THE TURBULENT INTERGALACTIC MEDIUM

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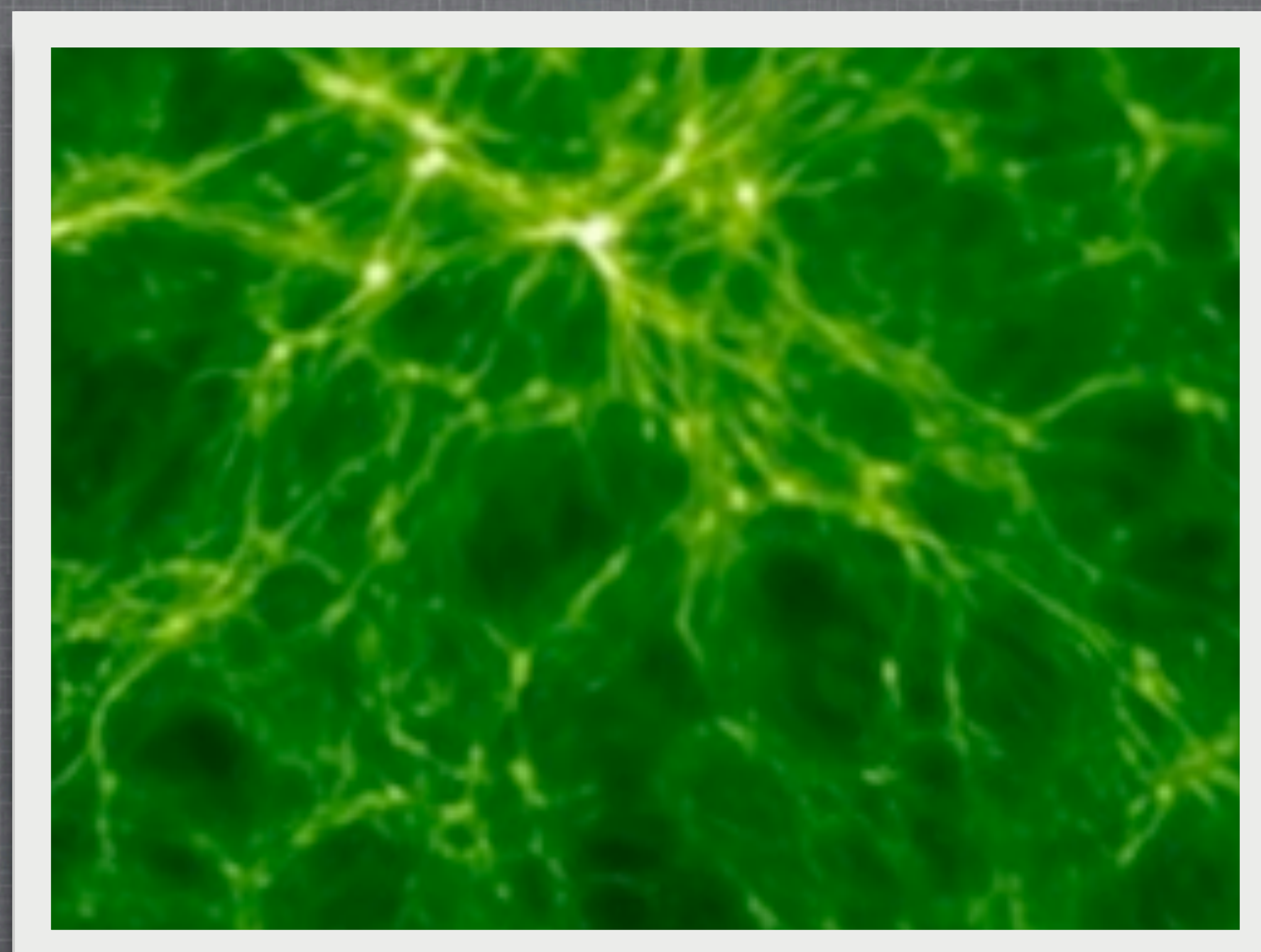
(PhD Student)

under the supervision of **Andrea Ferrara**



Timing : 15 min

Scuola Internazionale Superiore di Studi Avanzati
- ma per seguir virtute e conoscenza -

TALK'S OUTLINE

- **Motivations**: should the IGM be turbulent?
- Brief description of **the model**.
- Some **results** of the model.
- **Conclusions**.

Evoli & Ferrara, *in preparation*

MOTIVATIONS

The Turbulent ISM

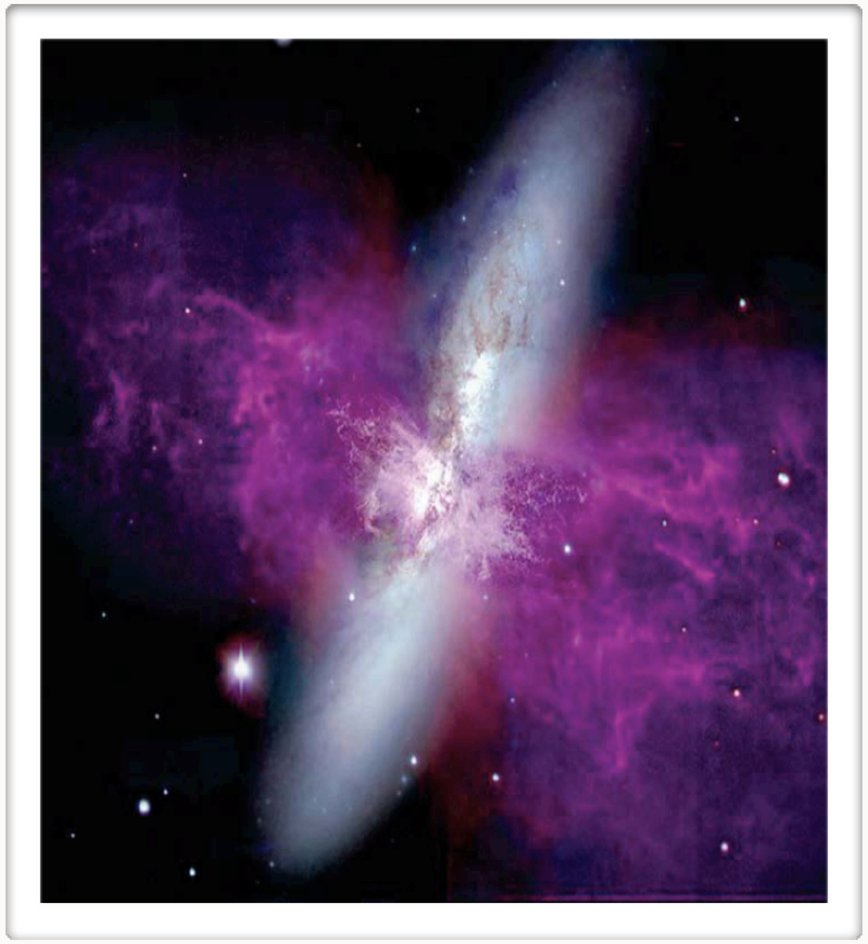
The are strong **evidences** of turbulent motions in the ISM of spiral galaxies:

- **cosmic rays** (only for the MW and a few nearby)
- **diffractive radio scintillation** (only for the MW)
- HI disks of local spiral galaxies exhibit **21 cm line widths** of 5-15 km/s within SF regions. The thermal contribution does not exceed 8 km/s for the warm phase.

SN explosions are thought to be the dominant agent for producing turbulent motions in star forming regions of galaxies. Interaction between blast waves from multiple SN shocks lead to **compression** and **shearing** of the gas (Norman & Ferrara, 1996).

Galactic Outflows

- In some cases, explosions that are **spatially** and **temporally** correlated may collectively generate an **outflow**, observed at both low (Martin 1999; Heckman et al. 2000) and high redshifts (Pettini et al. 2001, 2002; Shapley et al. 2003; Weiner et al. 2008).
- A number of theoretical arguments suggest that this powerful outflows might have been polluted the IGM with **metals** produced by early star formation.
- The presence of heavy elements like C, N and Si in the **Lyα forest** clouds at z~3 is the smoking gun of the galaxy-IGM interplay (Cowie et al. 1995; Simcoe et al. 2004; Adelberger et al. 2003).



NOAO/AURA/NSF

Observational Hints: Kinematics of the IGM

The Impact of Galaxies on Their Environment from Observations of Gravitationally Lensed QSOs

Michael Rauch

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Abstract. Observations of absorption systems in close, multiple lines of sight to gravitationally lensed QSOs can be used to infer the density fluctuations and motions of the gas clouds giving rise to the Lyman α forest phenomenon and to QSO metal absorption systems. We describe a survey of lensed QSOs with the Keck HIRES instrument and argue that one can derive limits on the frequency and impact of hydrodynamical disturbances inflicted by galaxies on the surrounding gas from such data. We discuss differences between the kinematic properties of low density unsaturated Lyα forest absorption systems, high ionization CIV absorption systems, and low ionization gas visible in (e.g.) SiII and CII. The general intergalactic medium (as seen in the Lyα forest) shows very little turbulence, but the presumably denser CIV systems exhibit evidence of having been stirred repeatedly (by winds?) in the past on time scales similar to those governing stellar feedback and possibly galaxy mergers. The quiescence of the low density IGM can be used to put upper limits on the incidence and energetics of galactic winds on a cosmological scale.

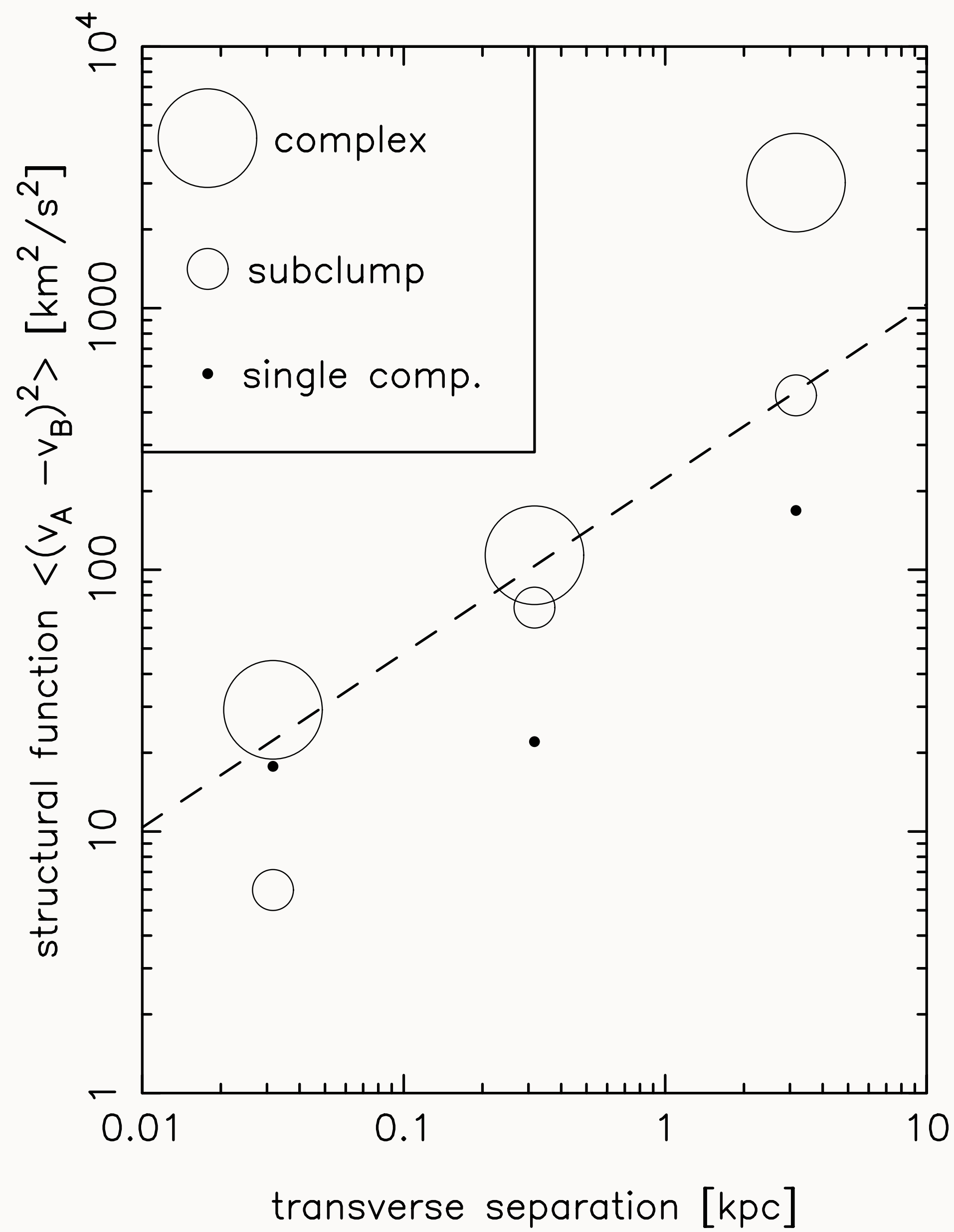
Observational Hints: Kinematics of the IGM

Observations of absorption systems in close lines of sight to gravitationally lensed QSOs can be used to infer the density fluctuations and motions of IGM down to tens of parsecs at redshift z ~3.

The structure function can be measured from the pairs of C IV column density weighted velocities as a function of the l.o.s. separation:

$$\mathbf{B}(s) \sim (\epsilon s)^{2/3} \;\to\; \boldsymbol{\epsilon \sim 10^{-3}\ \mathrm{cm}^2\ \mathrm{s}^{-3}}$$

Could it be due to residual turbulence from an earlier phase of metal ejection?



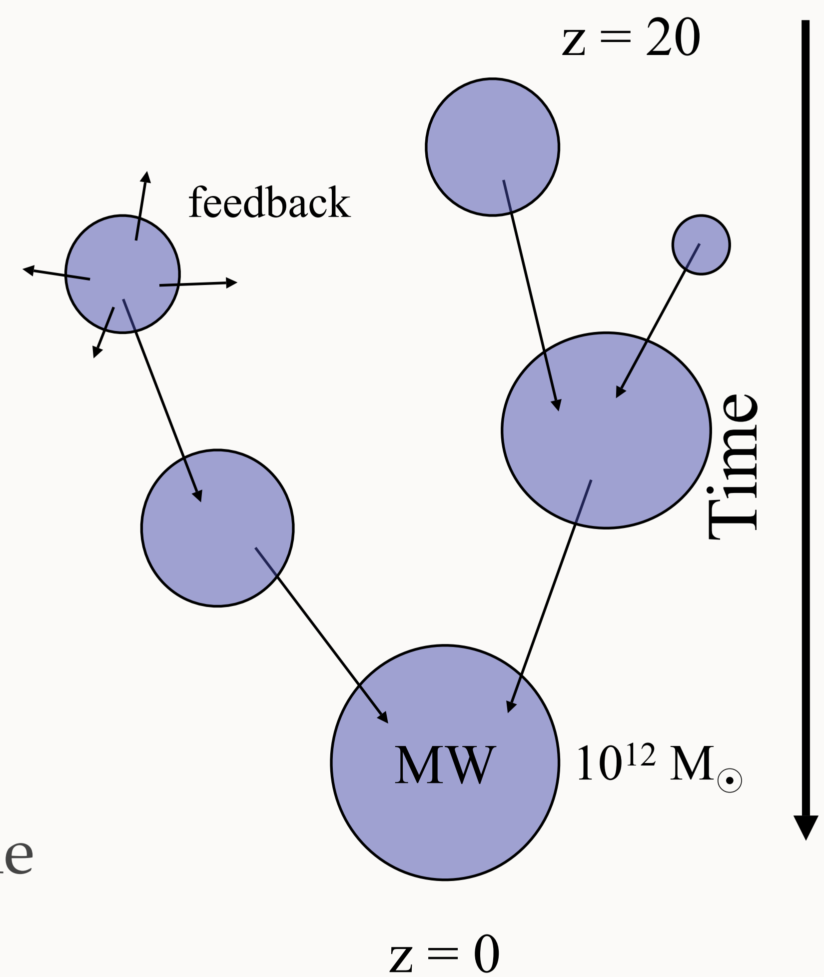
Rauch, 2001

MODEL

Galaxy Formation Model

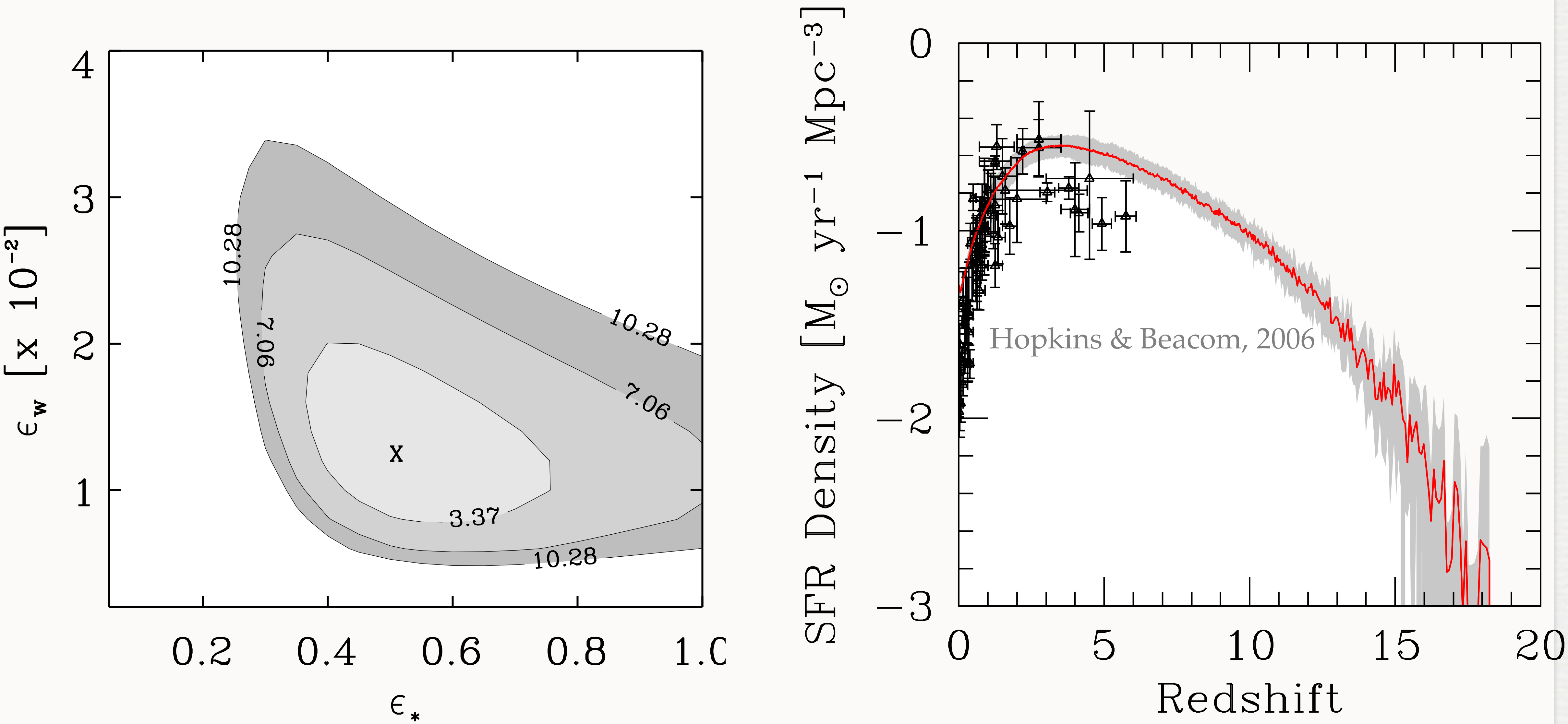
Merger Tree approach, one-zone model:

- Stars form in Lyα cooling haloes
  $T_{vir} > 10^4$K → $M > M_4(z{=}20)$
- $\mathrm{SNR} \propto \mathrm{SFR} = \varepsilon_* \frac{M_g}{t_{ff}}$
- Mechanical feedback: $\frac{dM_{ej}}{dt} = \frac{2\varepsilon_w E_{SN}}{v_e^2} \frac{dN_{SN}}{dt}$
- IRA approximation relaxed.
- Model free parameters calibrated by reproducing the global MW properties (stellar/gas mass & SFR)



Salvadori et al., 2007; Parkinson et al., 2008

Galaxy Formation Model



Galactic Outflow Evolution

Galactic outflows are treated as **pressure-driven bubbles** of hot gas emerging from star-forming galaxies. They expand working against IGM pressure, and are driven by the energy injected by multi-SN explosions:

$$\frac{d}{dt}(V_s \rho \dot{R}_s) = 4\pi R_s^2 (P_b - P) - \frac{GM(R_s)}{R_s^2} \rho V_s \,,$$

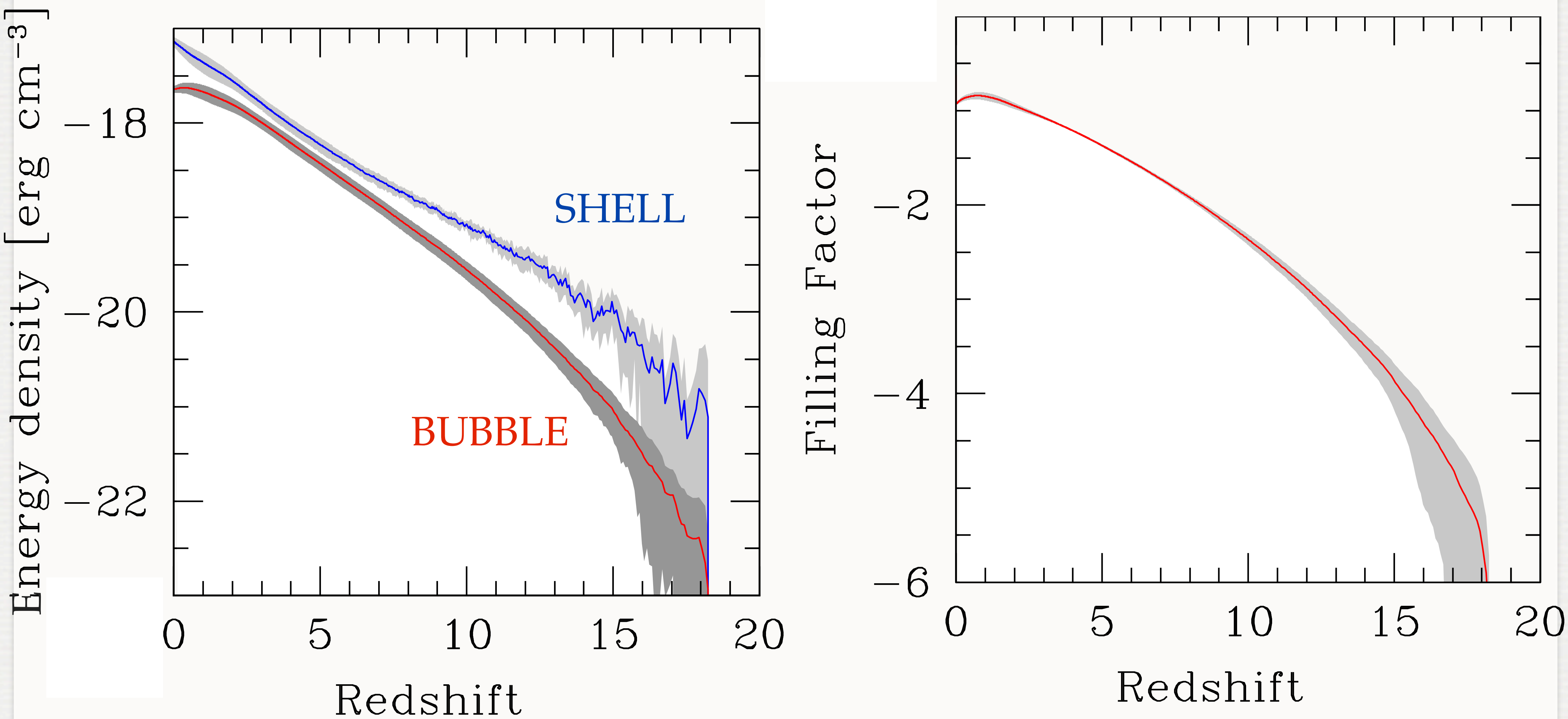
$$\frac{dE_b}{dt} = L(t) - 4\pi R_s^2 P_b \dot{R}_s - V_s \bar{n}_{\mathrm{H},b}^2 \Lambda(\overline{T}_b) \,,$$

Most of the swept-up mass, both in the early adiabatic and in the following radiative phases, is concentrated in a dense **shell** bounding the hot over-pressurized interior:

$$\frac{\mathrm{d}M_s}{\mathrm{d}t} = \dot{M}_w + 4\pi \rho R_s^2 \frac{\mathrm{d}R_s}{\mathrm{d}t}$$

Madau et al. 2001; Bertone et al. 2005; Samui et al. 2008

Galactic Outflow Evolution



Turbulence Evolution

The equation governing the evolution of the turbulent spectrum:

$$\frac{\partial}{\partial t}\int_0^k \mathrm{d}k'\mathcal{E}(k',t) =$$

$$\int_0^k \mathrm{d}k' F(k',t) - 2\nu \int_0^k \mathrm{d}k' k'^2 \mathcal{E}(k',t) + \int_0^k \mathrm{d}k' \mathcal{S}(k',t)$$

transfer function **dissipation** **source**

$$\int_0^k \mathrm{d}k' F(k',t) = -\alpha \mathcal{E}^{3/2}(k,t) k^{5/2}$$

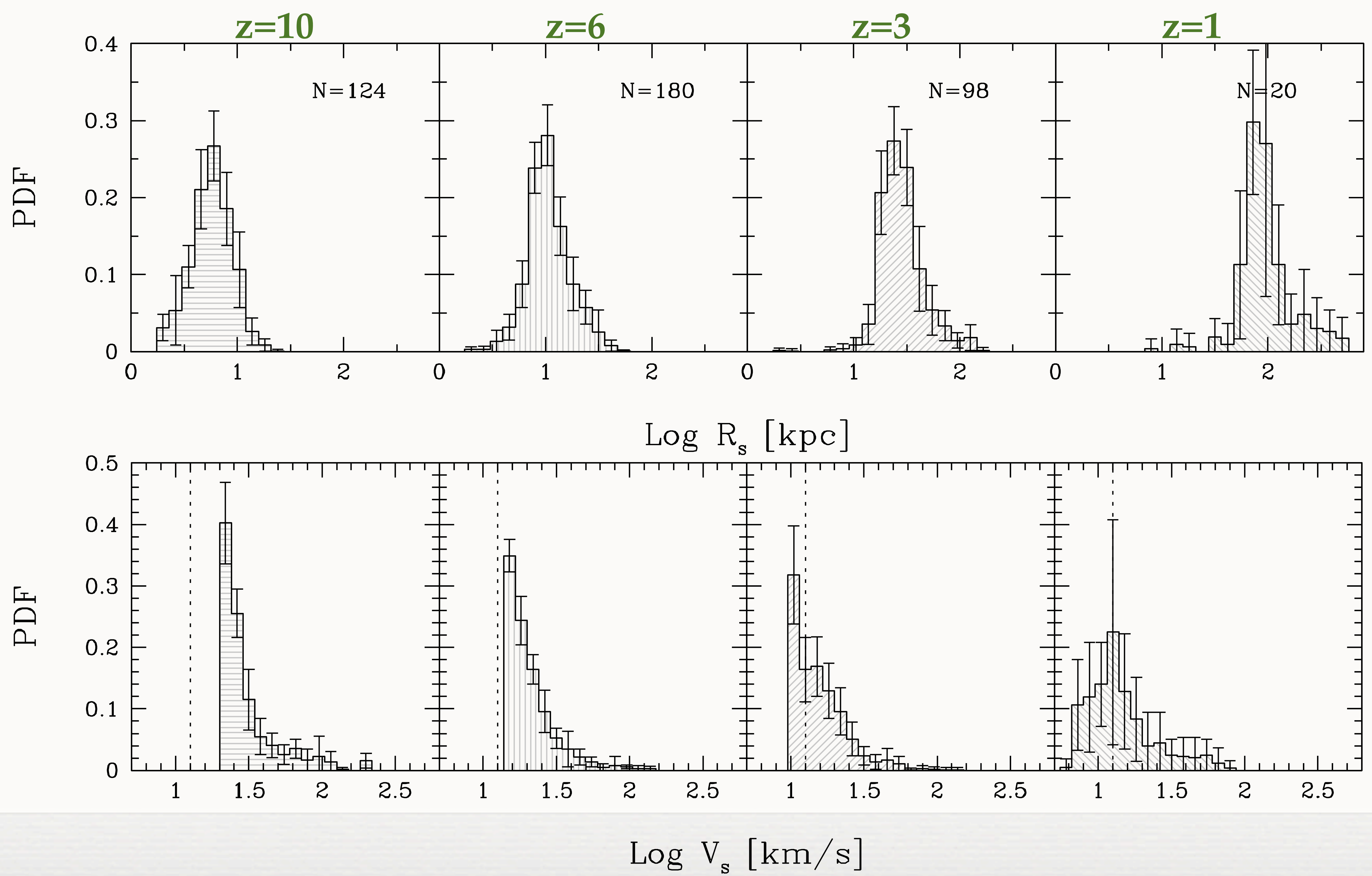
$$\frac{\partial}{\partial t}\mathcal{E}(k,t) = -\alpha \frac{\partial}{\partial k}\left[\mathcal{E}(k,t)^{3/2} k^{5/2}\right] - 2\nu k^2 \mathcal{E}(k,t) + \mathcal{S}(k,t)$$

Kovasznay, 1948

RESULTS

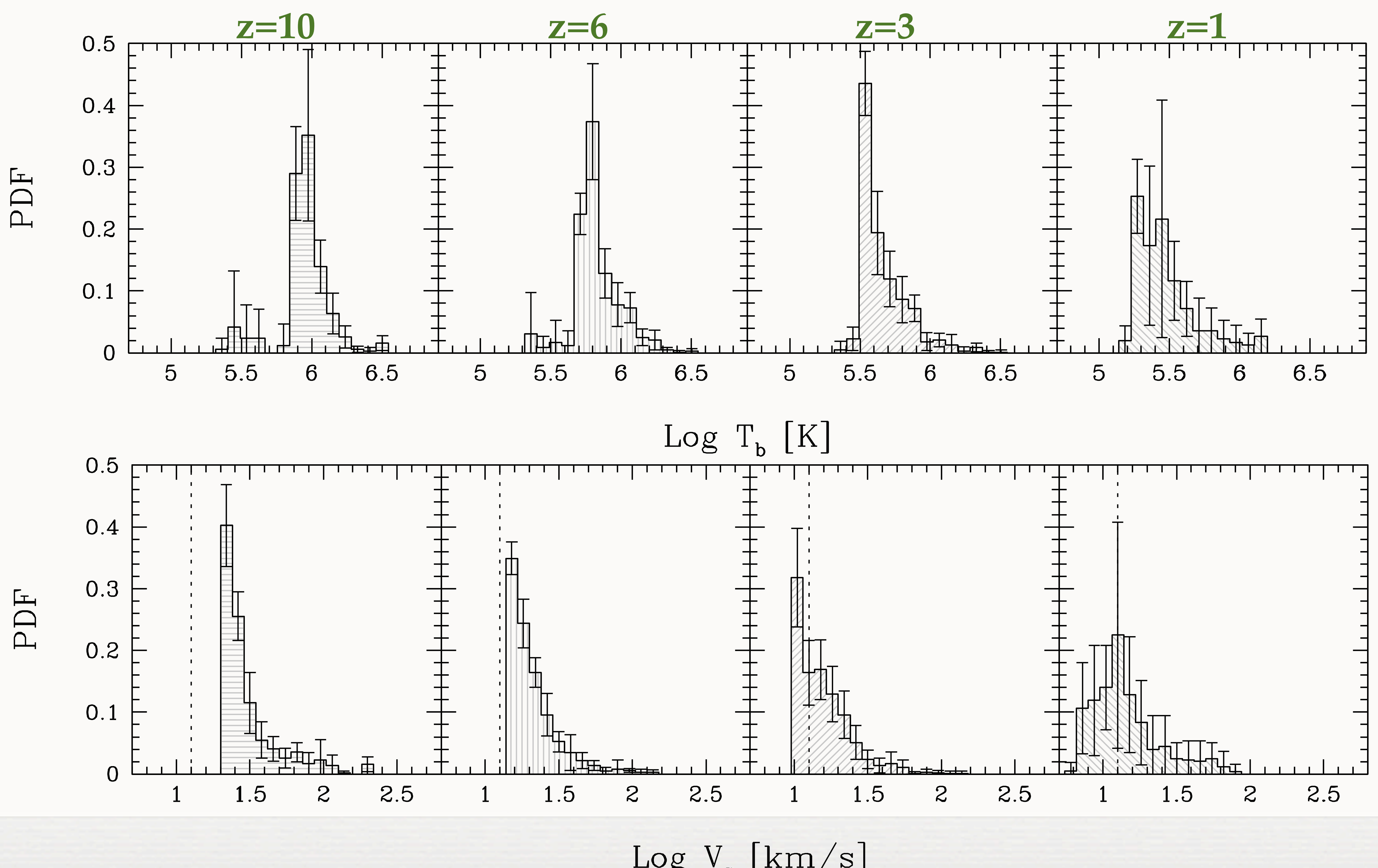
Galactic Outflow Evolution

The MW Progenitors

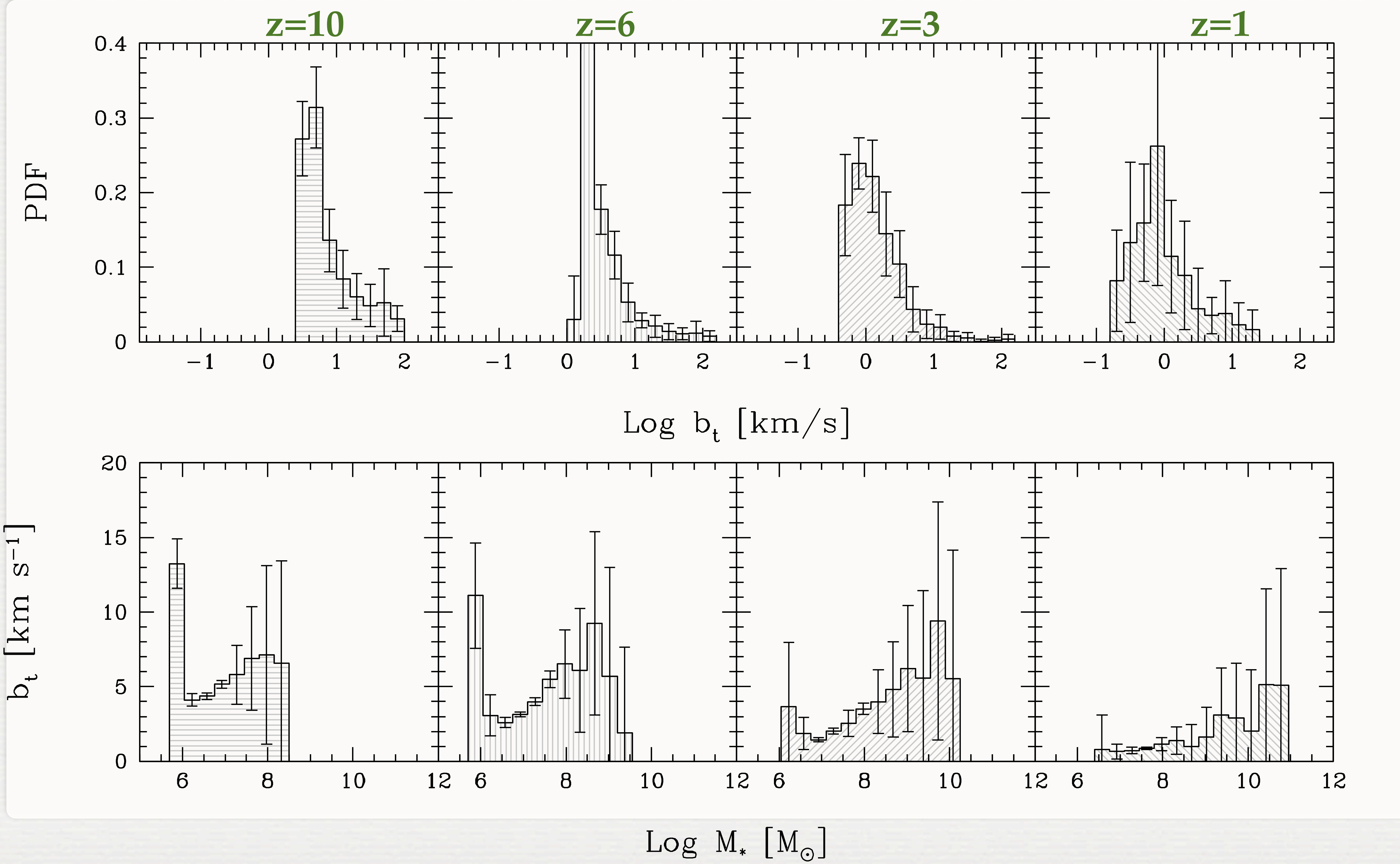


Galactic Outflow Evolution

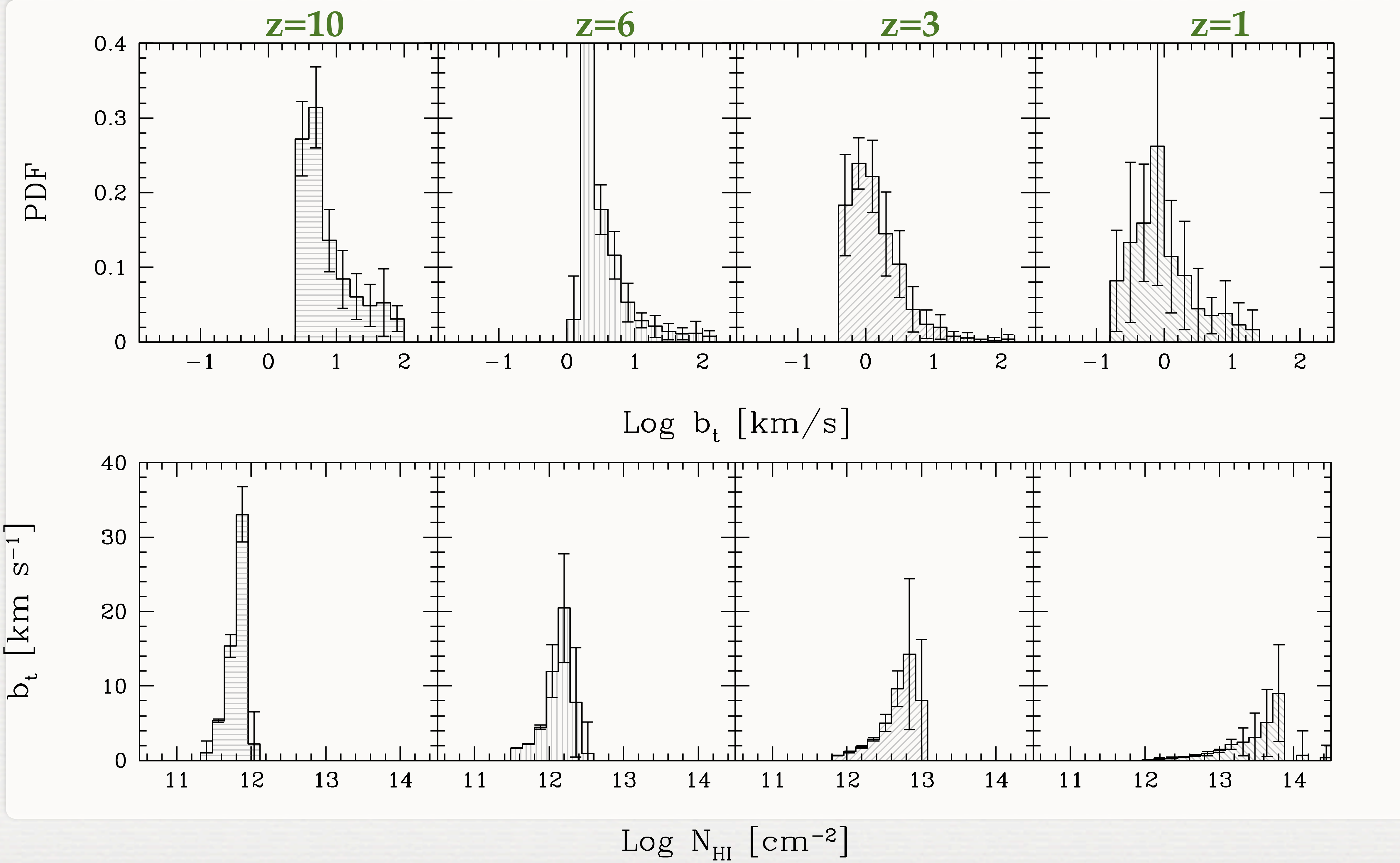
The MW Progenitors



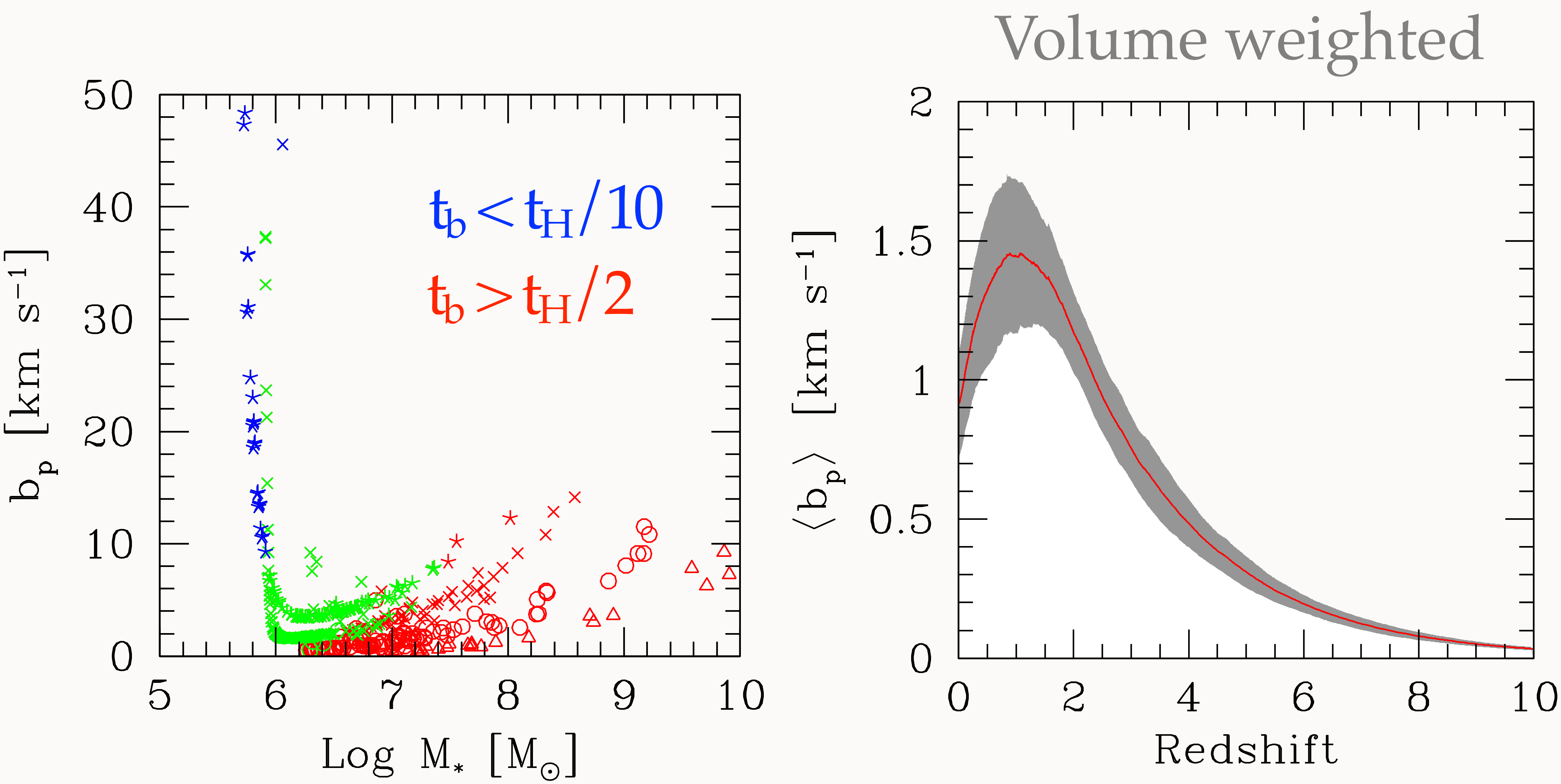
Turbulence Evolution



Turbulence Evolution



Doppler Parameter: Mass Dependence and Evolution



CONCLUSIONS

Conclusions

- Following the turbulence cascade and its dissipation over cosmological time-scales could give us some important hints about galaxies evolution and **galaxy-IGM interactions**.
- Turbulence can possibly reconcile the discrepancy between the observed Doppler parameters and those predicted by theoretical modeling of Lyα forest.
- Dedicated observations will be necessary to test the scenario.