`Lya Blobs as a Observational Signature of Cold Flows’

by **Mark Dijkstra**

w. Avi Loeb *arxiv:0902:2999*

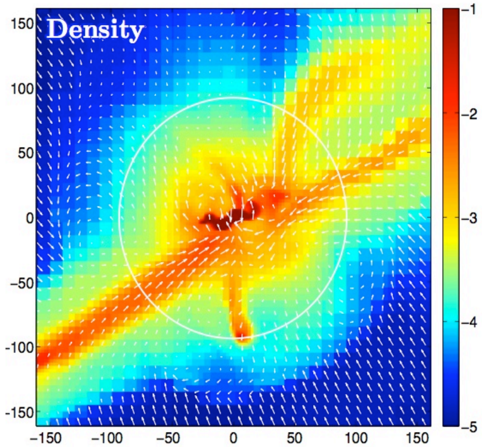
Resubmitted to MNRAS in April

Background

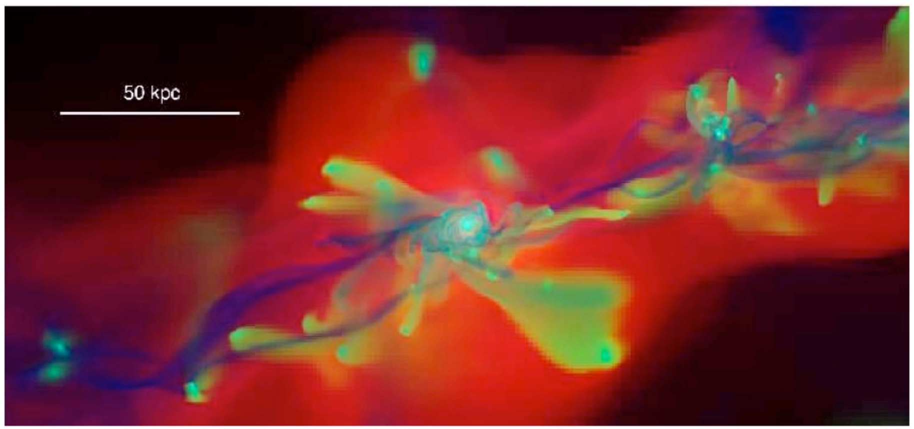
• How galaxies get/accrete their gas is a fundamental problem in astrophysics.

• Simulations indicate that galaxies that reside in massive halos are fed by cold (1e4 K), continuous streams of gas in pressure equilibrium within a hot virialized gaseous halo. (see talk by Prof. A. Dekel)

• Intriguing geometry of spatially extended (hundreds of physical kpc), narrow streams.



Dekel+09



Agertz+09

also see e.g. Ocvirk+09, Keres+09

Background

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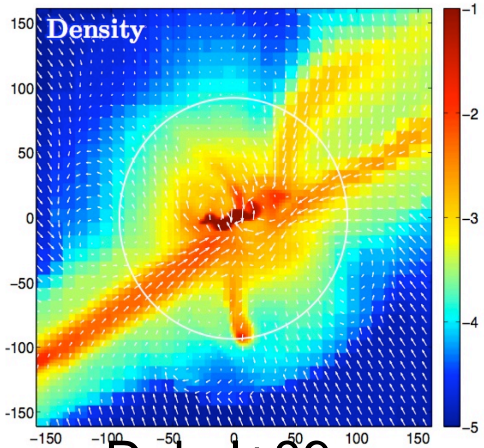
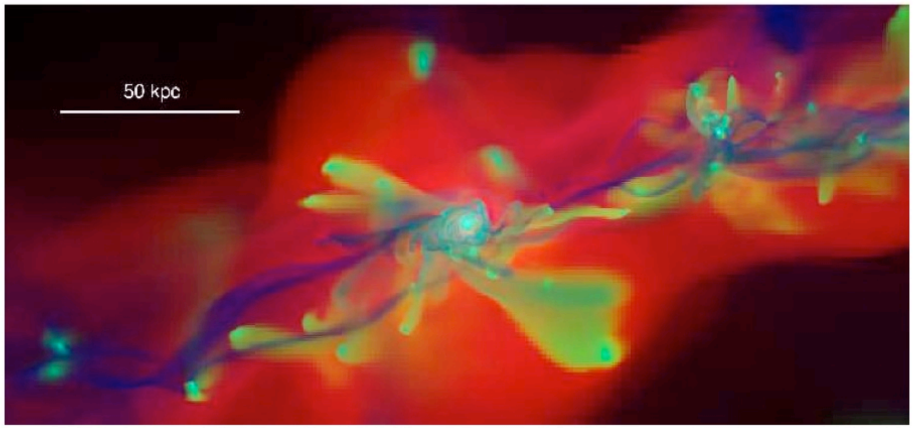
• Intriguing geometry of spatially extended (hundreds of physical kpc), narrow streams.

• This view is shared by different simulation techniques (AMR vs SPH) & groups:
Theoretically, the existence of cold flows appears quite well established
(but debatable simulations do not resolve instabilities that may disrupt cold streams).



Dekel+09



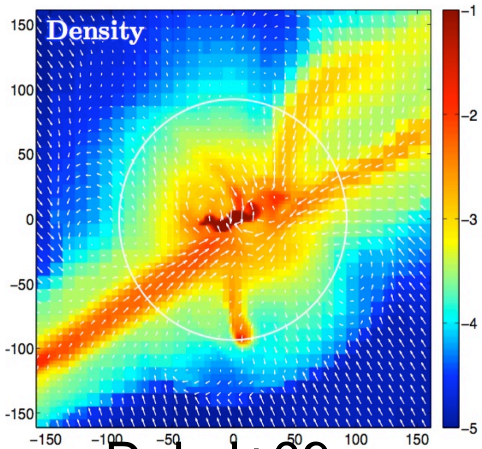
Agertz+09

also see e.g. Ocvirk+09, Kereš+09

Background

- Theoretically, the existence of cold flows appears quite well established
  (but debatable simulations do not resolve instabilities that may disrupt cold streams)

- Observationally, no direct evidence for these cold flows exist.
  Cold gas makes up a subdominant fraction of the total gas mass, in compressed form.-> low volume factor, difficult detect through absorption line studies.



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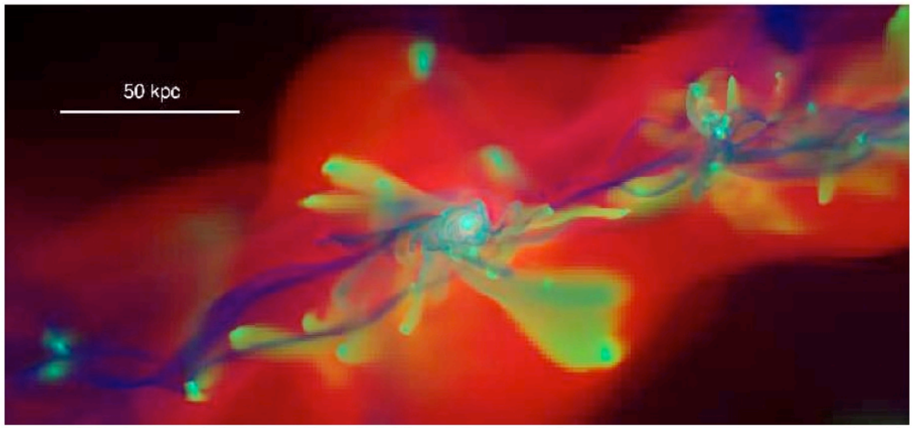

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o natural prediction of cold flow model is spatially extended Lya emission (Katz & Gunn ‘91, Haiman+00, Fardal+01, Furlanetto+05)

o natural explanation for ‘mysterious’ Lya `blobs’.

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'Space blob' baffles astronomers

By Jason Palmer
Science and technology reporter, BBC News

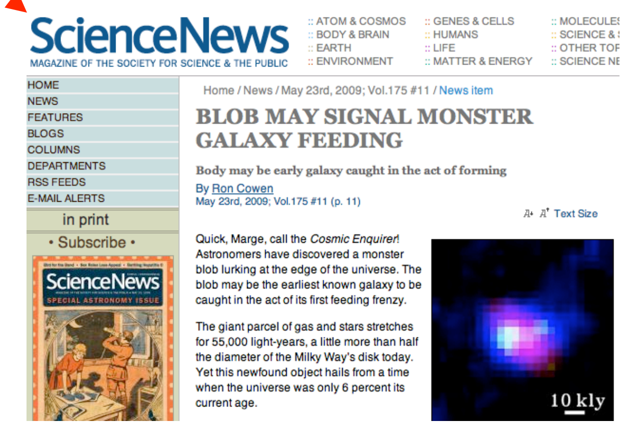
It might not look like much, but this image represents one of the most distant objects astronomers have ever seen, 12.9 billion light years away.

It is a "Lyman-alpha blob" and is 55,000 light years across - as large as present-day galaxies.

Though younger such blobs have been found, "Himiko" confounds

M OUCHI

The blob may have a giant black hole at its centre



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Home / News / May 23rd, 2009; Vol.175 #11 / News item

BLOB MAY SIGNAL MONSTER GALAXY FEEDING

Body may be early galaxy caught in the act of forming

By Ron Cowen
May 23rd, 2009; Vol.175 #11 (p. 11)

Text Size

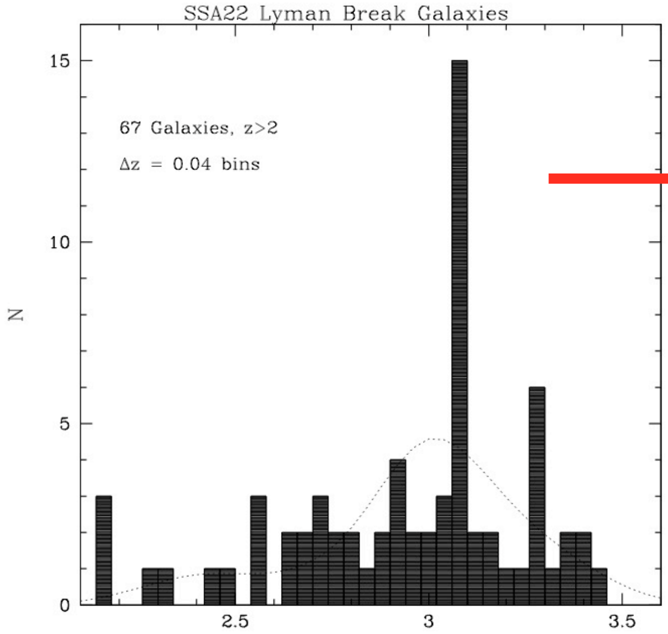
Quick, Marge, call the *Cosmic Enquirer*! Astronomers have discovered a monster blob lurking at the edge of the universe. The blob may be the earliest known galaxy to be caught in the act of its first feeding frenzy.

The giant parcel of gas and stars stretches for 55,000 light-years, a little more than half the diameter of the Milky Way's disk today. Yet this newfound object hails from a time when the universe was only 6 percent its current age.

10 kly

Taken from the Internet -> true.

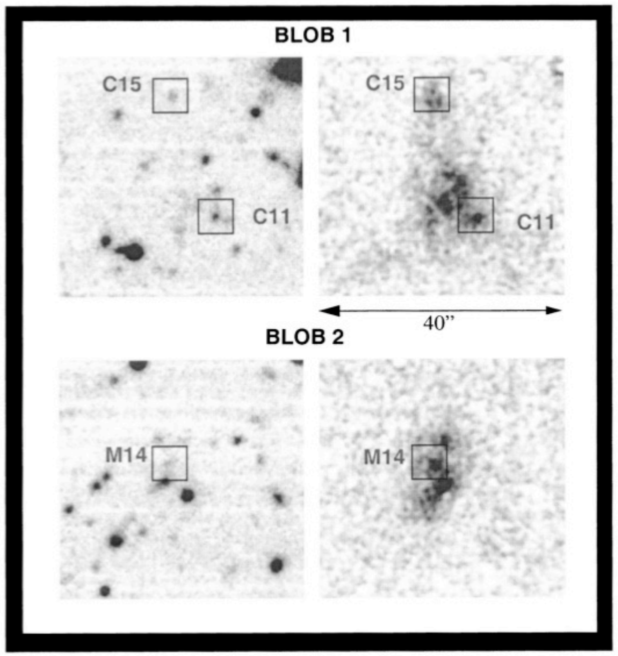
Lyman Alpha Blobs (see talk by Prof. T Yamada)



Overdensity over LBGs at z=3 (Steidel+98)

narrowband imaging (Steidel+00)

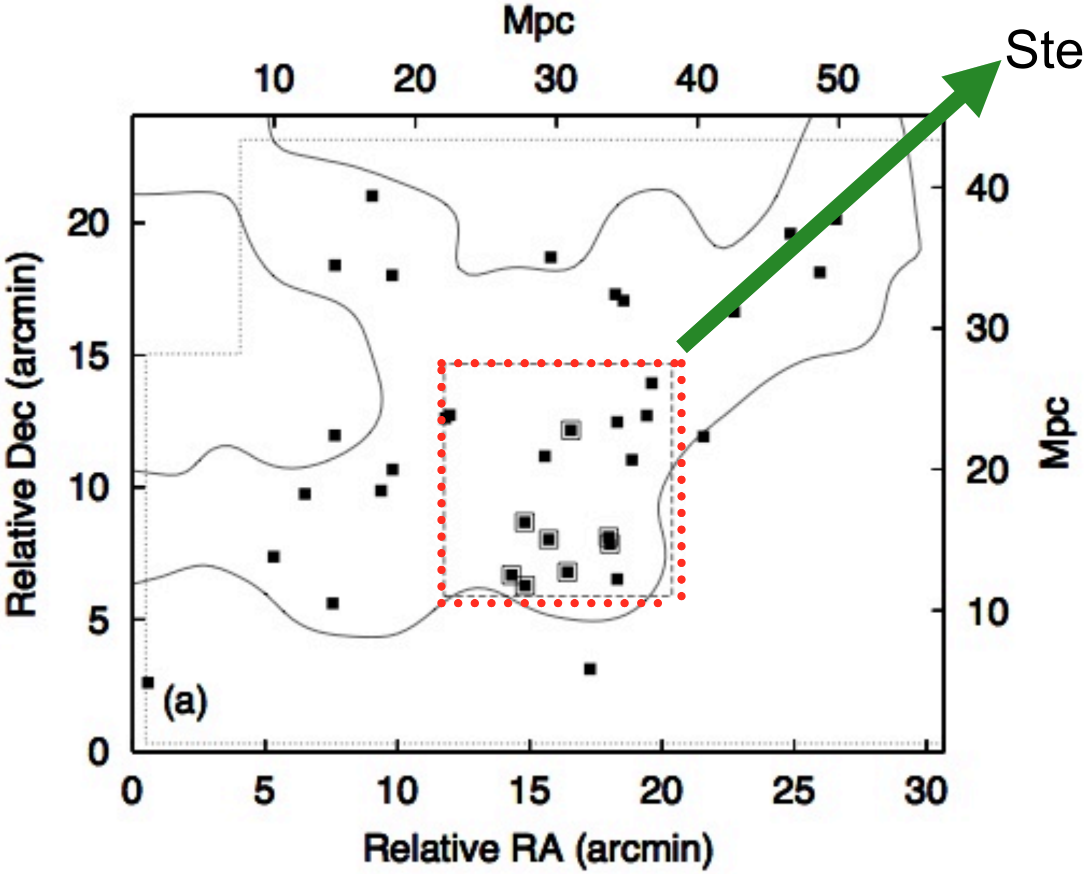
~300 physical kpc



Lyman Alpha Blobs

Matsuda+04

33 more Blobs!



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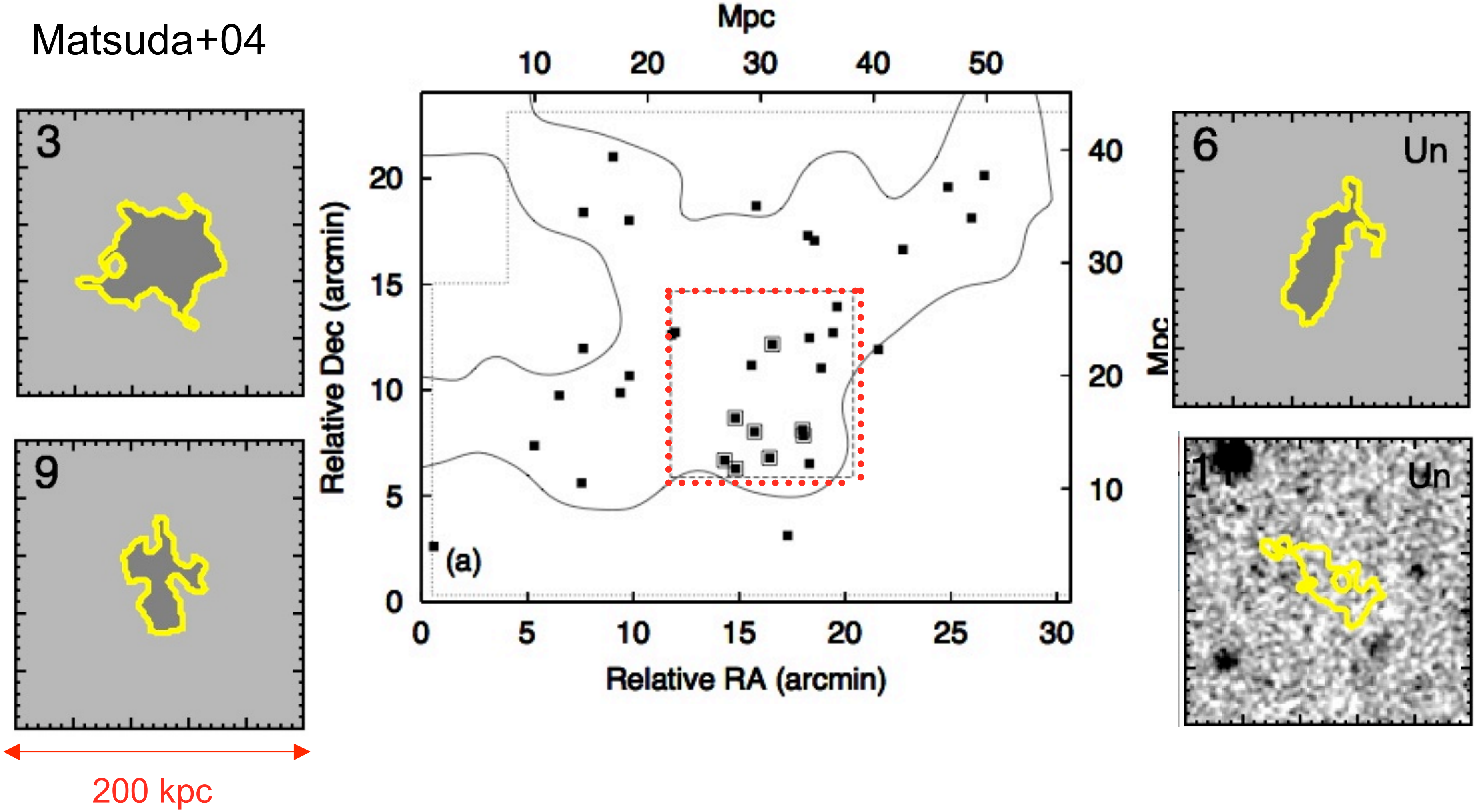
Matsuda+04



Lyman Alpha Blobs: (Some) things we know

- Several tens of known blobs at z=2-6.5 (e.g. Matsuda+04, Saito+06, Ouchi+08)

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

  (*far) more than LBG population*

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

  for standard Salpeter IMF requires SFR~5-100 Msun/yr

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

  Virial diameter of 1e12 msun halo ~ 160 kpc.

Lyman Alpha Blobs: What we know

- Lya line widths 500-2000 km/s (Matsuda+05,Saito+08)
  - circular velocity of DM halo is ~ $220(M_{12})^{1/3}$ km/s

- Wide variety in morphological shapes (Matsuda+04)

- Associated with all kinds of sources:
  - submm (Chapman+01,Geach+05, 4/35 significant detections)
  - Type 1 and 2 AGN (Bunker+03,Weidinger+05,Basu-zych+04,Geach+07, Geach+09),
  - regular LBGs (Matsuda+04)
  - no obvious association at all (Nilsson+06,Smith+07,Smith+08).

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

Lyman Alpha Blobs: What we know

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Associated source not responsible for powering Lya emission?

Are Lya blobs produced by Lya emitting cold flows in massive halos?

Cold Flows as Lyman Alpha Blobs?

Model Assumptions

• Total amount of cold gas taken from simulations of Keres+09.

• Cold flow gas in pressure equilibrium with hot virialized gas (the dominant gas component), as found in the simulations.

• As cold gas flows toward the halo center it undergoes some heating, which is balanced by radiative cooling. A fraction of this cooling is Lya emission.

Cold Flows as Lyman Alpha Blobs?

- As cold gas flows toward the halo center, it undergoes some heating.

$$H(r) = f_{grav} \times F_g \frac{dr}{dt} + H_{photo}(r) = f_{grav} \times F_g \frac{dr}{dt}$$

'Gravitational heating efficiency'.

f_{grav}=0 freefall; f_{grav}=1 infall at constant v

=0 in self-shielding gas

Work done by gravity

- Heating dominated by 'gravitational heating' (Haiman+00,Fardal+01).

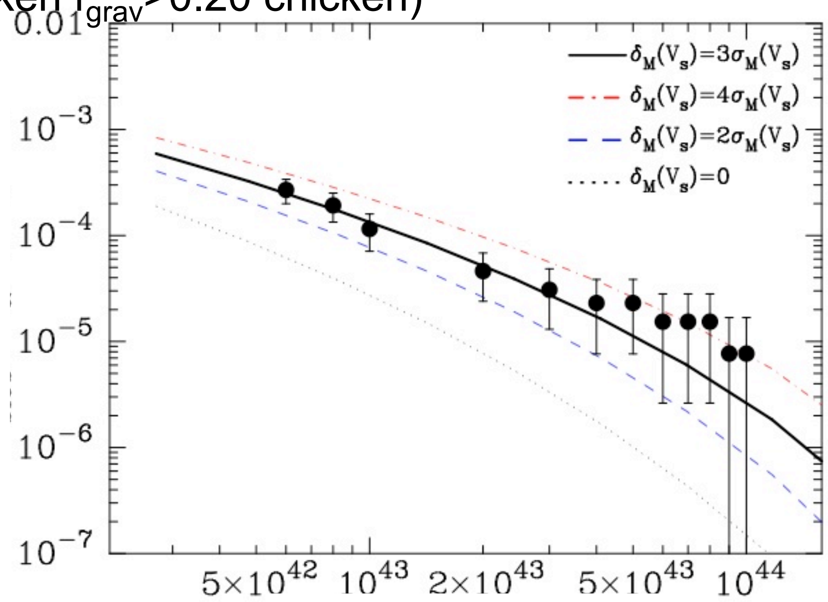
- Heating is balanced by radiative cooling, which at T=1e4 K is mostly in form of Lya.
  Note that heating is required, in our case heating is gravitational. *Any additional heating terms will only boost our computed Lya signal.*

Chicken chicken chicken chicken chicken?

- Chicken: Chicken+04. Chicken: chicken chicken f_{grav}=0.30 chicken chicken chicken (Chicken & chicken).

(chicken chicken chicken f_{grav}>0.20 chicken)

Chicken



]

chicken

- Chicken chicken chicken f_{grav}=0.2-0.3 chicken chicken (Mickey Mouse):

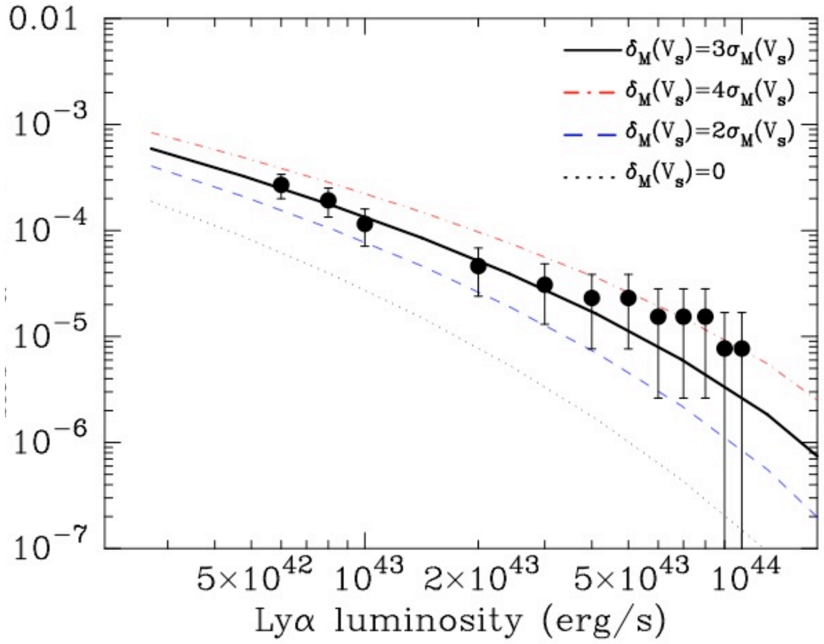
chicken chicken chicken chicken chicken chicken chicken chicken chicken.

Cold Flows as Lyman Alpha Blobs?

- Data: Matsuda+04. Curves: models with $f_{grav}=0.30$ at different overdensities (D & Loeb).

  (models that assume $f_{grav}>0.20$ work)

Number density

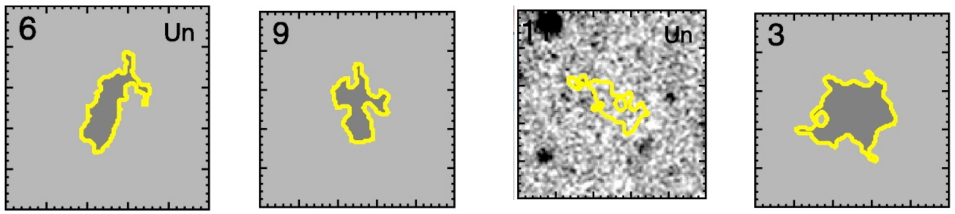


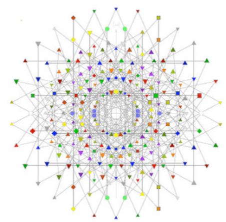
- Simulations suggest that f_{grav}=0.2-0.3 is conservative (both SPH and AMR):

  difficult to NOT make cold flows be spatially extended Lya sources at observed densities

Observations vs Model

- In model Lya blobs are associated with cold inflows in massive galactic halos
  - Strongly clustered (e.g. Steidel+00,Matsuda+05,Yang+08) ✓
- Duty cycle of cold accretion ~1, contrary to star burst /AGN activity.
  - Associated with all kinds of sources. ✓ (cold dense flows can survive despite powerful outflows.)
- Gas flows in at ~1-2.5 v_{circ} -> line widths 250-2000 km/s (D & Loeb)
  - Lya line widths 500-1800 km/s (Matsuda+05,Saito+08) ✓
- Cold flows exhibit a wide variety of morphological shapes (depends e.g. on viewing angle)
  - Wide variety in morphological shapes (Matsuda+04) ✓





- Lya properties not related to central source properties (Geach+07,Yang+08) ✓
- Observed sizes 50-150 kpc smaller than predicted by our model ✖ , but probably **NOT** an issue because of our assumed constant f_{grav} (and f_{cold}).

Discussion & Conclusions

• The Lyman Alpha blob population *as a whole* may provide a direct observational signature of cold accretion flows in massive halos.

• In our model gravitational heating suffices, but alternative heating mechanisms may contribute/dominate in different blobs:

  - photoionization by pop II/III stars (Jimenez & Haiman ‘06), type I/II AGN (Haiman & Rees ‘01), spatially extended X-Ray emission (Scharf+03)
  - star formation triggered by relativistic jets (Rees 89)

- Completely difference mechanisms can explain blobs: collisional excitation of H in dense outflowing shells in superwinds (Taniguchi+01,Mori+04)
- Scattering of emission by point sources?
- Generally one needs spatially extended cold gas.

This gas is either outflowing or inflowing. Dust is likely a greater problem for outflow models (see D & Loeb ‘09 for a detailed discussion).

Discussion & Conclusions

• The Lyman Alpha blob population *as a whole* may provide a direct observational signature of cold accretion flows in massive halos.

• The observed number density of blobs already places interesting constraints on cold flow models.

• If the model is correct, then deeper and/or higher resolution Lya observations should more prominently reveal the cold flow geometry in the near future.

• Alternatively, suppose that none of Lya blobs are not associated with cold flows, then this may pose a serious challenge to the cold flow model:

  • hard to not make cold flows ‘glow’ in Lya at observed number densities of blobs.

  • even harder to make them glow at much lower luminosities -> empirical constraints on the properties of cold flows

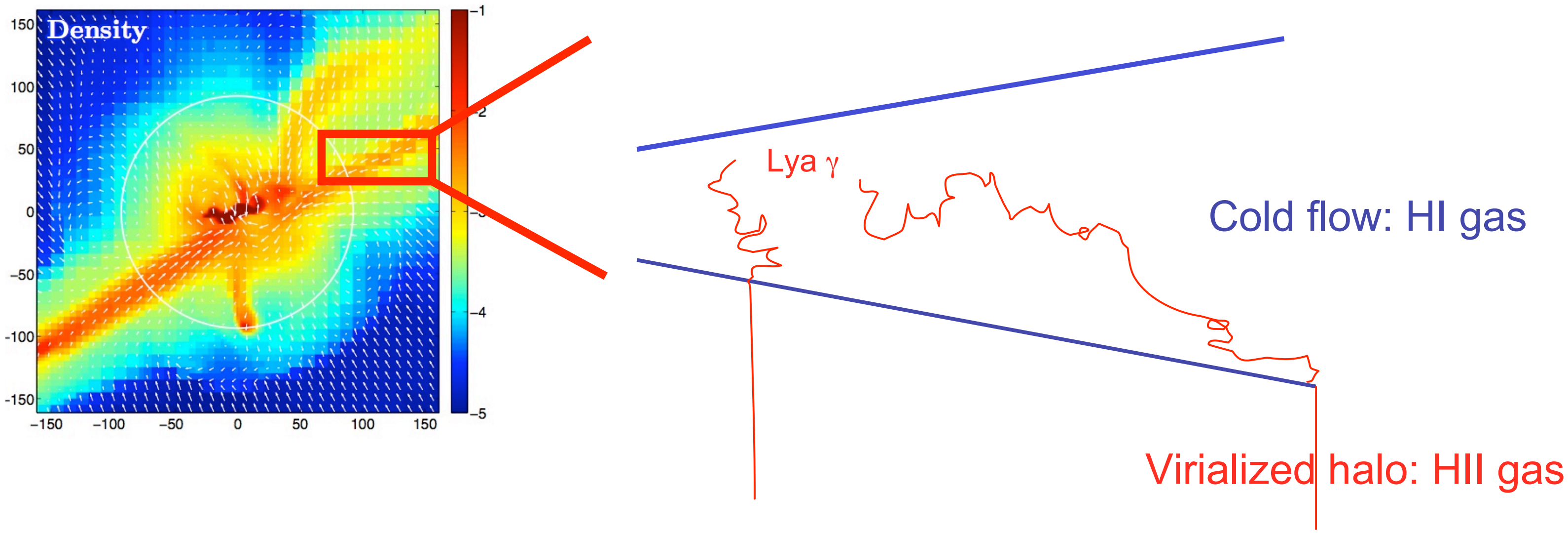
• In any case (optimistic and pessimistic), *we expect Lya observations (imaging, spectroscopy, polarimetry) to strongly constrain on the properties of cold flows (and the role of instabilities).*

Appendix

Testable Predictions of Model

- Cold flows contain small fraction of mass (5-25%) in ‘compressed’ form:

  Low volume filling factor -> Lya radiative transfer is relatively easy.



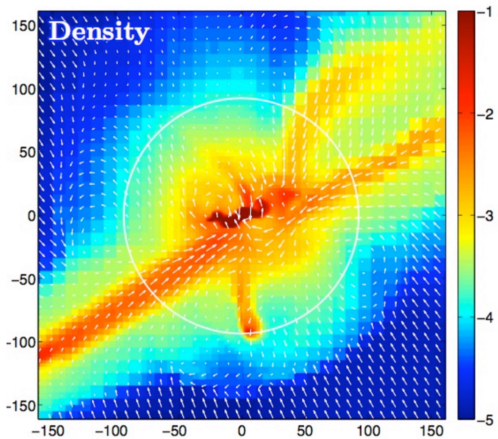
- Lya photons likely escape from filament not far from where they were emitted.

Testable Predictions of Model

• Cold flows contain small fraction of mass (5-25%) in ‘compressed’ form:

Low volume filling factor -> Lya radiative transfer is relatively easy.

• Low volume filling factor-> low probability that Lya photons scatter in other filaments.



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Lya image

• Optically thin approximation OK (for images): Filamentary structure preserved.

• Higher resolution and/or deeper imaging should reveal filamentary structure

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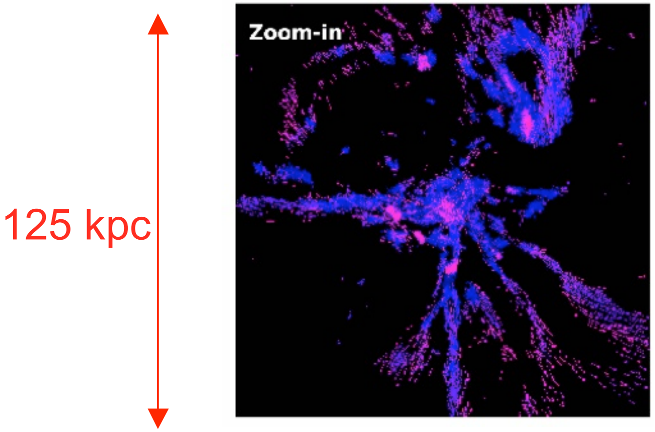
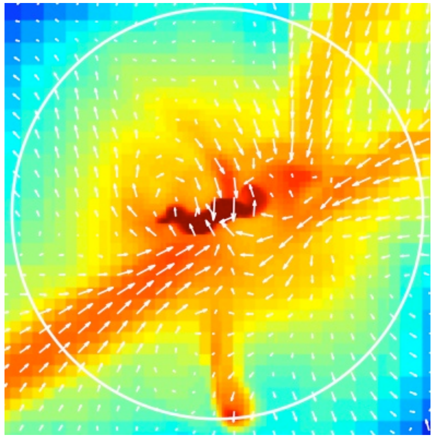


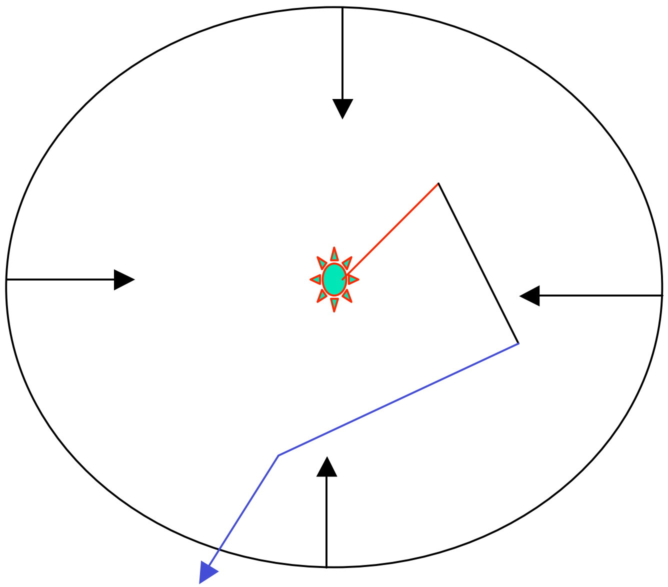


- Center may be more complicated: covering factor of HI increases?->RT important (although in the center, gas may be ionized).
  - Lya scattering through optically thick contracting gas results in a systematic blueshift of the Lya line (e.g. Zheng Zheng & Miralda-Escude 2002)
  - and…can result in up to 40% linear polarization (D & Loeb ‘08) !

Testable Predictions of Model

• Lya scattering through optically thick contracting gas results in a systematic blueshift of the Lya line (e.g. Zheng Zheng & Miralda-Escude 2002).

• Reason: energy is transferred from gas to Lya photons: ‘*gas does work on photons’ as photons stream outward*.’



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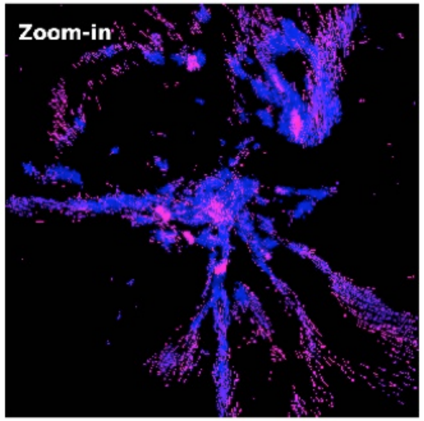
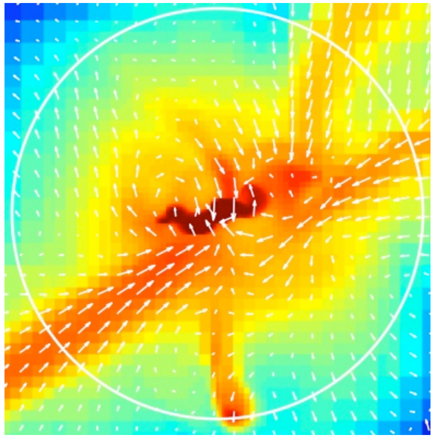
125 kpc





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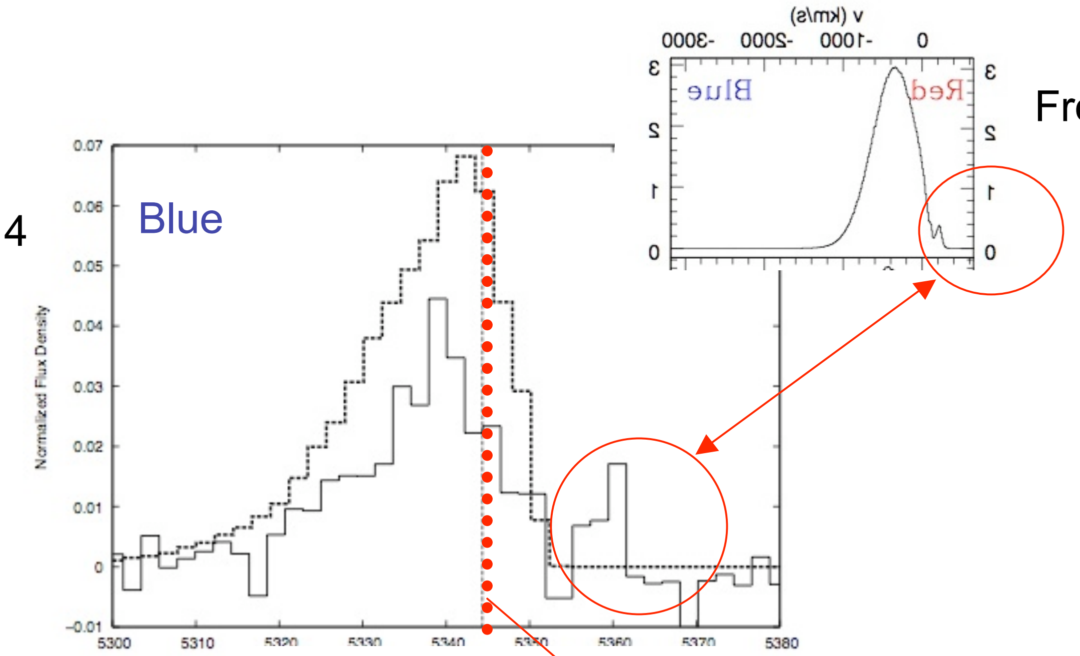
Adams+09:

Lya spectra of z=3.4 radio galaxy



From: D+06

Wavelength

Systemic z from 21-cm absorption

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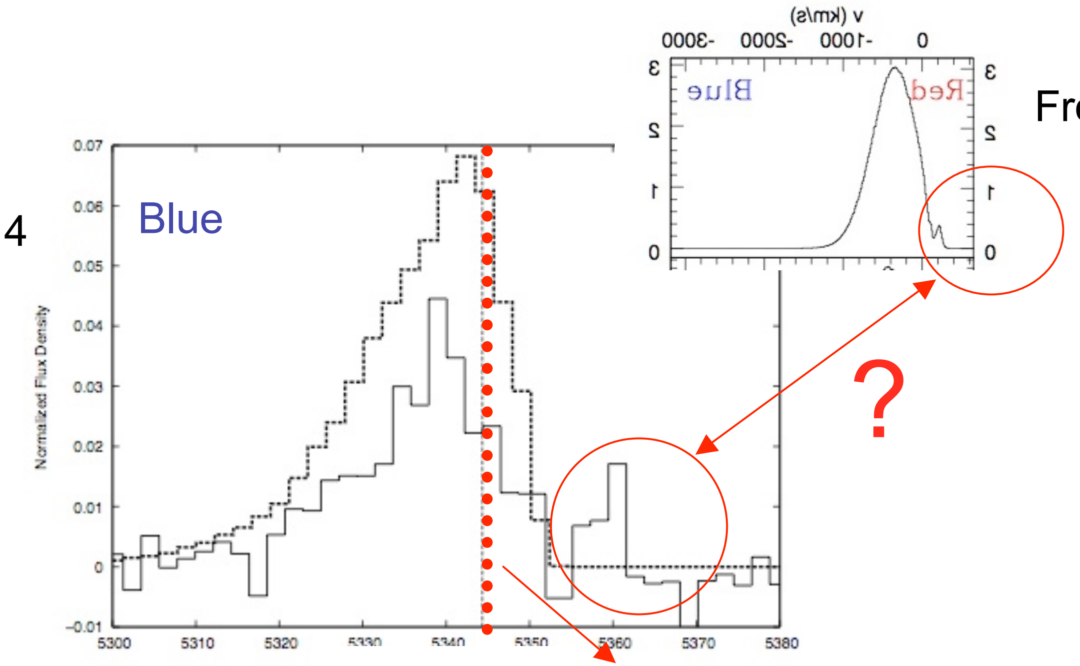


Wavelength

From: D+06

Systemic z from 21-cm absorption

Testable Predictions.

• Lya forms mostly in collisions, Ha flux is lower by 54x $f_{esc,Lya}$. This would be quite frustrating as simultaneous Ha/Lya measurements-> handle on RT.

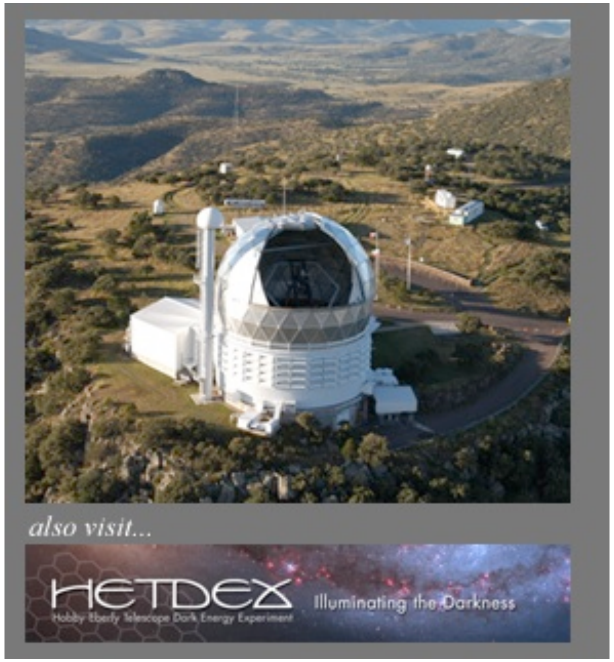
• Cold accretion has duty cycle close to 1 in massive halos: natural association with known bright quasars-> Sufficiently deep imaging should reveal halo at level L_{Lya}~1e43 ergs/s (note that Matsuda+04 required 7hr integration on 8-m telescope..)

• Further in future: HETDEX (www.hetdex.org)

• BAO with Lya emitting galaxies.

• Expects to find thousands of blobs + spectra of them.

• Clustering + LF -> mass + duty cycle.

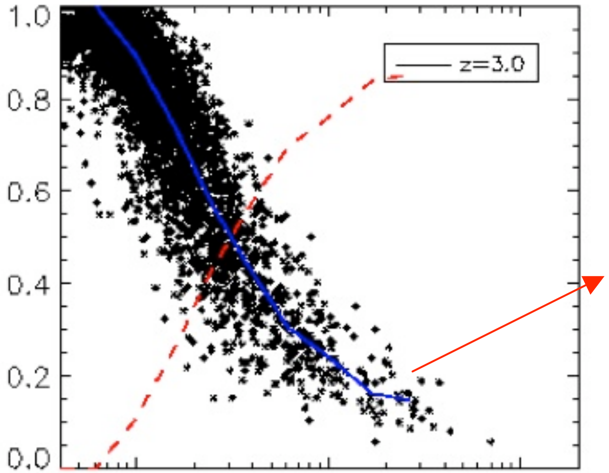


Cold Flows

• Important: cold (T~1e4 K) spatially extended gas exists in massive halos.

Keres+09

Mass Fraction
in cold gas



1e11 1e12 1e13

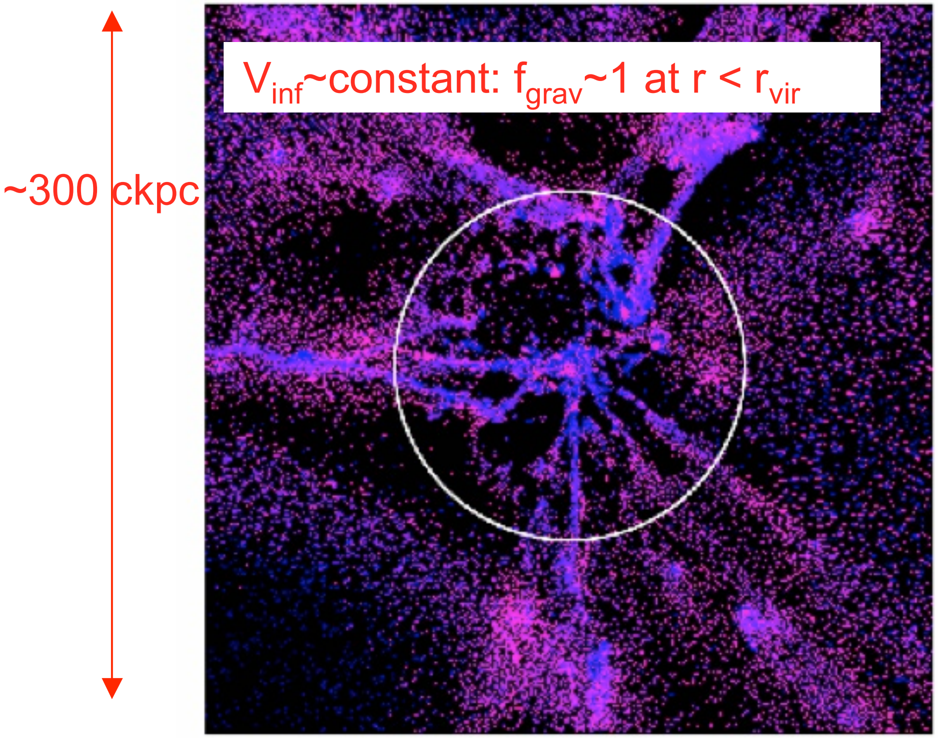
Halo Mass (solar Mass)

f_{cold}~5-20% for
M_{halo}=1e12-1e13 m_{sun}

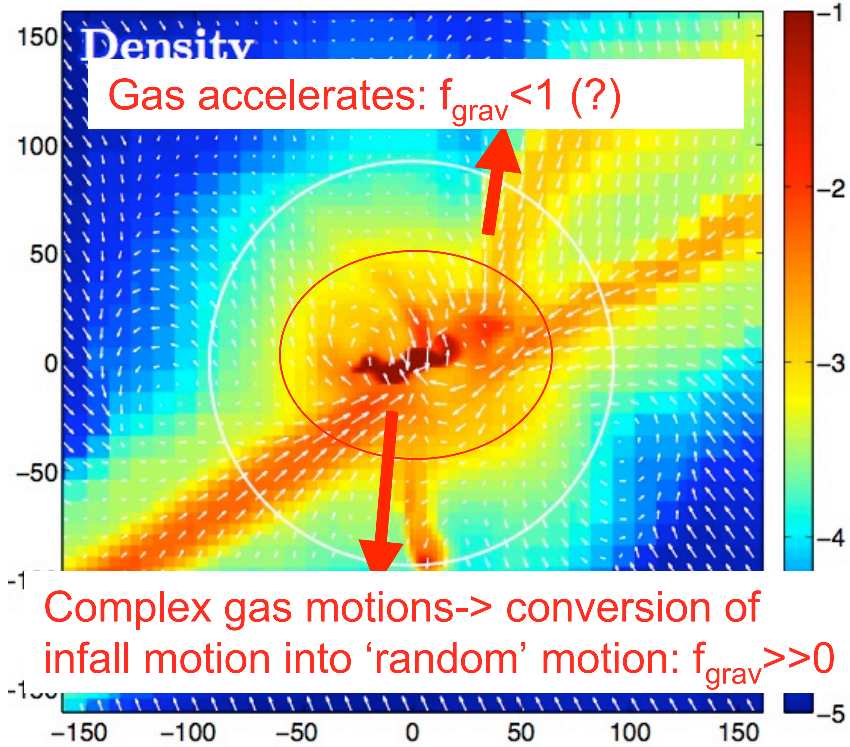
• Cold gas in pressure equilibrium with hot gas (T~1e6-1e7 K) -> dense + neutral. Collisional excitation of the Lya transition & recombination extremely efficient

-> Spatially extended Lya source?

f_{grav} in Simulations of Structure Formation in Massive Halo



Keres+09



Dekel+09

Cold Flows as Lyman Alpha Blobs?

- For a given f_{grav}, compute the Lya luminosity, L_{Lya}, of a halo of mass M as follows

- $$H(r) = f_{grav} \times F_g \frac{dr}{dt} \qquad \Lambda(r) = H(r) \qquad n_c T_c = n_H T_H$$

Infall velocity   Heating=collisional + rec.+ … cooling   pressure eq.

- Given T_c and n_c, compute:

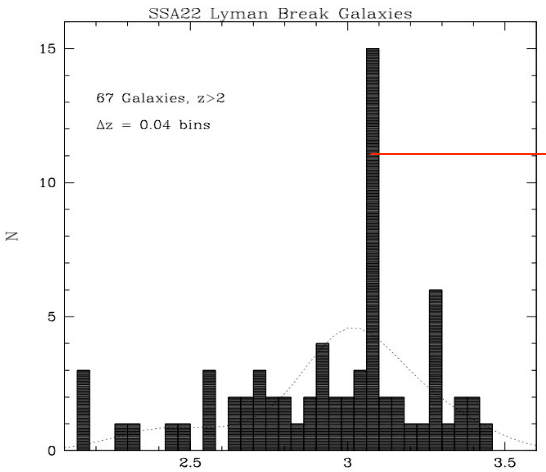
- $$L_{Ly\alpha}(M) = 4\pi \int_0^{r_{vir}} r^2 dr \varepsilon_{Ly\alpha}(r) \left(\frac{T_c}{T_{vir}}\right) f_{cold}$$

Relate L_{Lya} with mass: compute Lya luminosity function from halo mass function.

Cold Flows as Lyman Alpha Blobs?

- Relate L_{Lya} with mass: compute Lya luminosity function from halo mass function.

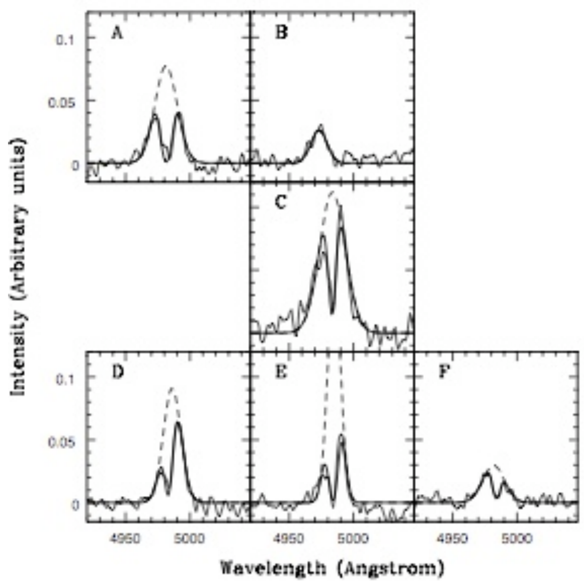
- Cannot use standard mass function of DM halos.



Matsuda+04 imaged known overdense region of our Universe:

Any model that reproduces the data, MUST account for this, otherwise overpredict number of blobs in other surveys

- Use Sheth-Tormen (1999) mass function appropriate for overdensity δ (Barkana & Loeb 2005). δ=3 $\pm 1\sigma_M$ -> δ_{LBG}~ 1.0±0.3 (Matusuda+05)


A
B
C
D
E
F
0.1
0.05
0
4950
5000
Intensity (Arbitrary units)
Wavelength (Angstrom)