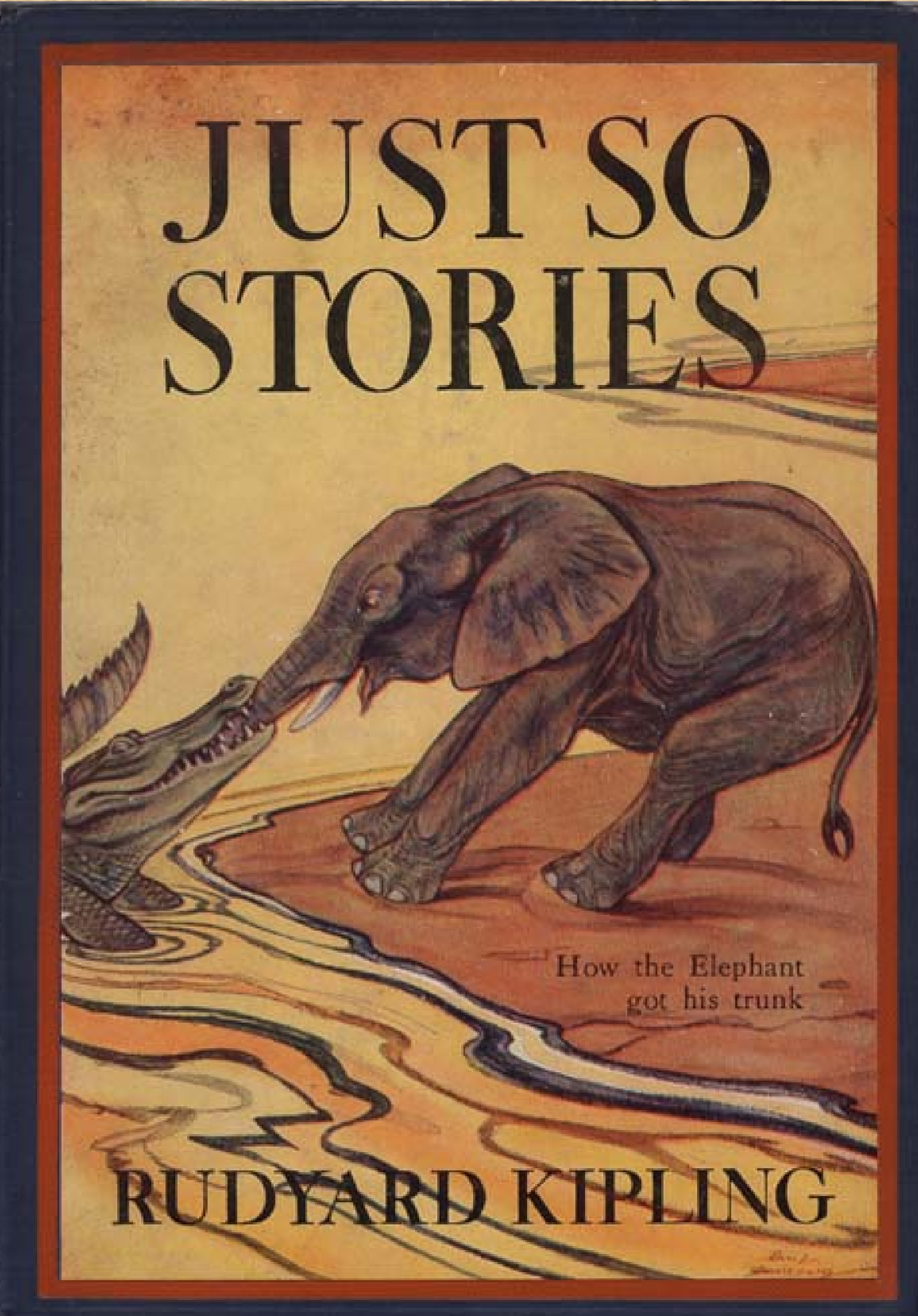

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How the Galaxy got its Mass...

and other Just So Stories

by

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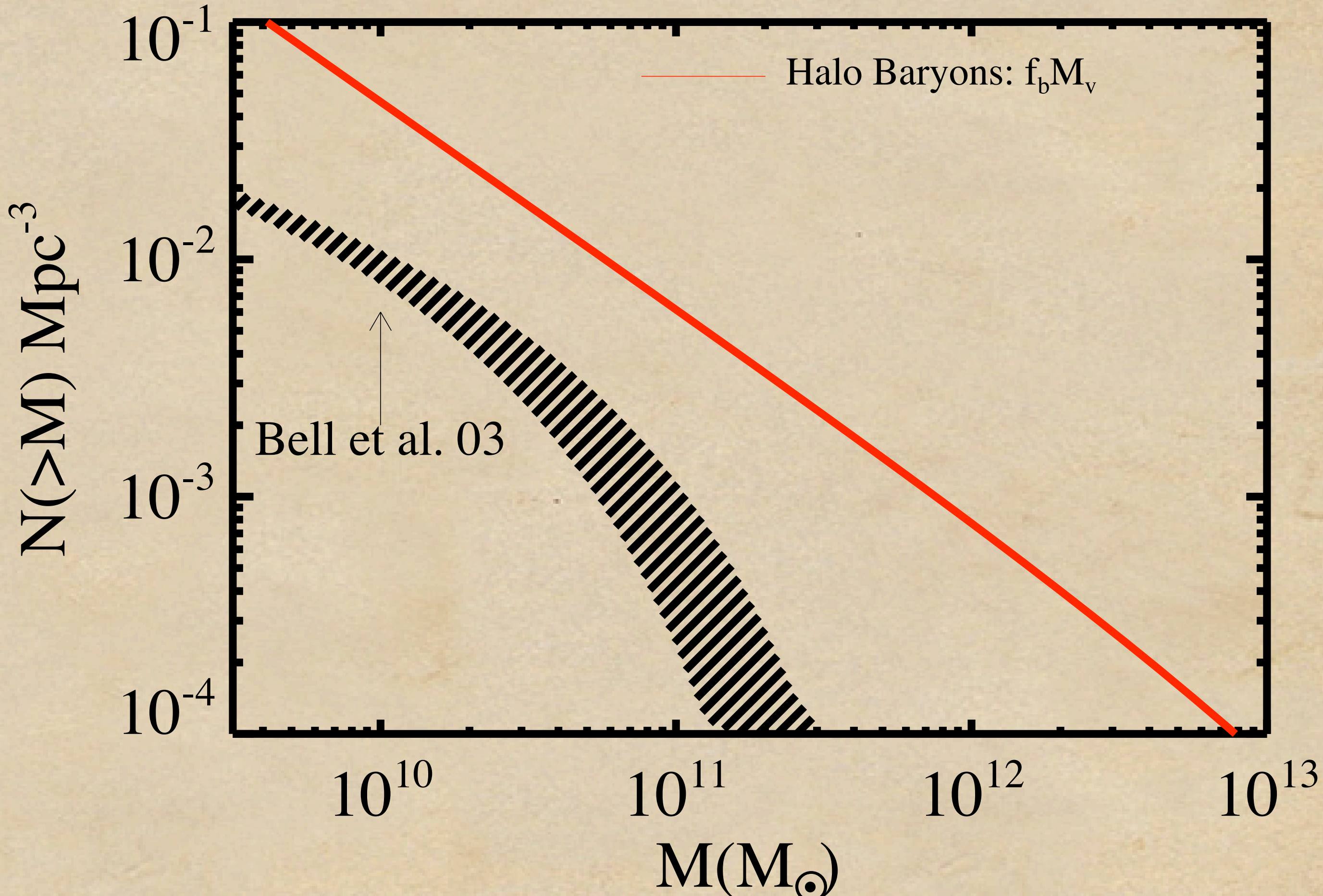
astro-ph/0406632

The Cosmological Baryon Conundrum

Only ~8% of baryons are in stars

(Fukagita, Hogan and Peeples 1998, Bell et. al. 2003, Fukagita et al. 2004)

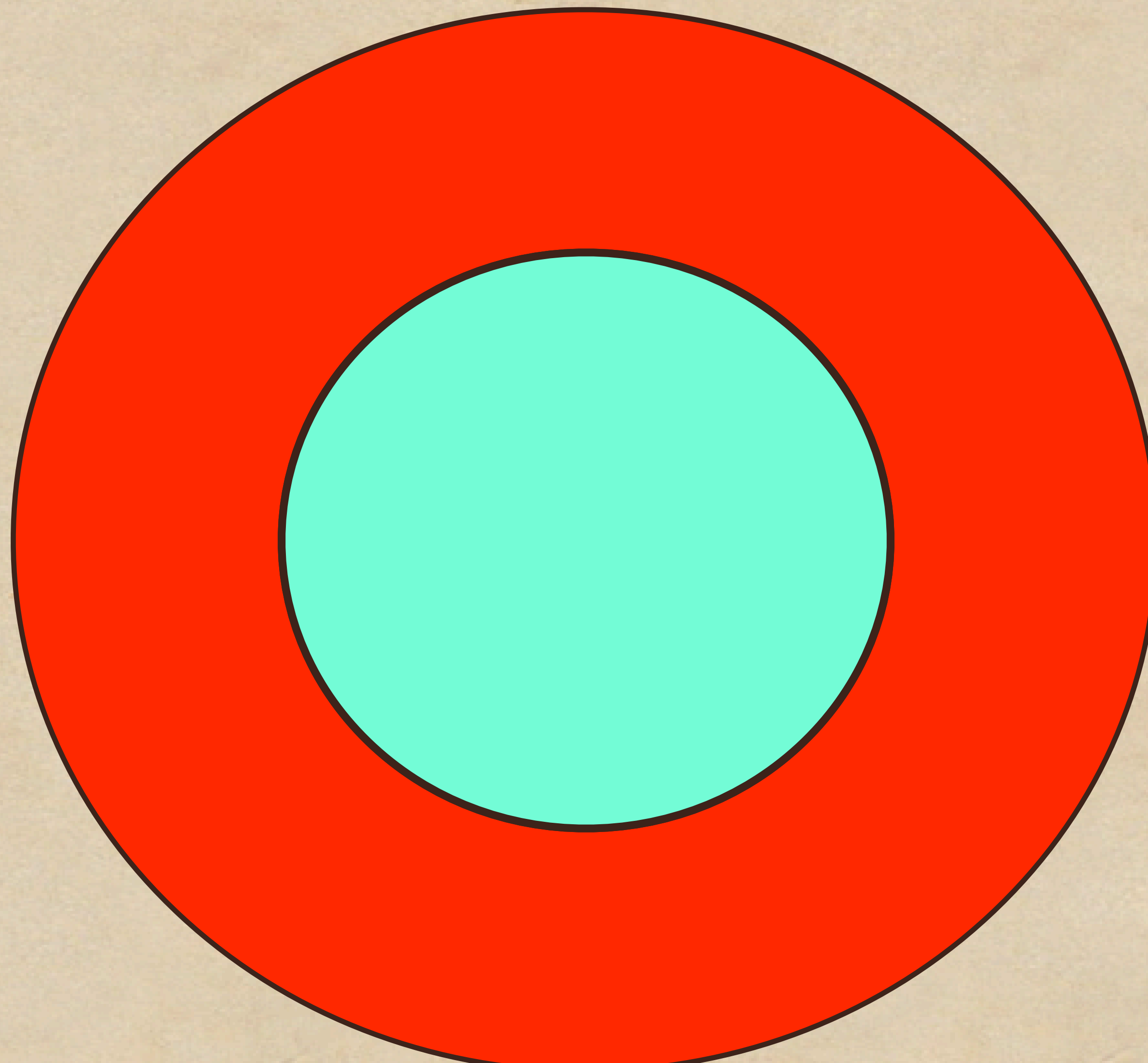


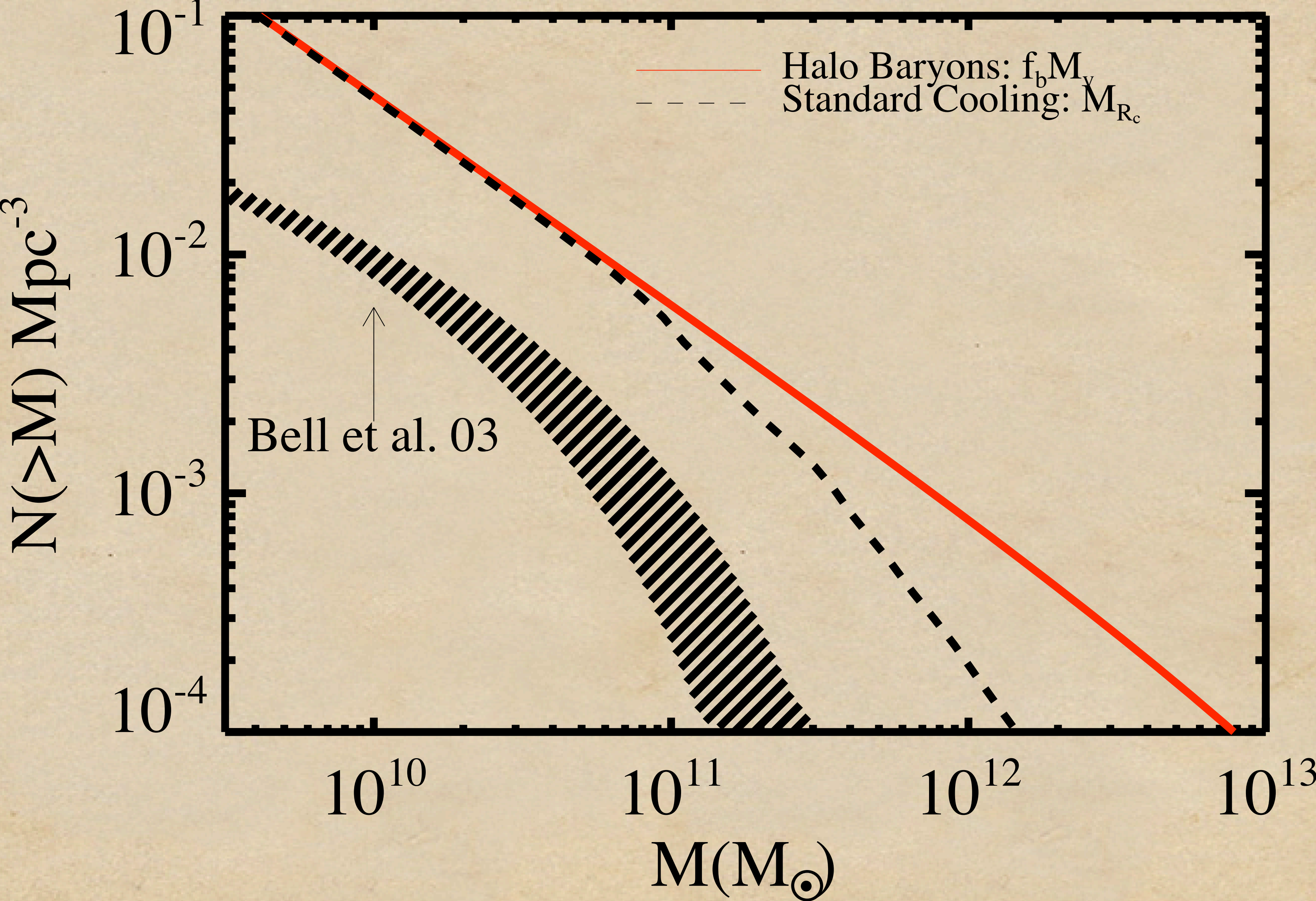
Take for example our own Milky Way:

$M_g = 4\text{-}6 \times 10^{10}$ (Dehnen and Binney 1998) $M_v = 10^{12}$ (Klypin et al. 2002)

$f_b = 0.17$ (Spergel et al. 2003) => $M_b = 17 \times 10^{10}$

This is 3 - 4 times the observed mass.





Halo Baryons: $f_b M_v$
Standard Cooling: M_{R_c}
Bell et al. 03
$N(>M)\ Mpc^{-3}$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{10}
10^{11}
10^{12}
10^{13}
$M(M_\odot)$

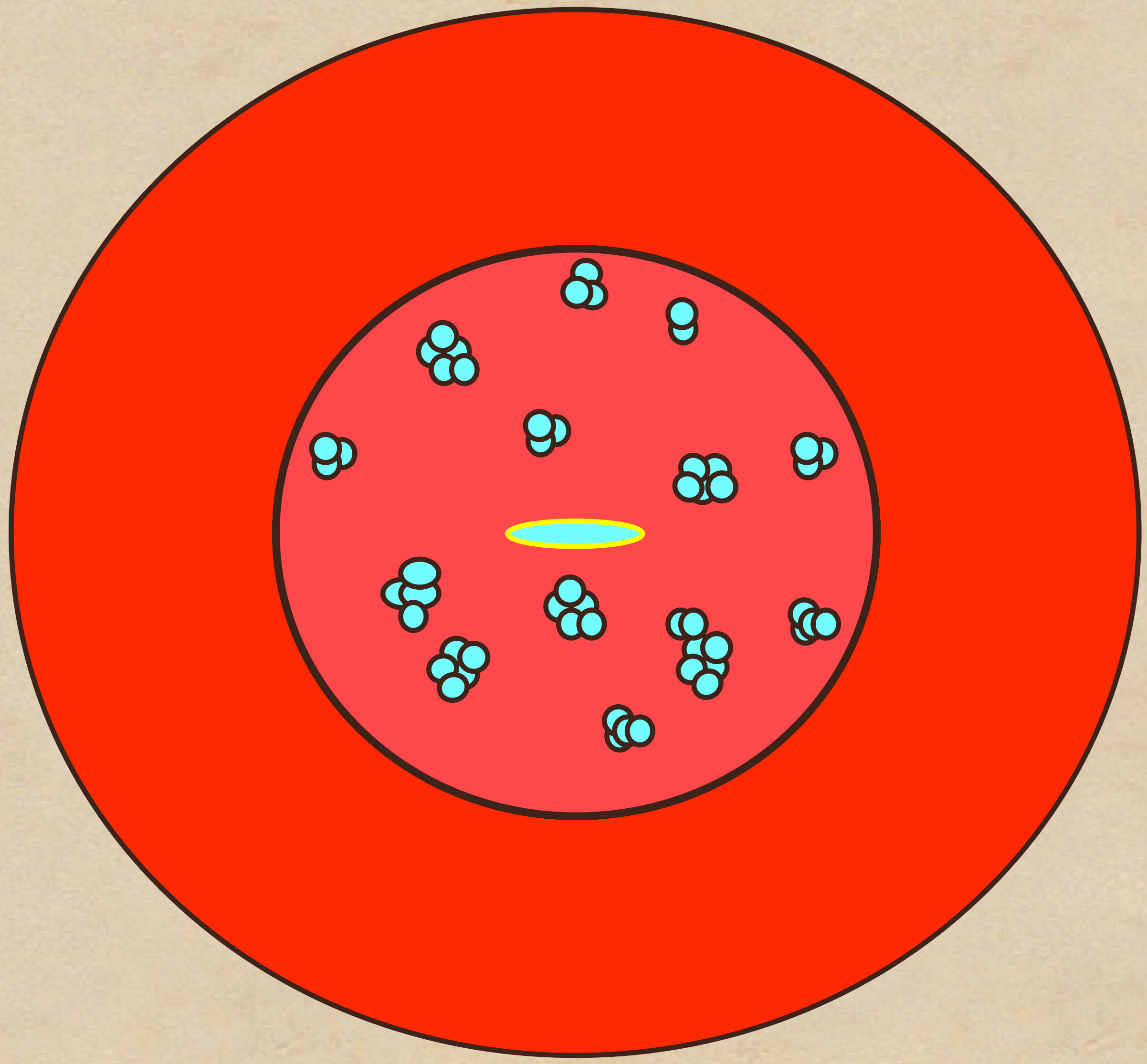
The Standard Picture

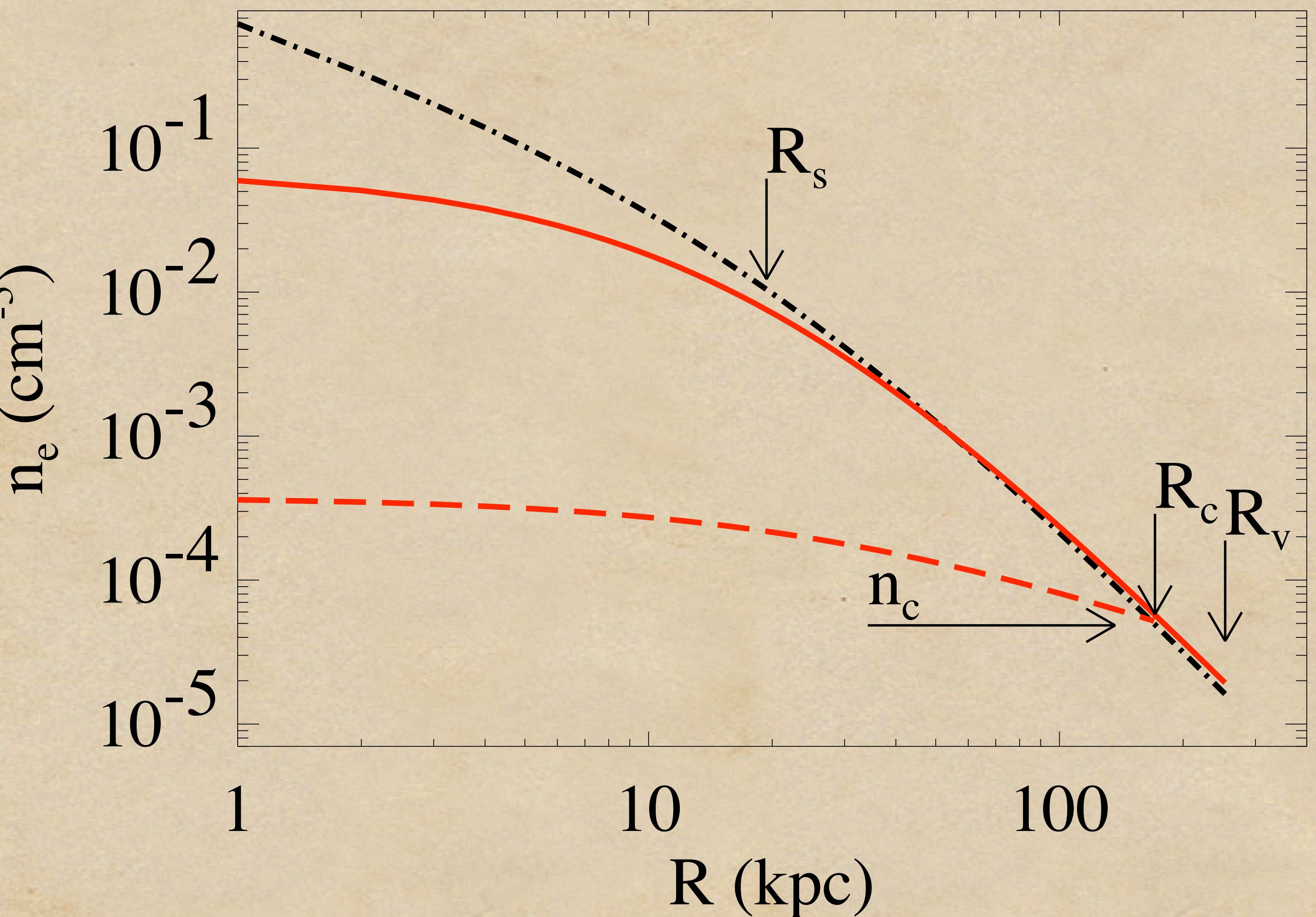
- 2/3 of the baryons cool forming a Milky Way mass of 12×10^{10}, twice what is observed.
- Supernova feedback is invoked to blowout half of the Milky Ways while not destroying the thin disk.
- Numerical simulations consistently fail to create such massive winds. (Mac Low and Ferrara 1999)

Is there another solution?

Cooling and Fragmentation in Astrophysical Plasmas

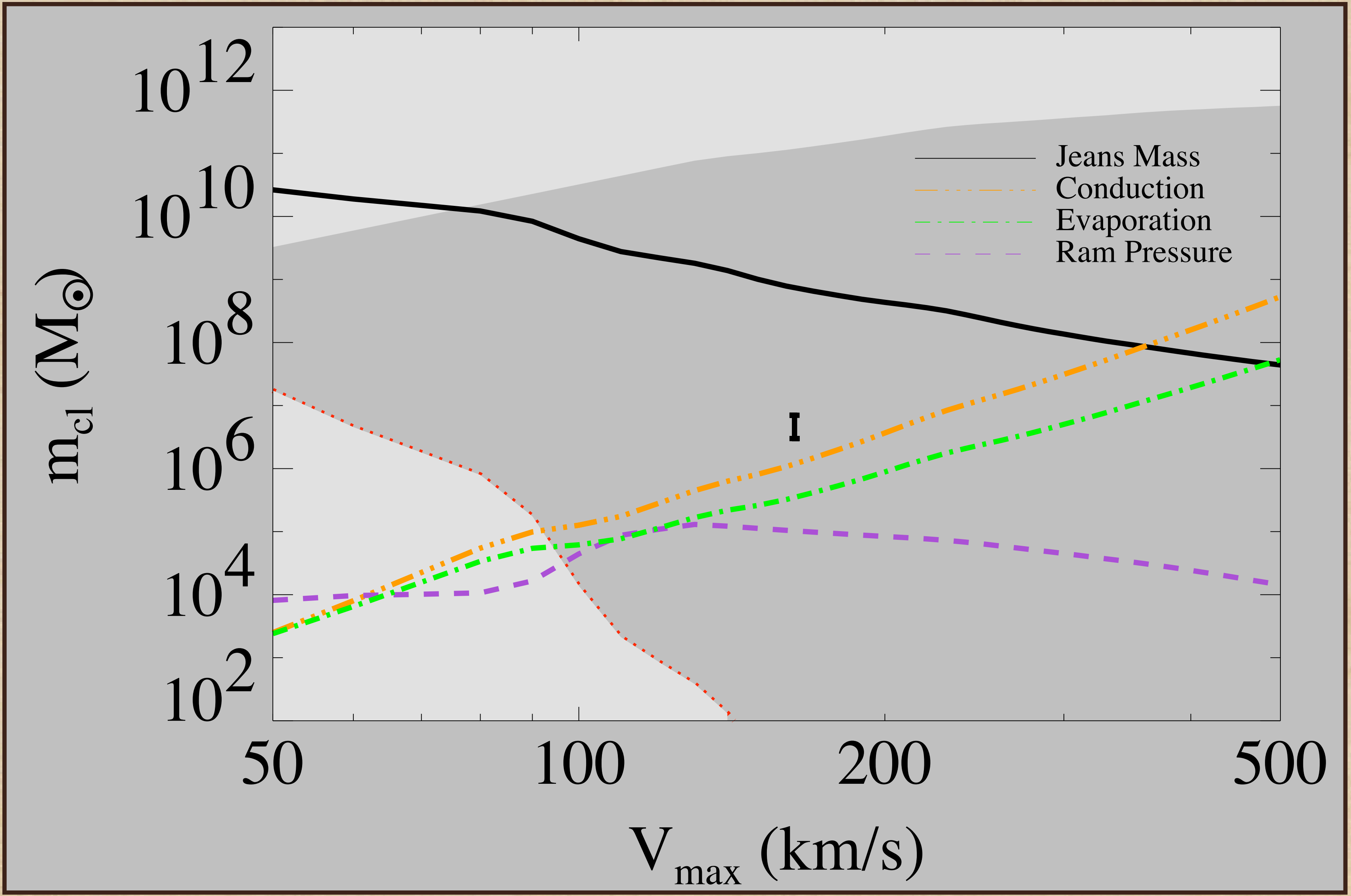
- A cooling plasma is hydrodynamically unstable (Field 1965)
- Higher density regions will cool faster, becoming denser and therefore cooling faster. Low density regions won't cool as quickly, will expand into the space left by the high density regions, thus decreasing their density and the rate that they cool.
- One ends up with a two phase medium of low density hot gas and warm clouds.





10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
n_e (cm^{-3})
1
10
100
R (kpc)
R_s
R_c
R_v
n_c

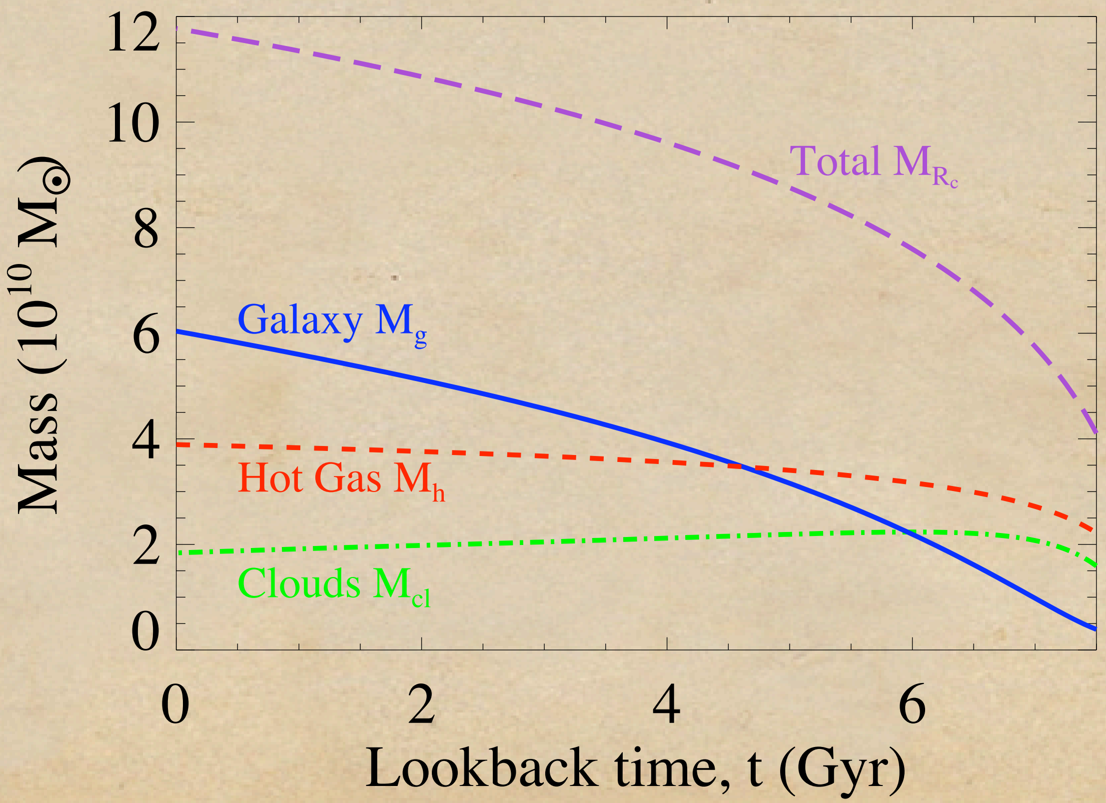
Constraints on the Cloud Mass



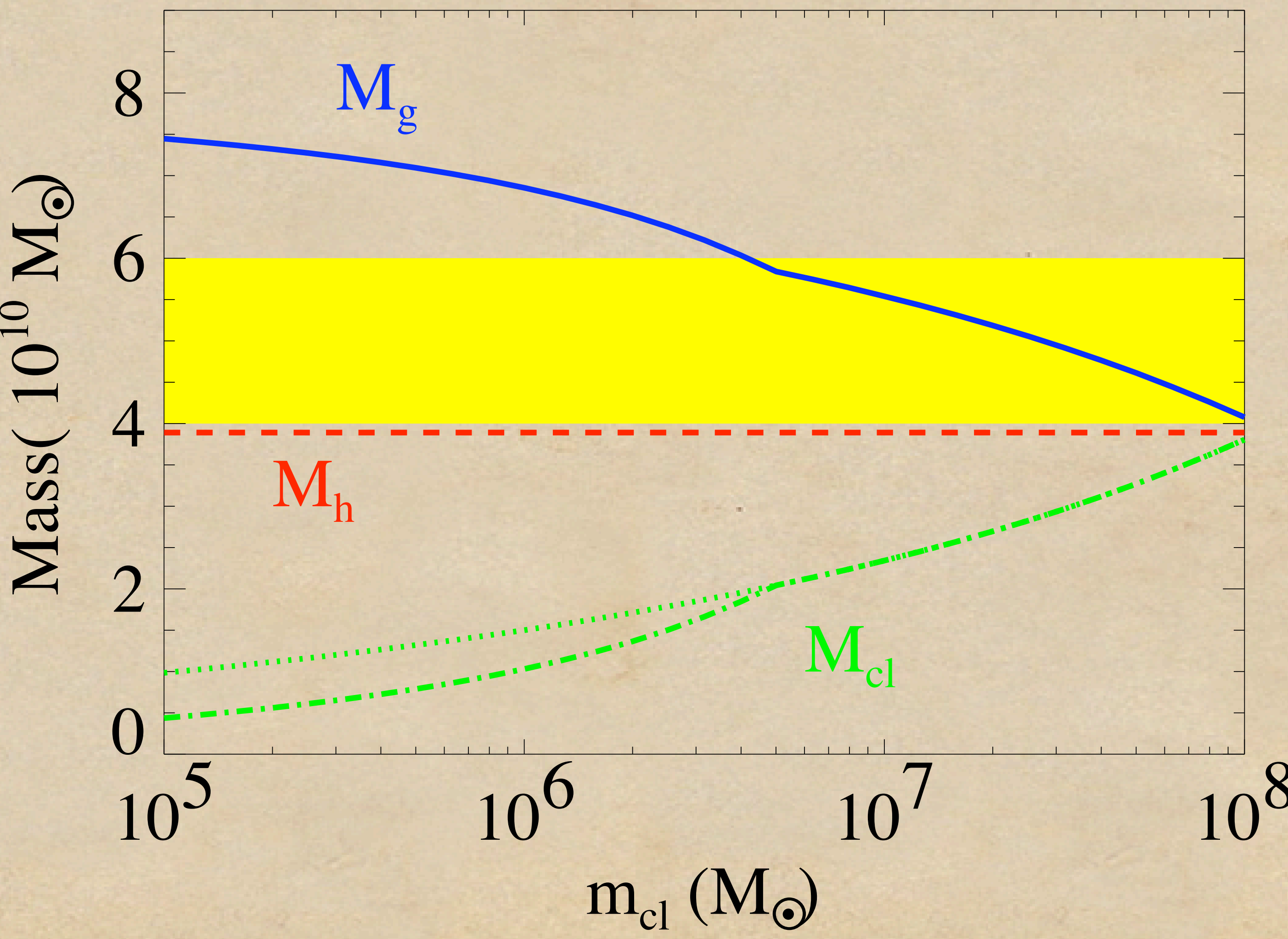
Cloud-Cloud collisions

Clouds will move around in the halo until they collide or lose energy from ram pressure. Only then will they merge with the galaxy.

$$M_h \propto \rho_c R_c^3$$



Mass of the Milky Way

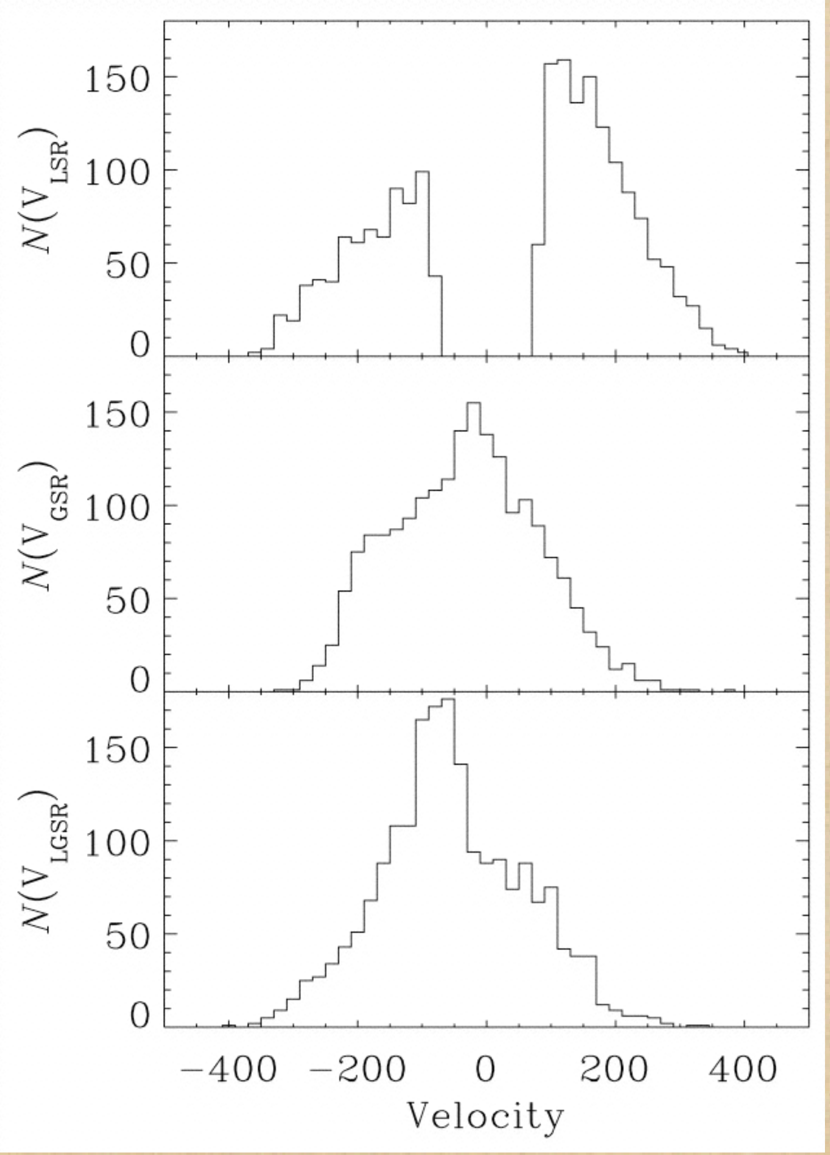


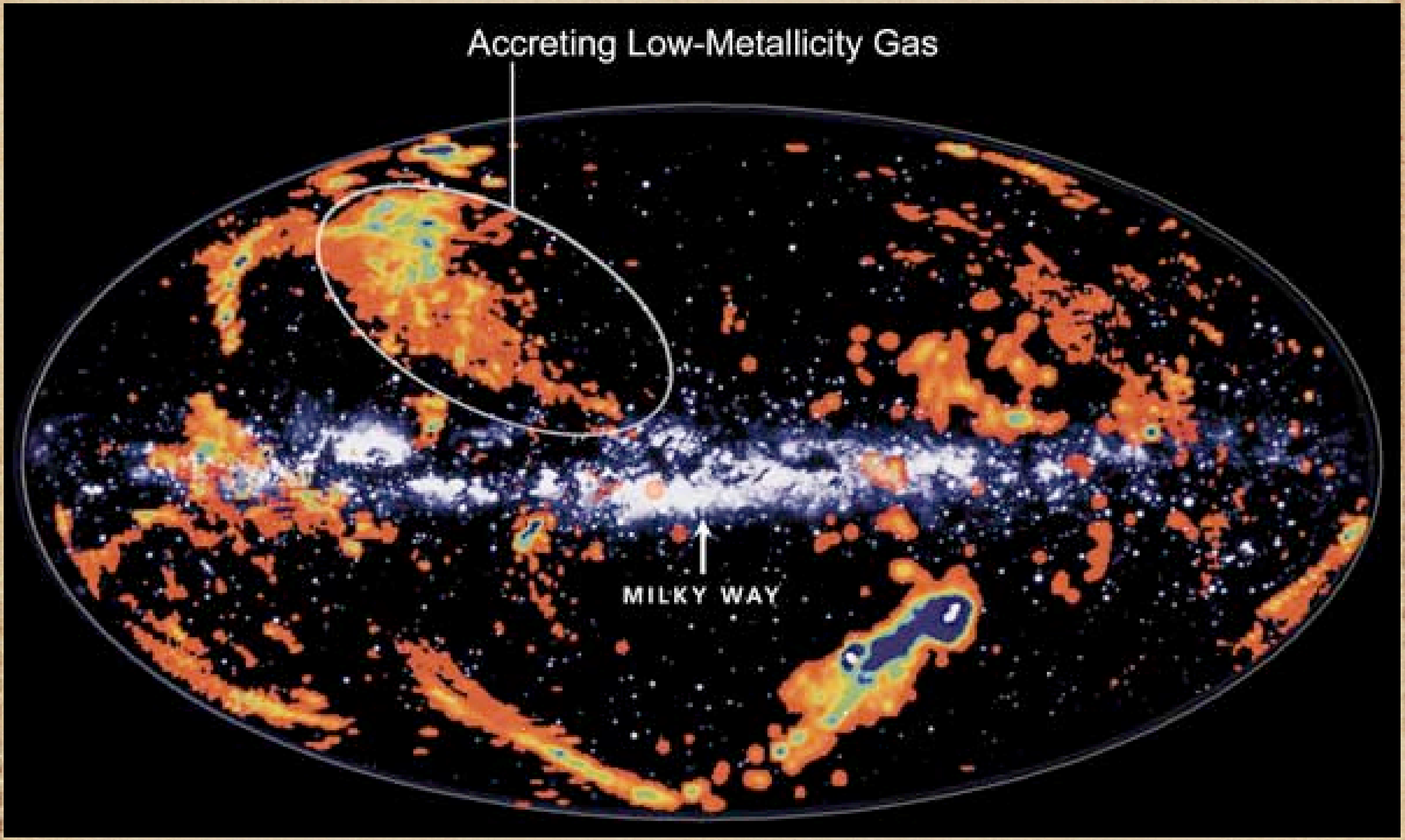
High Velocity Clouds

HI clouds detected around our galaxy not associated with the disk.

Their velocity dispersion is minimized if plotted relative to the Galaxy.

They have typical angular sizes of 0.5 deg^2, metalicities of 0.1 solar and there are 2000 in the Southern Sky.
(Putman et al 2002)

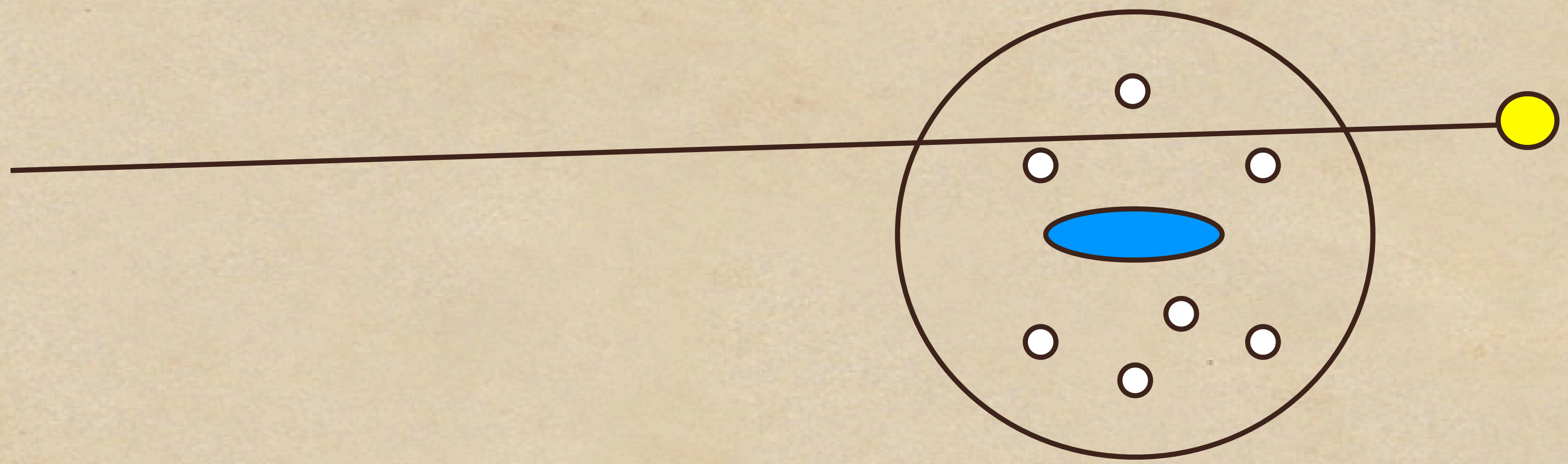




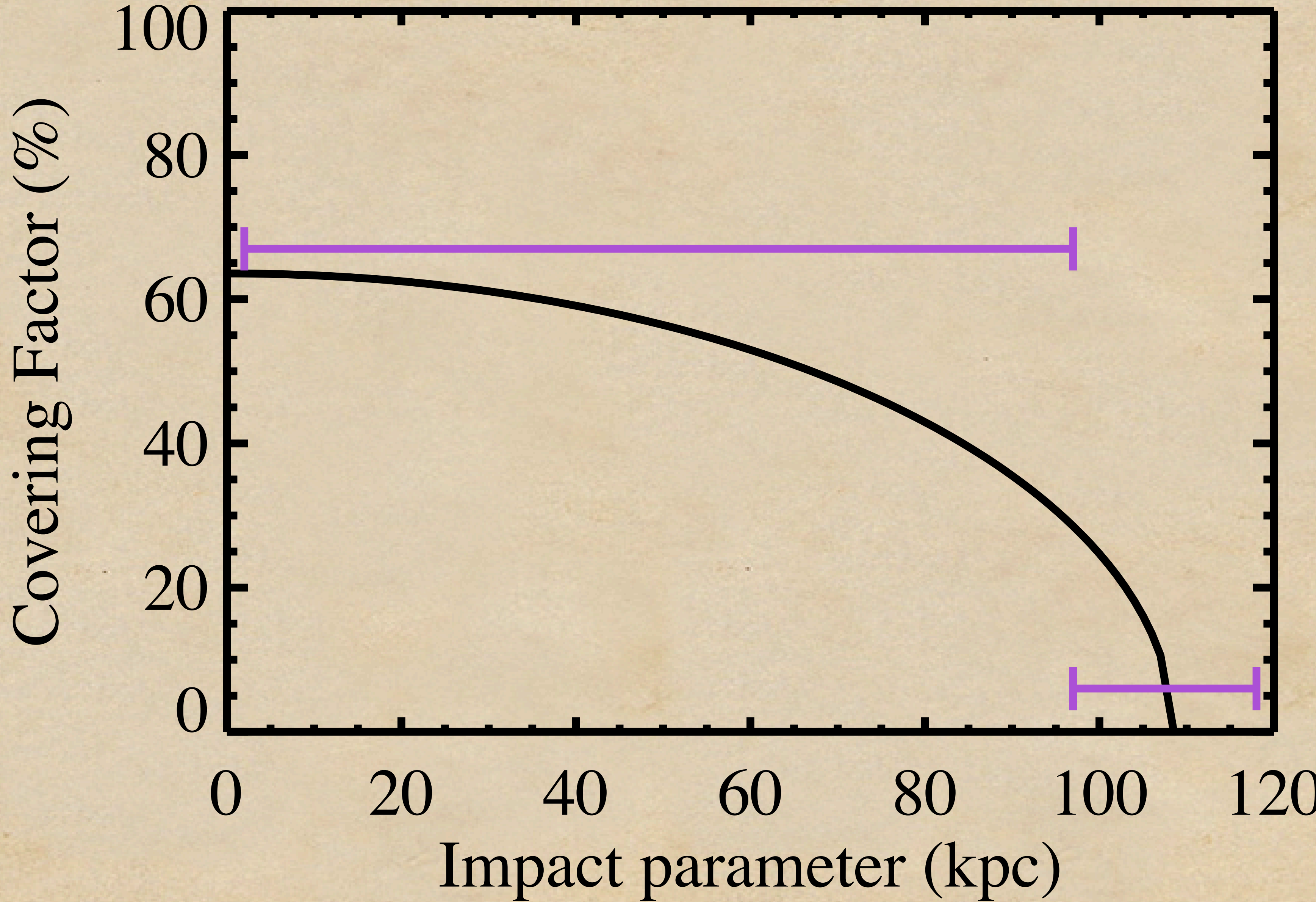
Accreting Low-Metallicity Gas
MILKY WAY

- To have a typical size of 0.5 deg^2 our clouds would need to have a mass of 5×10^6 solar masses.
- With this mass there is a total of 2×10^{10} solar masses in clouds or 4000 clouds.

Quasar Absorption Systems



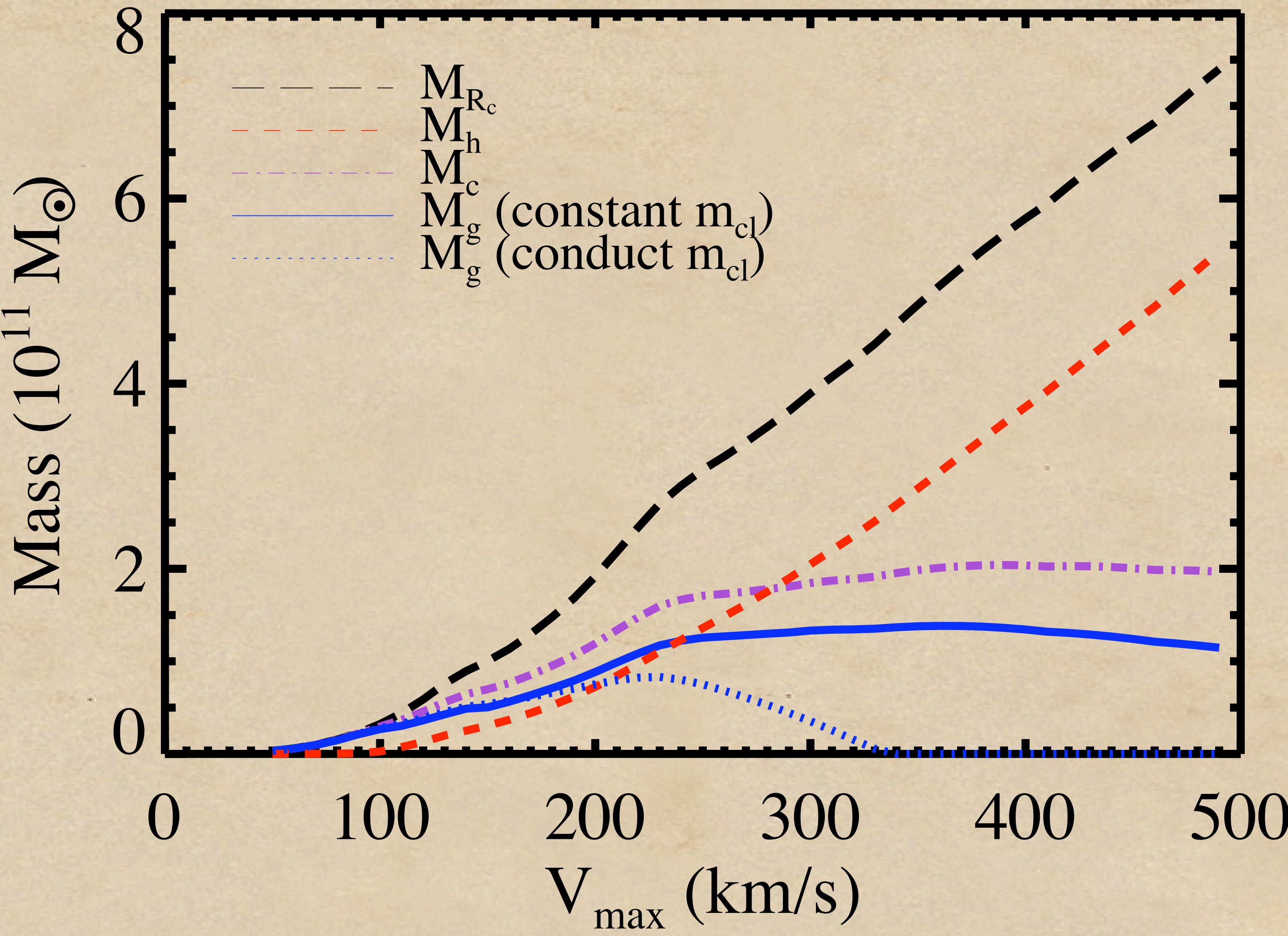
- Warm gas is seen around other galaxies as quasar absorption systems.
- Studying the correlation between CIV systems and galaxies Chen et al. (2001) found that for sightlines within 97 kpc of a galaxy 67% show a CIV system. While outside this distance only 6% do.



Covering Factor (%)
100
80
60
40
20
0
0
20
40
60
80
100
120
Impact parameter (kpc)

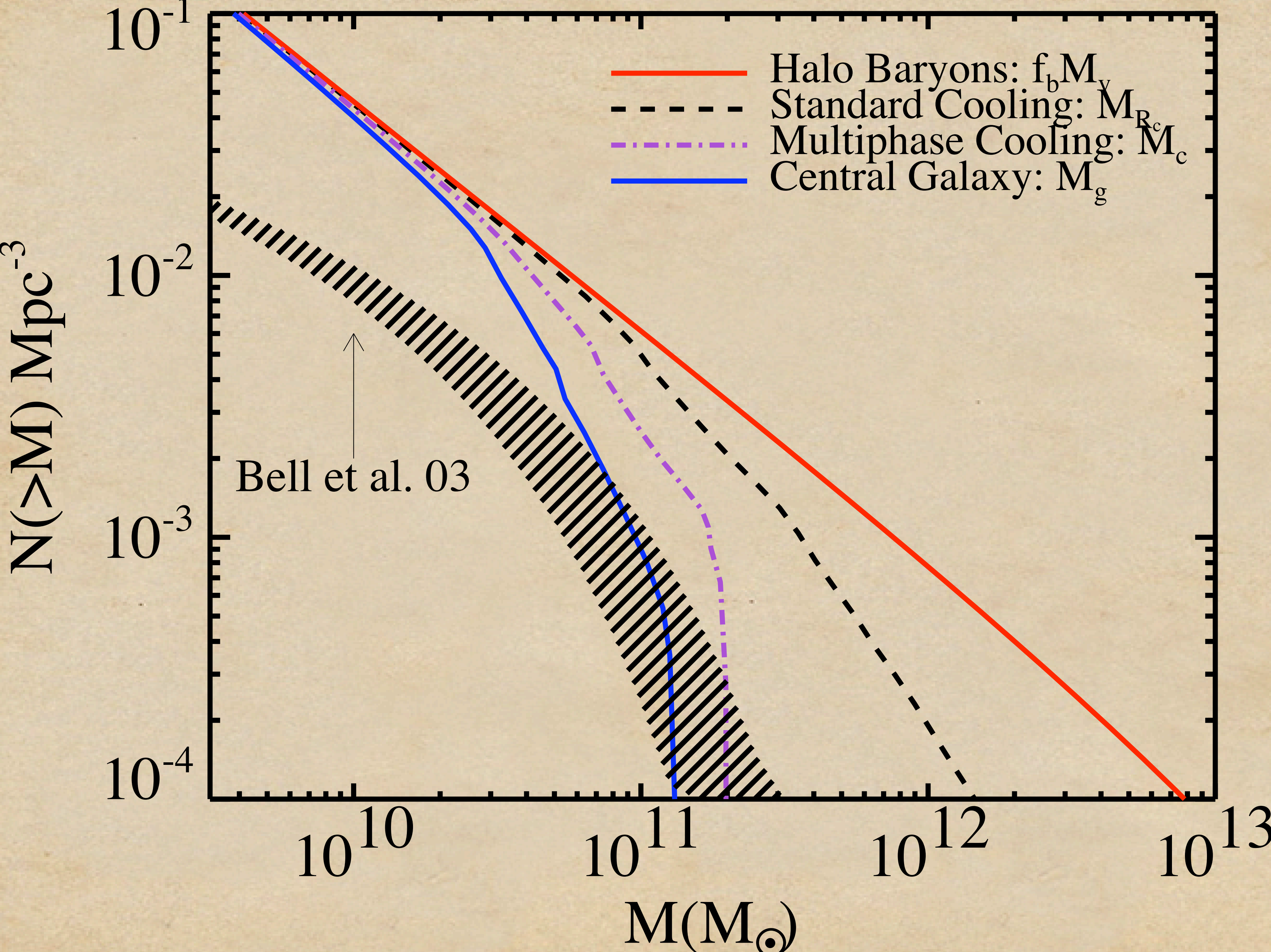
The Luminosity Function

- The Luminosity Function shows a sharp cutoff around the Milky Ways luminosity.
- However, there is no feature in the corresponding dark matter halo mass function.
- Semi-analytic models put this feature in by hand.
- Multi-phase cooling seems to predict this cutoff naturally.



$M_h \propto \rho_c R_c^3 \propto V_{\max}$

$M_{dm}(R_c) \propto V_{\max}$



Halo Baryons: $f_b M_v$
Standard Cooling: M_{R_c}
Multiphase Cooling: M_c
Central Galaxy: M_g
Bell et al. 03
$N(>M)\ Mpc^{-3}$
$M(M_\odot)$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{10}
10^{11}
10^{12}
10^{13}

Other Implications

- Clouds may retain their angular momentum solving the disk size problem seen in numerical simulations.
- If the cloud mass is larger than the Jeans Mass the cloud may collapse and form dwarf galaxy with no dark matter.
- Clouds may contribute to the substructure seen in strong gravitational lensing.

Summary

- When gas cools we expect a two phase medium to arise.
- To survive warm clouds must have masses of $10^5 - 10^8$ solar masses.
- To get the observed Milky Way mass clouds must have masses of 10^6-10^8

- To match the observed properties of high velocity clouds requires cloud masses of 3-7 x 10^6 solar masses.
- A similar range of cloud masses is needed to produce quasar absorption systems.

- Irrespective of the cloud mass, the hot low density core sets an upper limit on the amount of mass that can cool of 2×10^{11} solar masses explaining the exponential cutoff in the Luminosity function.

Conclusion

Warm clouds of the right mass range ($3\text{-}7 \times 10^6$) explain the mass of the Milky Way, the high velocity clouds, QSO absorption systems and the luminosity function, Just so...