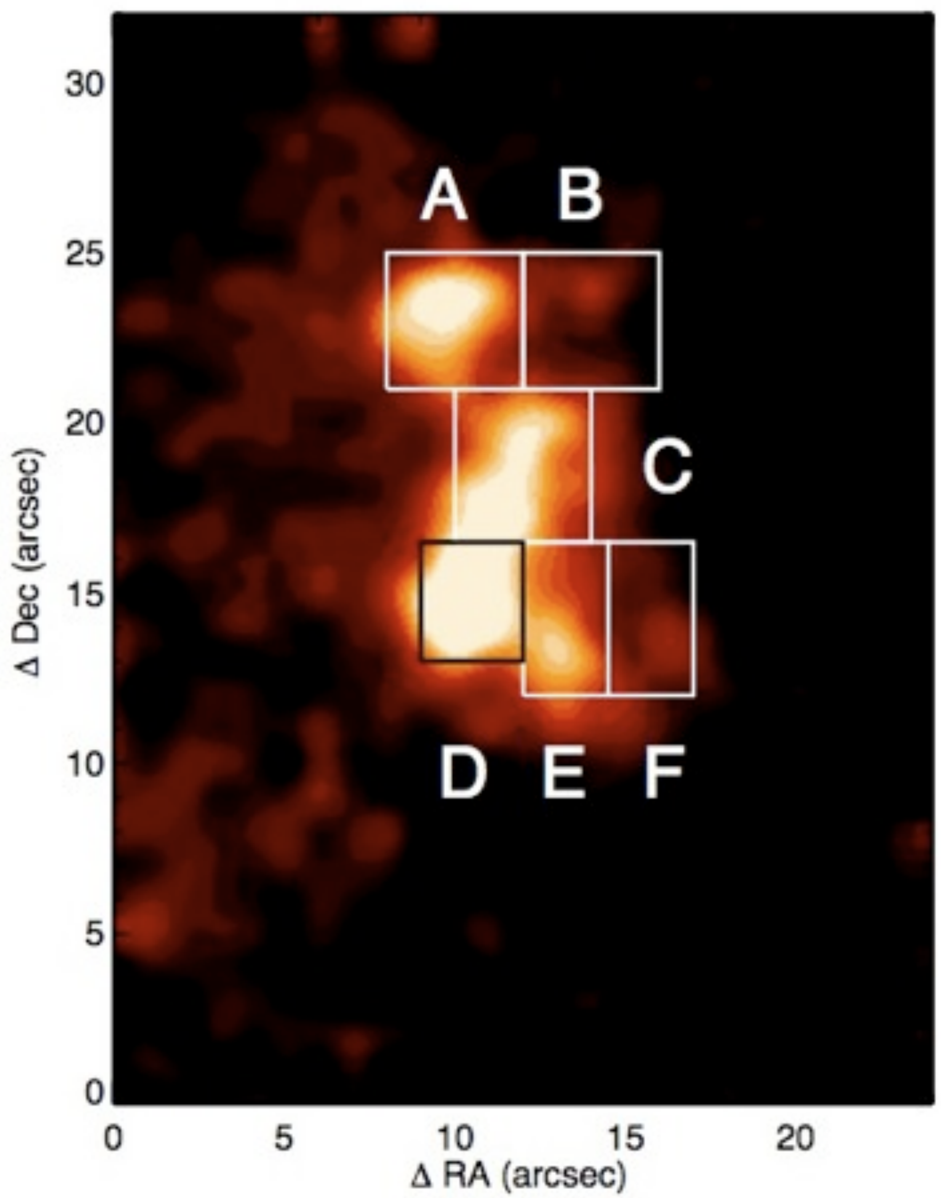
Symmetric double peaked Lya line profiles from cold streams.

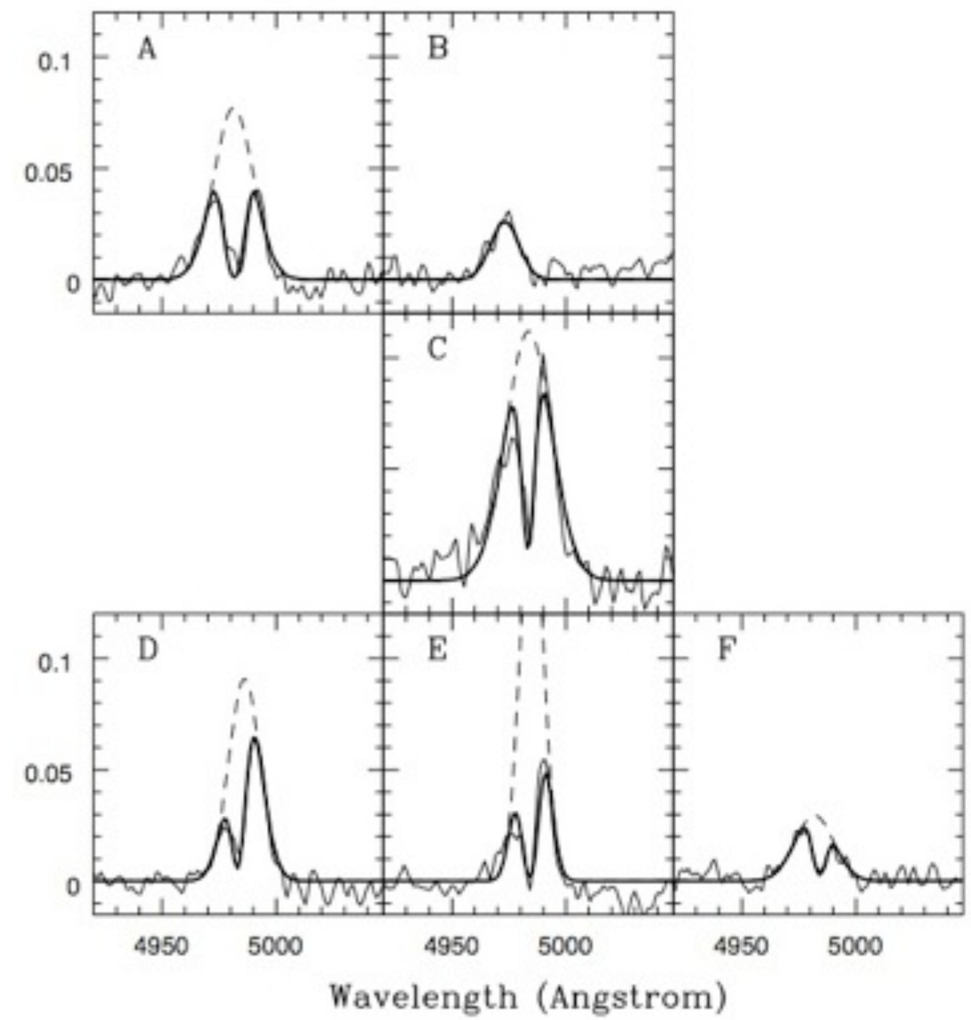


Faucher-Giguere+10

Observed Spectrum `Blob 2'.

this is seen, but rarely....

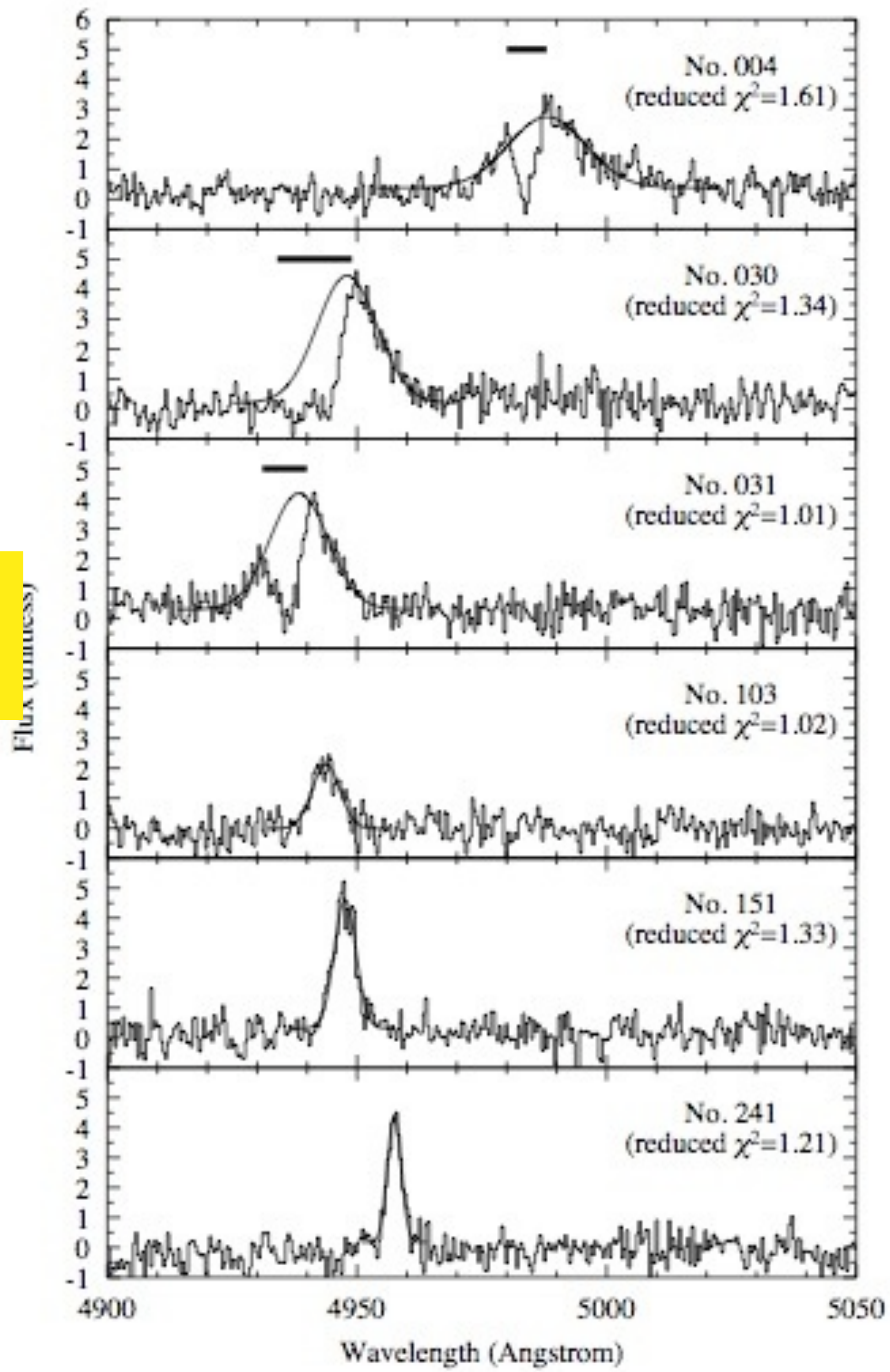




Wilman+05

Observed Spectra some other Blobs.

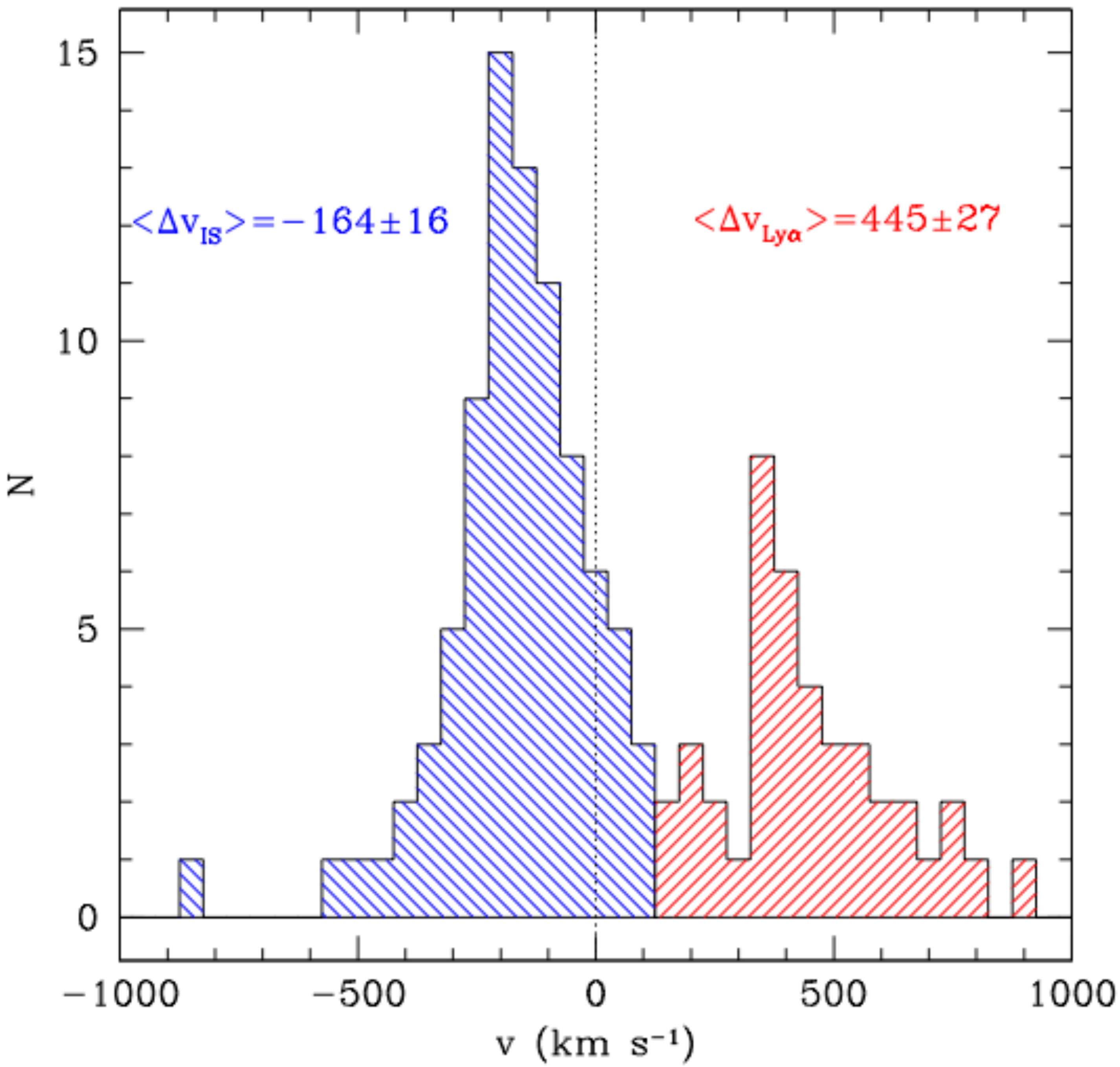
Line shapes asymmetric: indicative of outflows



Matsuda+06

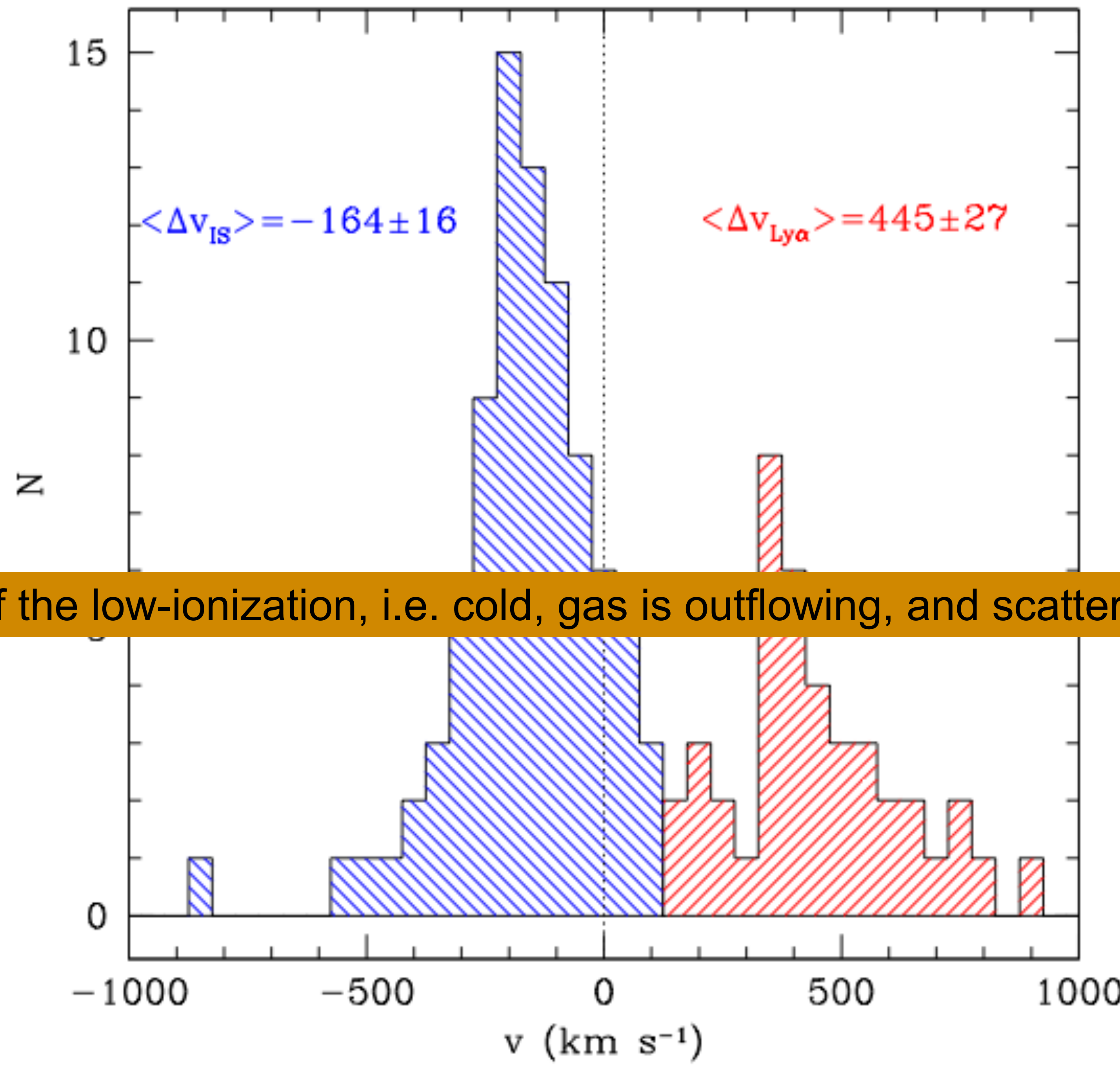
The Prevalence of Cold Outflowing Gas

Steidel et al. 2010: `down the barrell view'



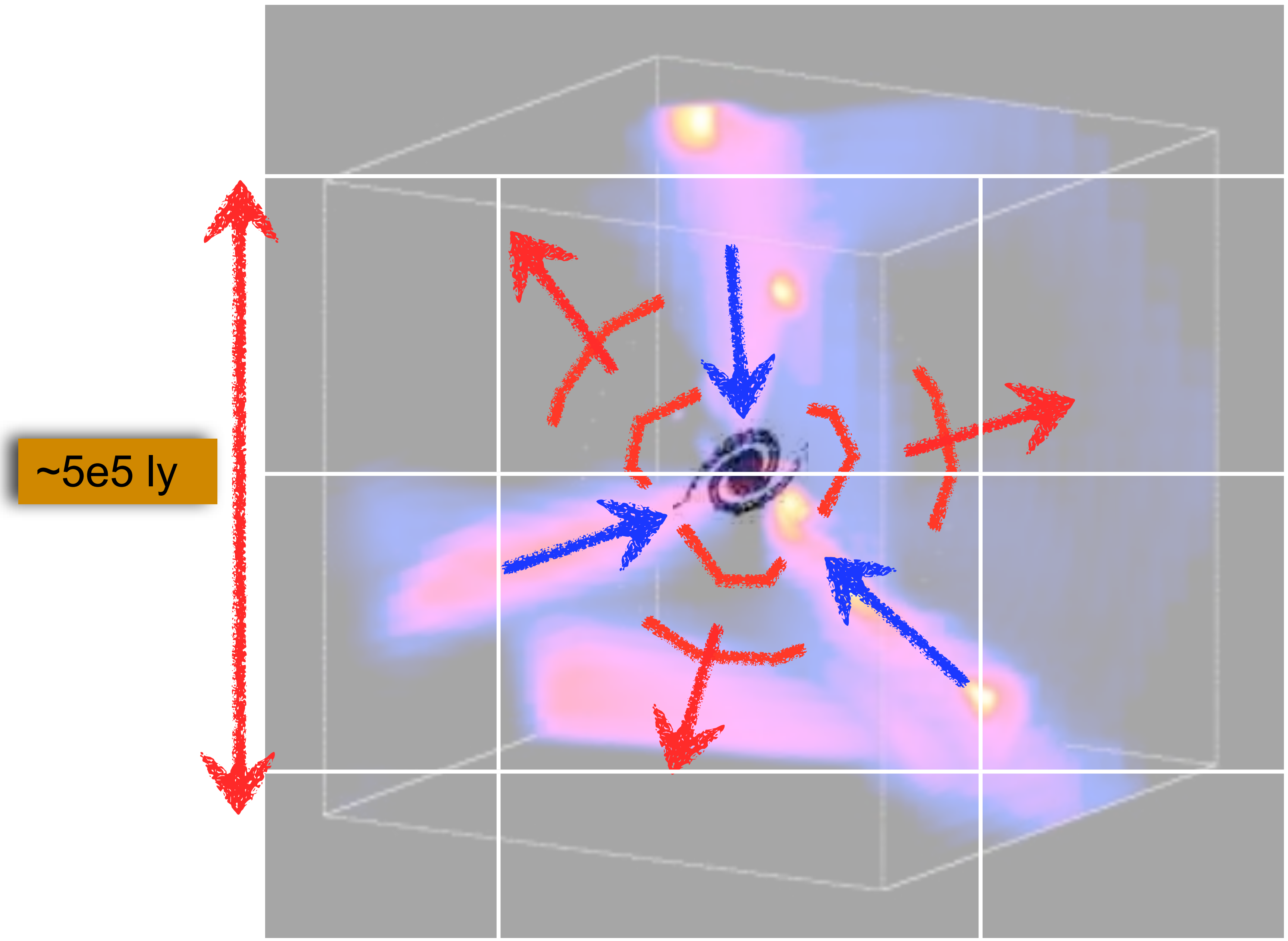
The Prevalence of Cold Outflowing Gas

Steidel et al. 2010: `down the barrell view’



Most of the low-ionization, i.e. cold, gas is outflowing, and scatters Lyα photons

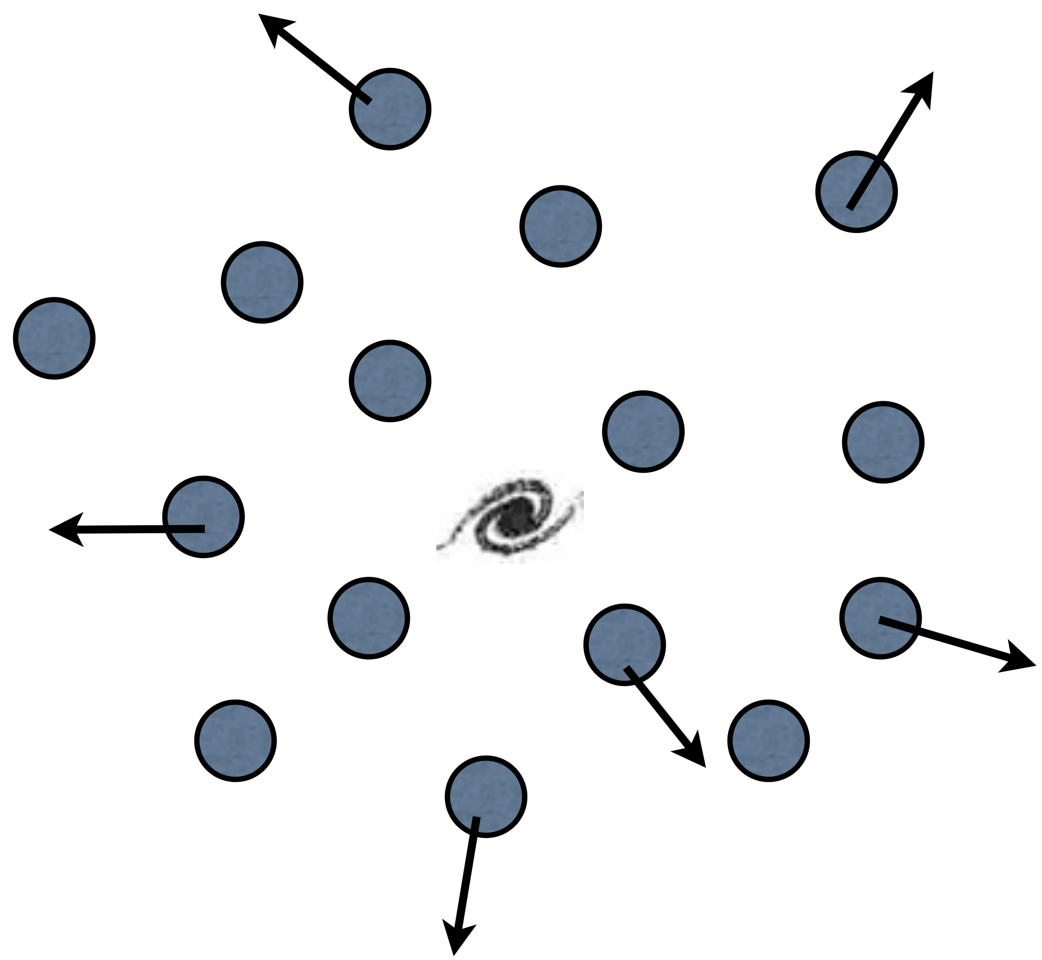
Galaxies and their CGM



`Fueling' via cold (T=1e4 K) gas

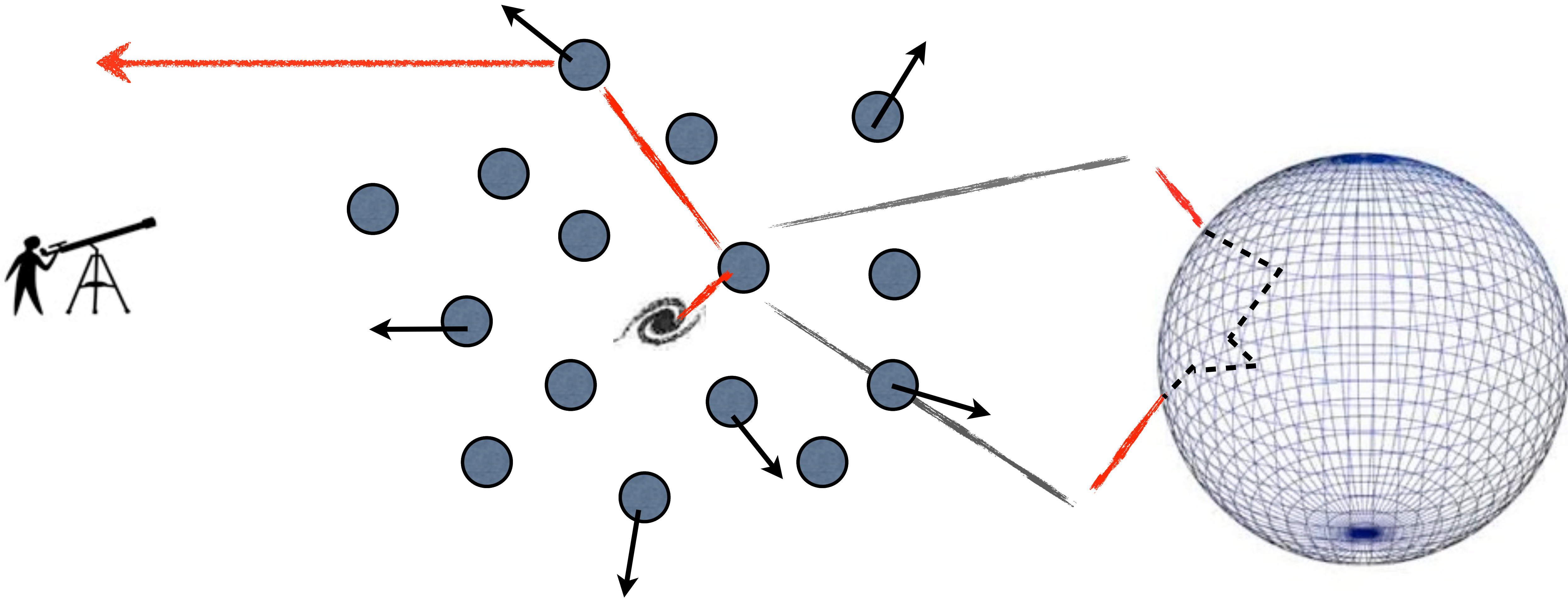
Outflows driven by stars and stellar remnants

`Lyα Halos/Blob are Scattered Radiation emitted by Pointsource' (Steidel+10,11)



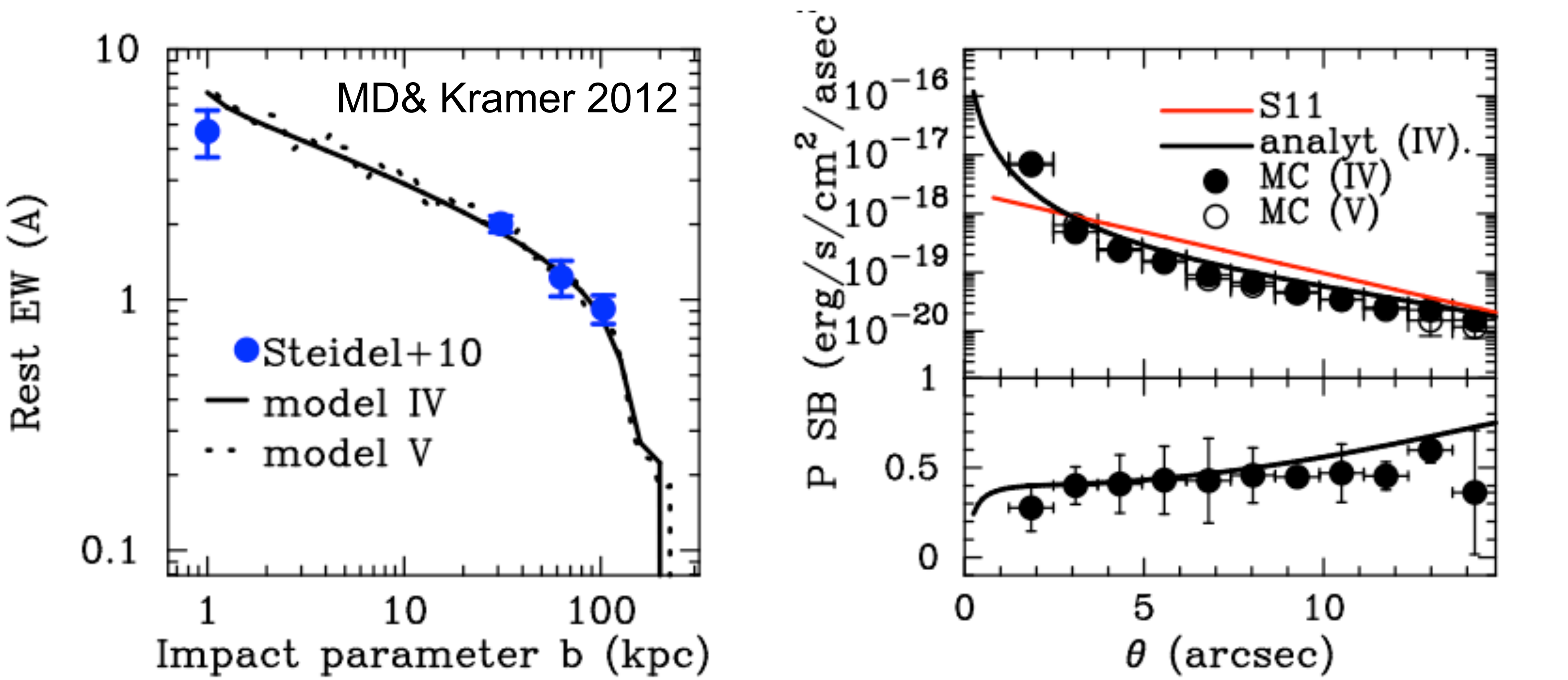
LBGs surrounded by outflowing cold gas that extends out to ~ 150 kpc; covering factor of outflow is large, decreases with r, spherically symmetric

Outflow Models for Lyα Halos/Blobs: II Scattered Radiation emitted by Pointsource (Steidel+10,11)



Scattering of Lyα through this clumpy outflows gives rise to Lya halos (and blobs); can be tested with MC Lya RT code (MD & Kramer 2012)

The 'Predicted' Surface Brightness Profiles: more realistic velocity profiles



Possible to explain Lya halos around LBGs via scattering in large scale outflow--> this implies large levels of polarization, which can be detected with existing polarimeters.

Conclusions & Outlook (1/2)

Cold accretion streams onto galaxies play central role in our understanding of galaxy formation & evolution.

No direct observational evidence that these `cold streams' actually exist.

Cold streams are expected to be spatially extended Lyα sources, and may have been observed as Lyα `blobs' and Lyα `halos' around LBGs....

but caution...the overall predicted Lyα luminosity is still uncertain.

Moreover, Lyα spectral line shape of blobs suggests significant fraction of photons scatter through outflows.

Conclusions & Outlook (2/2)

Tremendous progress is expected from observational side:

CGM absorption line studies (galaxy-galaxy; galaxy-qso, qso-qso pairs)

MUSE will provide us with Lyα images that go a factor of 5-10 deeper-> circum galactic medium -and cold flows- are expected to `light' up.

HETDEX will provide us with thousands of new Lyα blobs.

Polarimetric observations of spatially extended Lyα sources are currently ongoing -> can constrain amount of scattering.

To fully benefit from these observations we (urgently) need to develop models of radiative processes + transfer in gas flows in the circum galactic medium.