Elliptical Galaxy M87 ***Credit:*** *Anglo-Australian Telescope photograph by David Malin*

Angular Momentum in ETGs and LTGs

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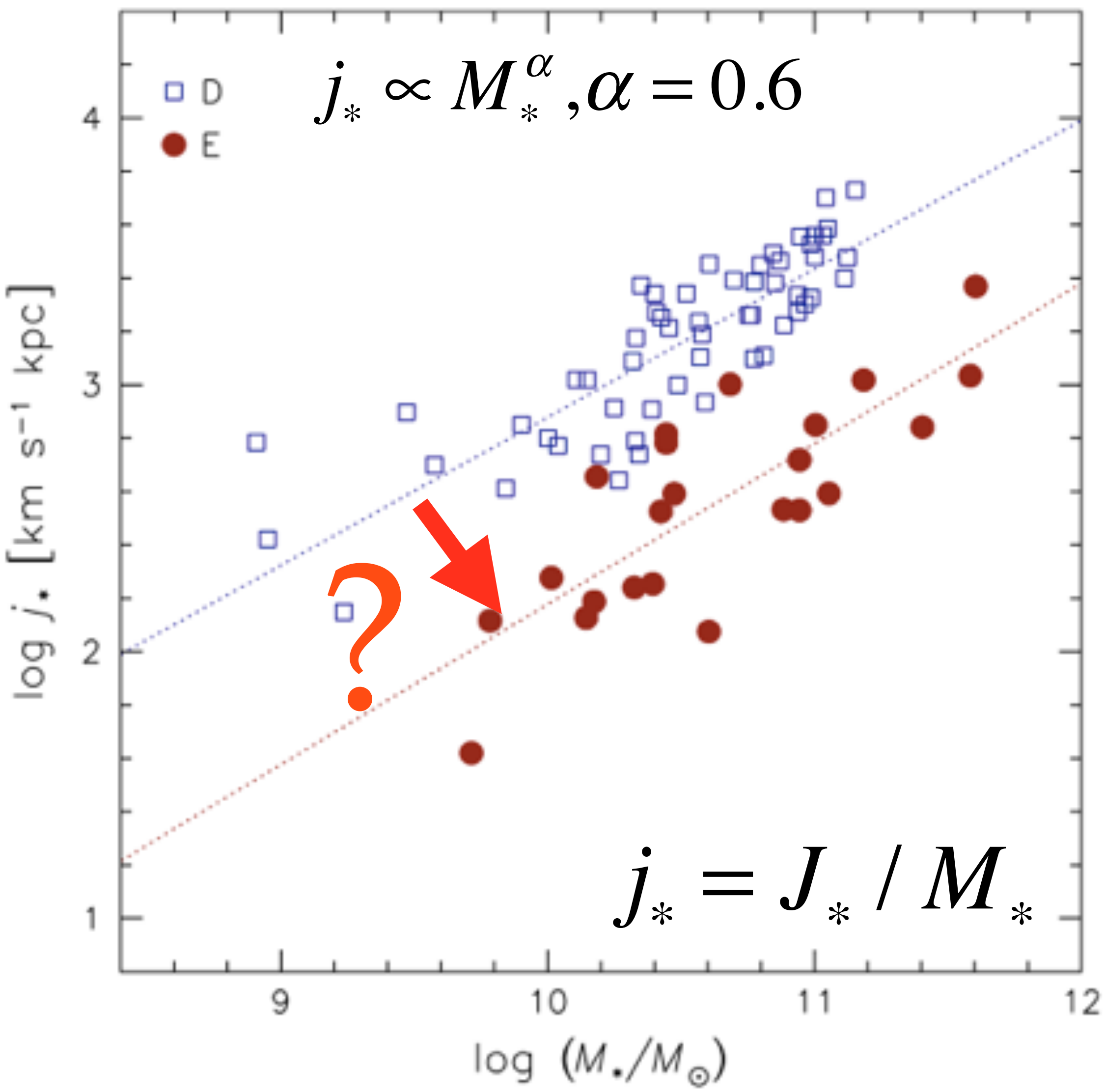
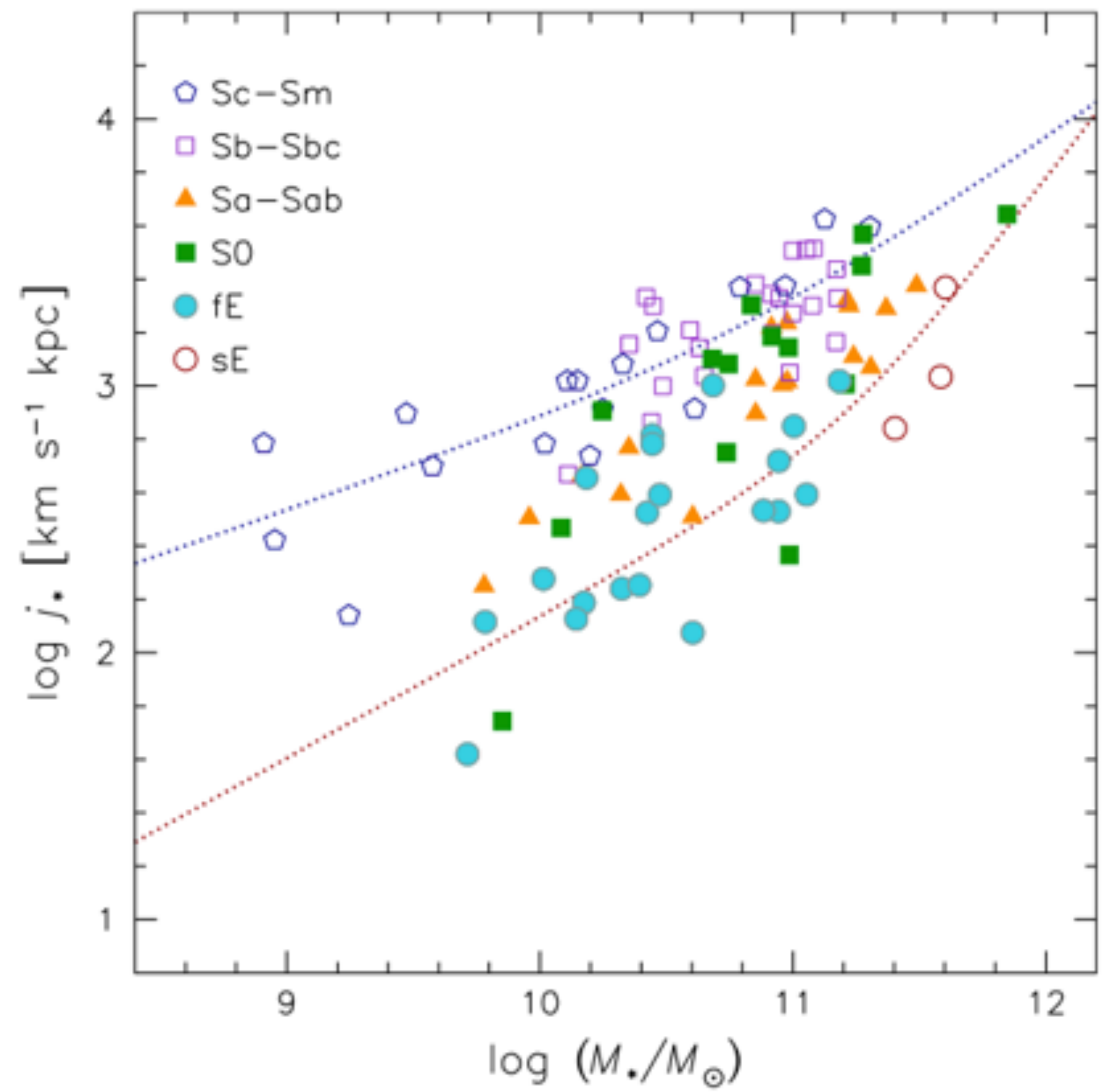
J. Shi, A. Lapi, C. Mancuso, H. Wang, L. Danese, 2017, ApJ, 843, 105

Summary of current observational properties of ETGs and LTGs

- **stellar population**: ETG - little SF now, relatively simple stellar population; LTG - significant ongoing SF now, multiple stellar population
- **metallicity**: high metallicity for ETG and low metallicity for LTG
- **alpha elements:** high [alpha/Fe] value for ETG(Thomas et. al 2005)
- **SFH**: ETG - SF happened at high-z in a short period and LTG - SF declines exponentially as a function of time
- **feedback**: SN feedback and AGN feedback(mostly in massive elliptical)

Stellar mass - Specific angular momentum





Fall & Romanowsky 2013

How do galaxies get the angular momentum?

Classic disc formation picture

- Angular momentum originates from LSS tidal torques
- Gas and dark matter are well mixed initially, with the same specific angular momentum
- Conservation of specific angular momentum during baryons collapse
- Baryon infall fraction $m_d / m_{b,i} \sim 1$

Formation of spheroids?

- Mergers of galaxies (Toomre 1977)
- Internal secular processes in the disc (Kormendy & Kennicutt 2004)
- Continuous gas infall with misaligned angular momenta (Sales et al. 2012)

Illuminations from chemical abundance

Halo

$$\lambda = \frac{J\,|E|^{1/2}}{GM^{5/2}}$$

$$j_{vir} = 4.2\times10^{4}\,\lambda\left(\frac{M_{vir}}{10^{12}}\right)^{2/3}\left(\frac{H(z)}{H_0}\right)^{1/3}$$

$$j(<r) = j_{vir}\left[\frac{M(<r)}{M_{vir}}\right]^{s}$$

$$j_b(<r) = j_{DM}(<r)$$

Galaxy

$$f_{\inf} \equiv \frac{M_{\inf}}{f_b M_{vir}}$$

$$j_{\inf} = j_{vir} f_{\inf}^{s}$$

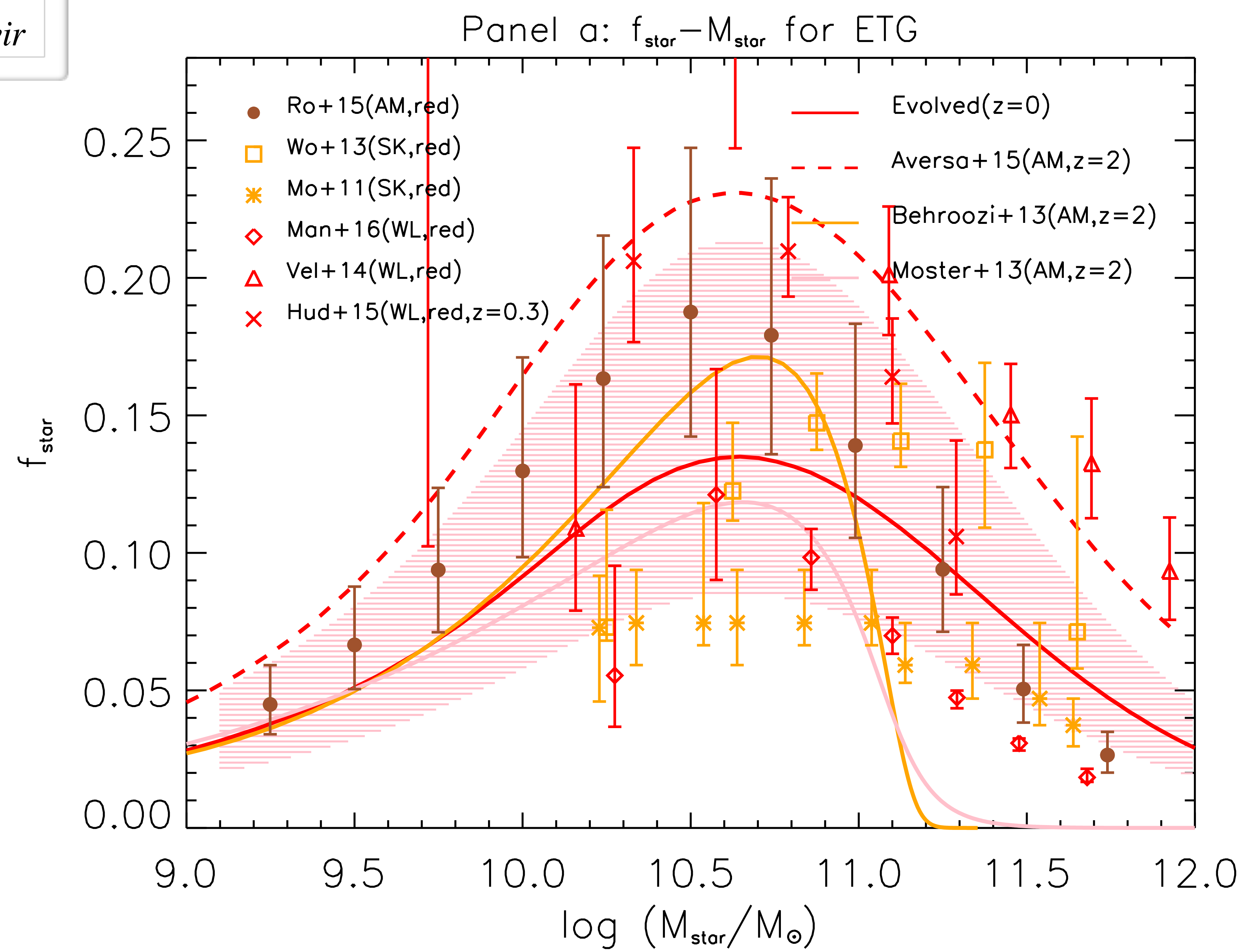
$$j_* = f_j\, j_{\inf}$$

$$f_{\inf} = f_*\left(\frac{y_z}{\zeta <z_*>} - \frac{M_{z,gal}}{\zeta <z_*> M_*} + \frac{M_{gal}}{M_*}\right)$$

$$f_* = \frac{M_*}{f_b M_{vir}},\quad f_b = \frac{\Omega_b}{\Omega_m}$$

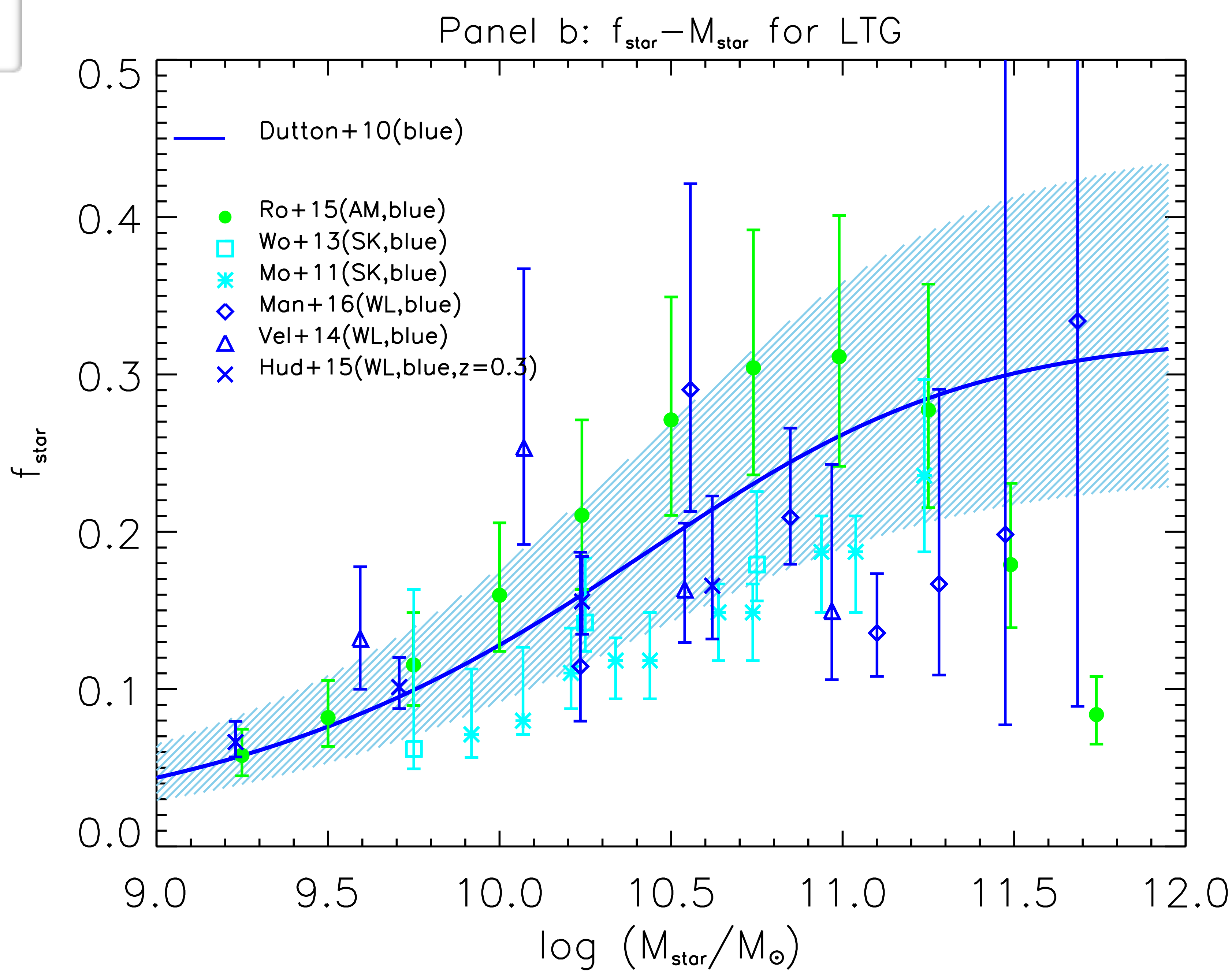
Star Formation Efficiency-ETGs

$$f_* = \frac{M_*}{f_b M_{vir}}$$

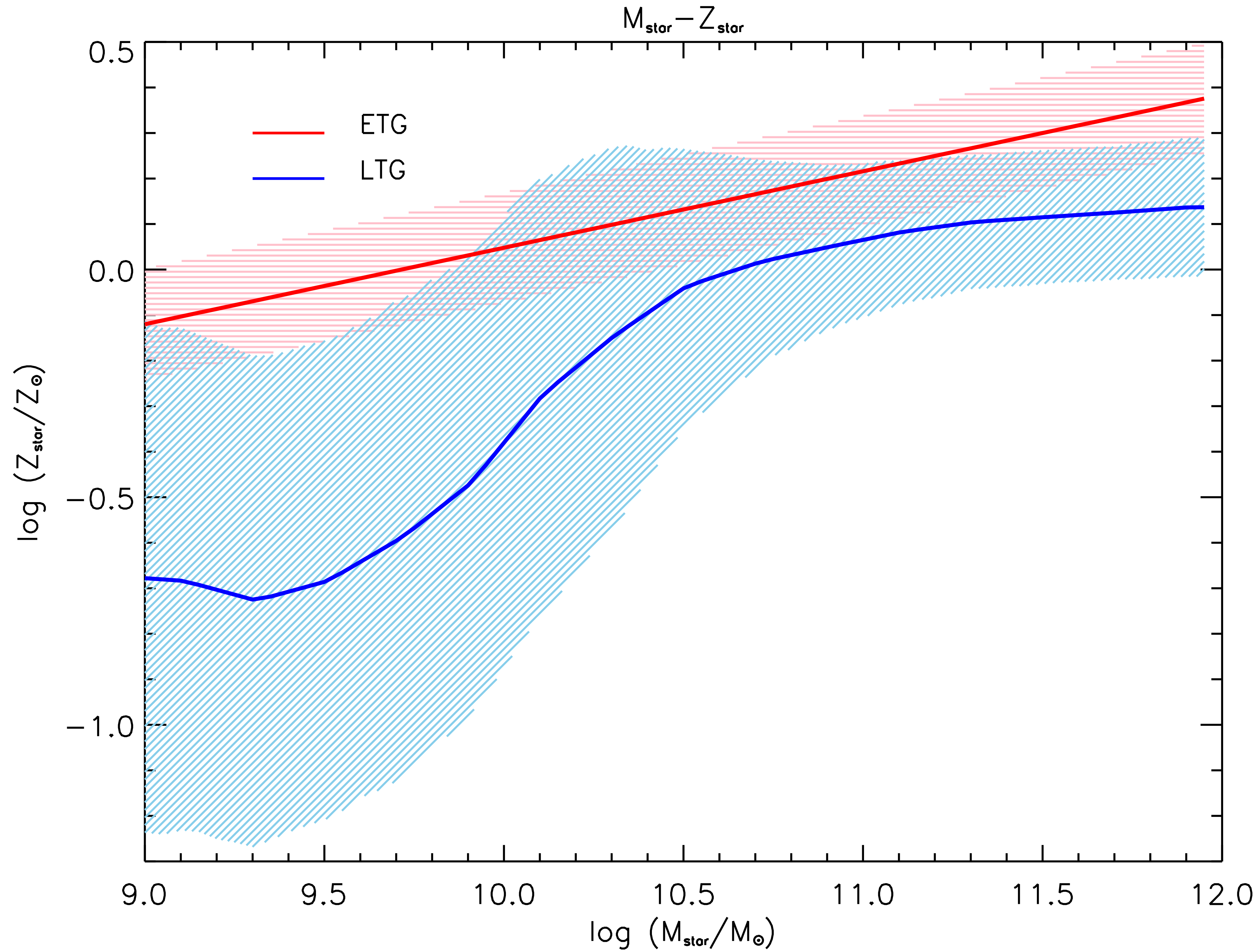


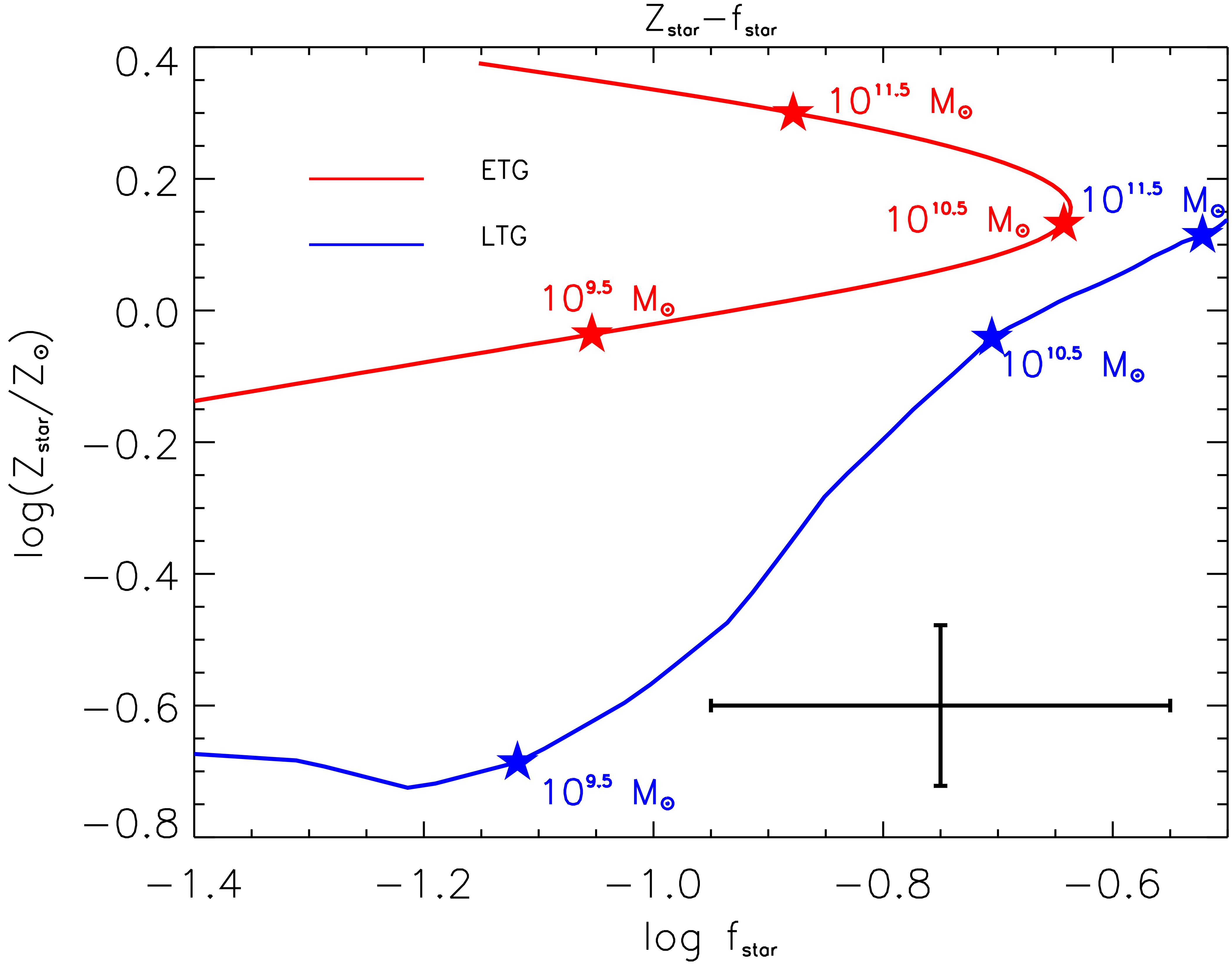
Star Formation Efficiency-LTGs

$$f_* = \frac{M_*}{f_b M_{vir}}$$



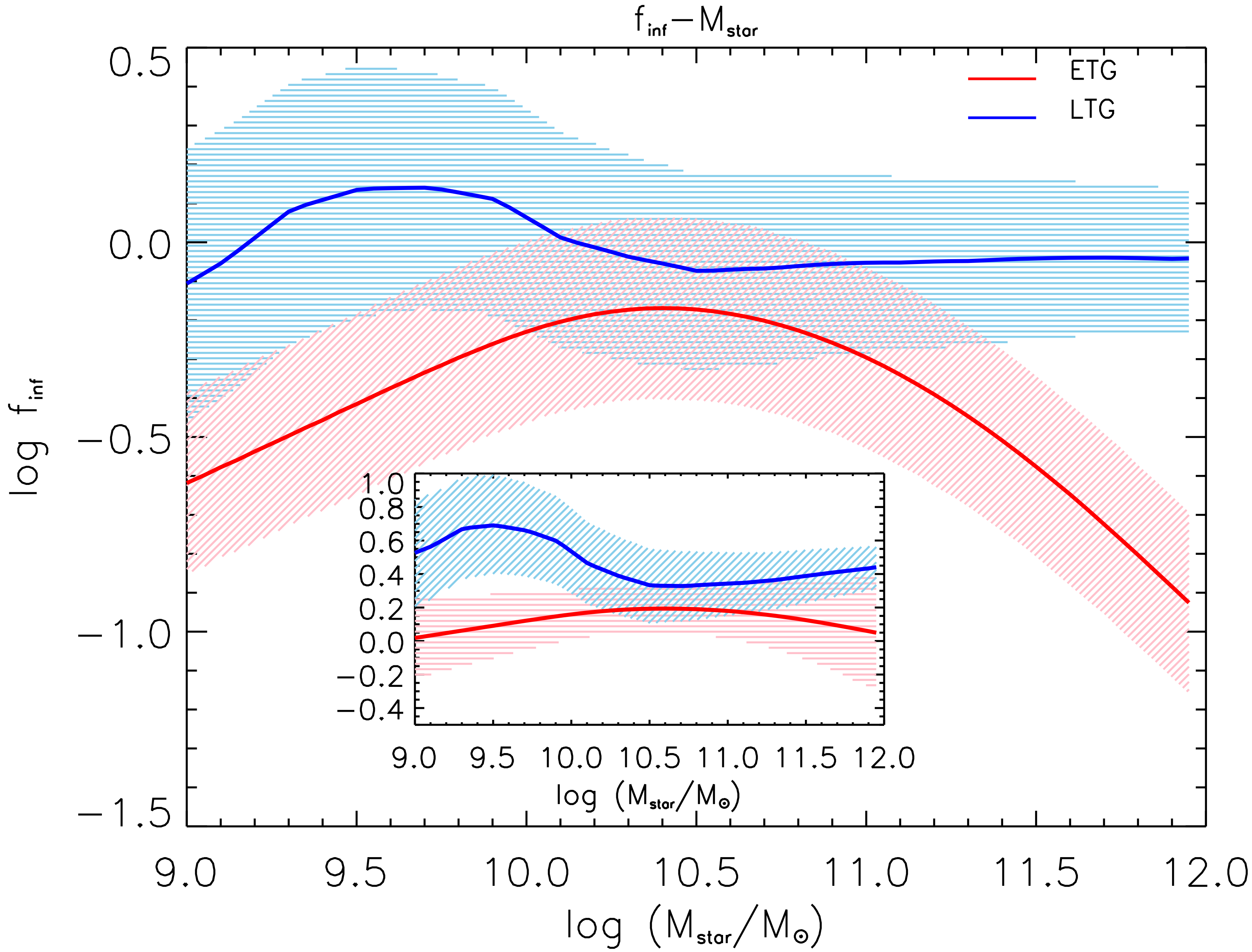
Stellar mass vs. stellar metallicity





Z_star − f_star
ETG
LTG
10^11.5 M⊙
10^10.5 M⊙
10^9.5 M⊙
10^11.5 M⊙
10^10.5 M⊙
10^9.5 M⊙
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
log(Z_star/Z⊙)
−1.4
−1.2
−1.0
−0.8
−0.6
log f_star

Baryon Infall Fraction



$$f_{\mathrm{inf}} = f_{*}\left(\frac{y_z}{\zeta < z_{*} >} - \frac{M_{z,gal}}{\zeta < z_{*} > M_{*}} + \frac{M_{gal}}{M_{*}}\right)$$

Illuminations from chemical abundance

Halo

$$\lambda = \frac{J\,|E|^{1/2}}{GM^{5/2}}$$

$$j_{vir} = 4.2\times 10^4 \lambda \left(\frac{M_{vir}}{10^{12}}\right)^{2/3} \left(\frac{H(z)}{H_0}\right)^{1/3}$$

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Galaxy

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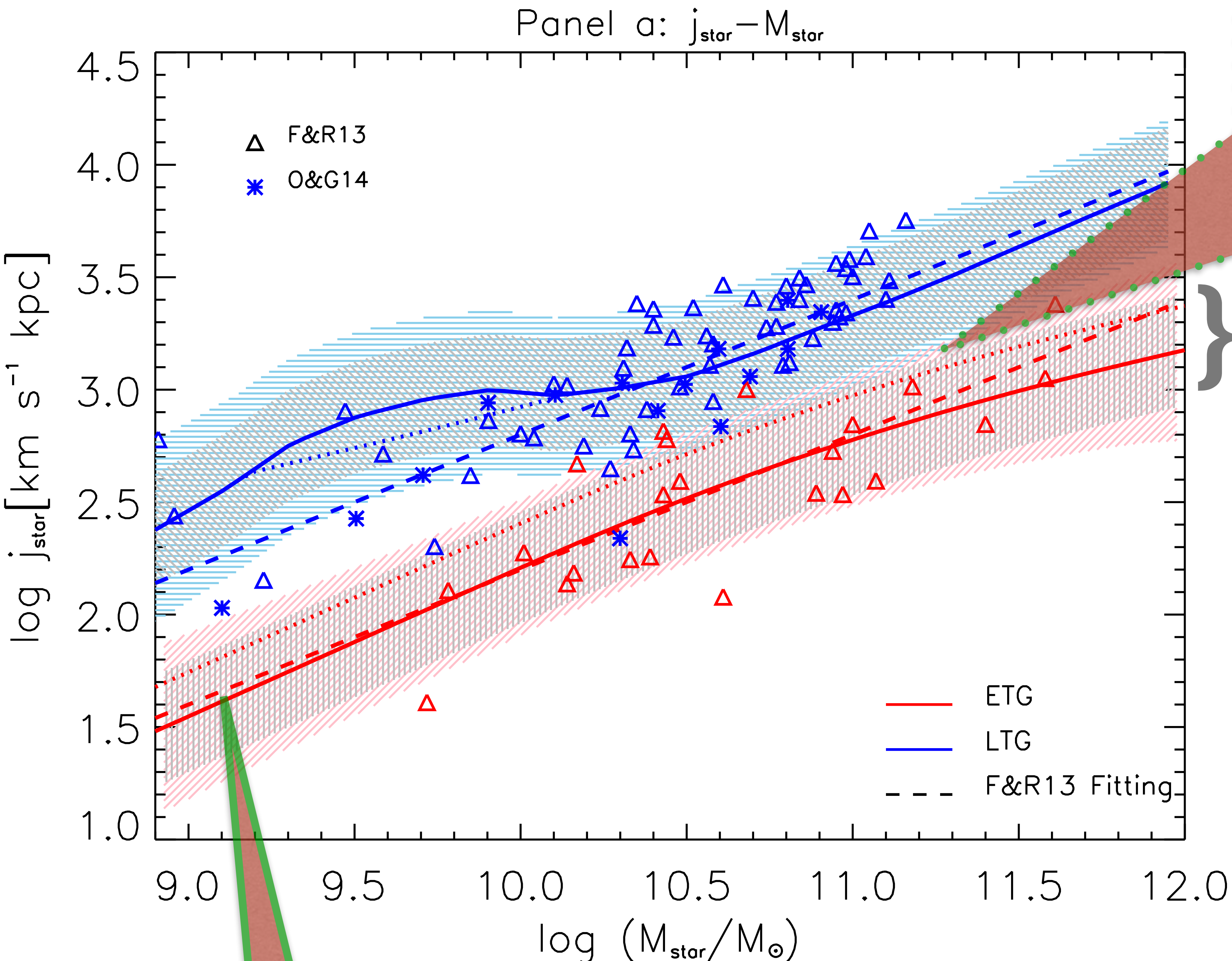
$$j_* = f_j j_{\inf}$$

$$f_{\inf} = f_*\left(\frac{y_z}{\zeta < z_* >} - \frac{M_{z,gal}}{\zeta < z_* > M_*} + \frac{M_{gal}}{M_*}\right)$$

$$f_* = \frac{M_*}{f_b M_{vir}}, f_b = \frac{\Omega_b}{\Omega_m}$$

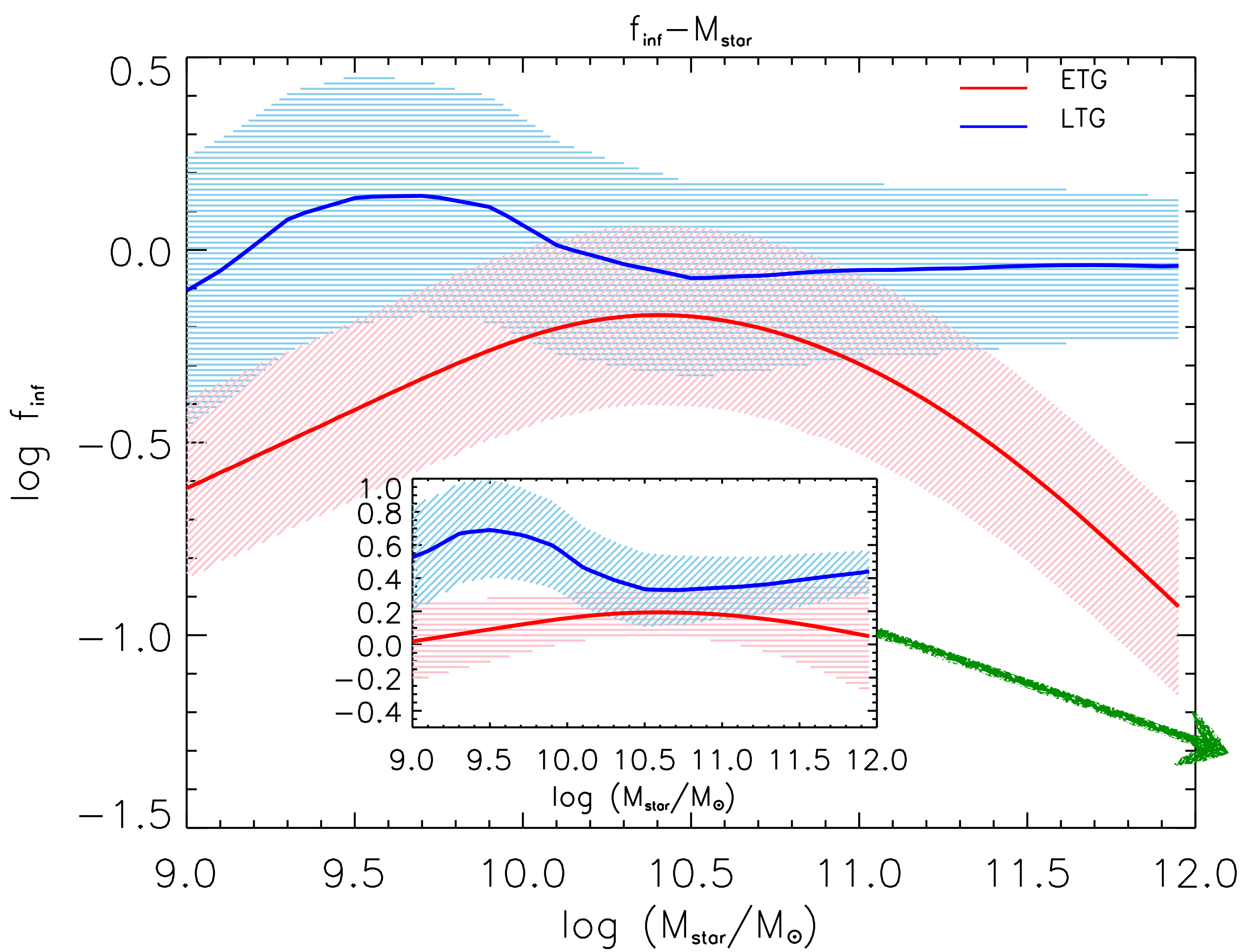
Stellar mass - Specific angular momentum



dry merger driven mass growth and retention fraction of 1.

scatter of spin parameter only

dry merger driven mass growth and retention fraction of 0.64



$$y_Z f_\star^{-2/3+s} \; Z_\star^{-s} \; M_\star^{0.15}$$

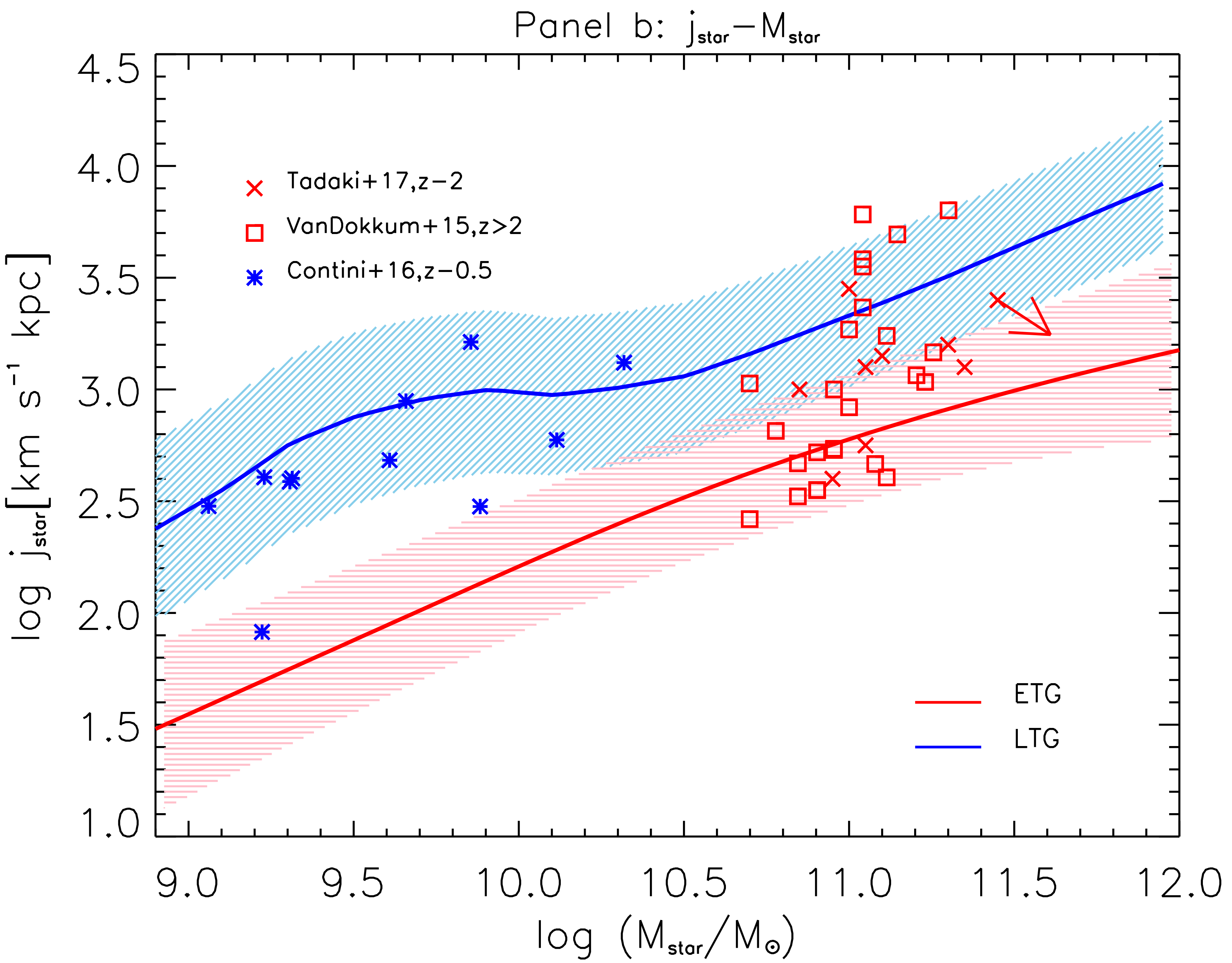
$$f_{\rm inf} = f_* \left(\frac{y_z}{\zeta < z_* >} - \frac{M_{z,gal}}{\zeta < z_* > M_*} + \frac{M_{gal}}{M_*} \right)$$

$$j_\star \propto \lambda f_j \, f_\star^{-2/3+s} \; Z_\star^{-s} M_\star^{2/3}$$

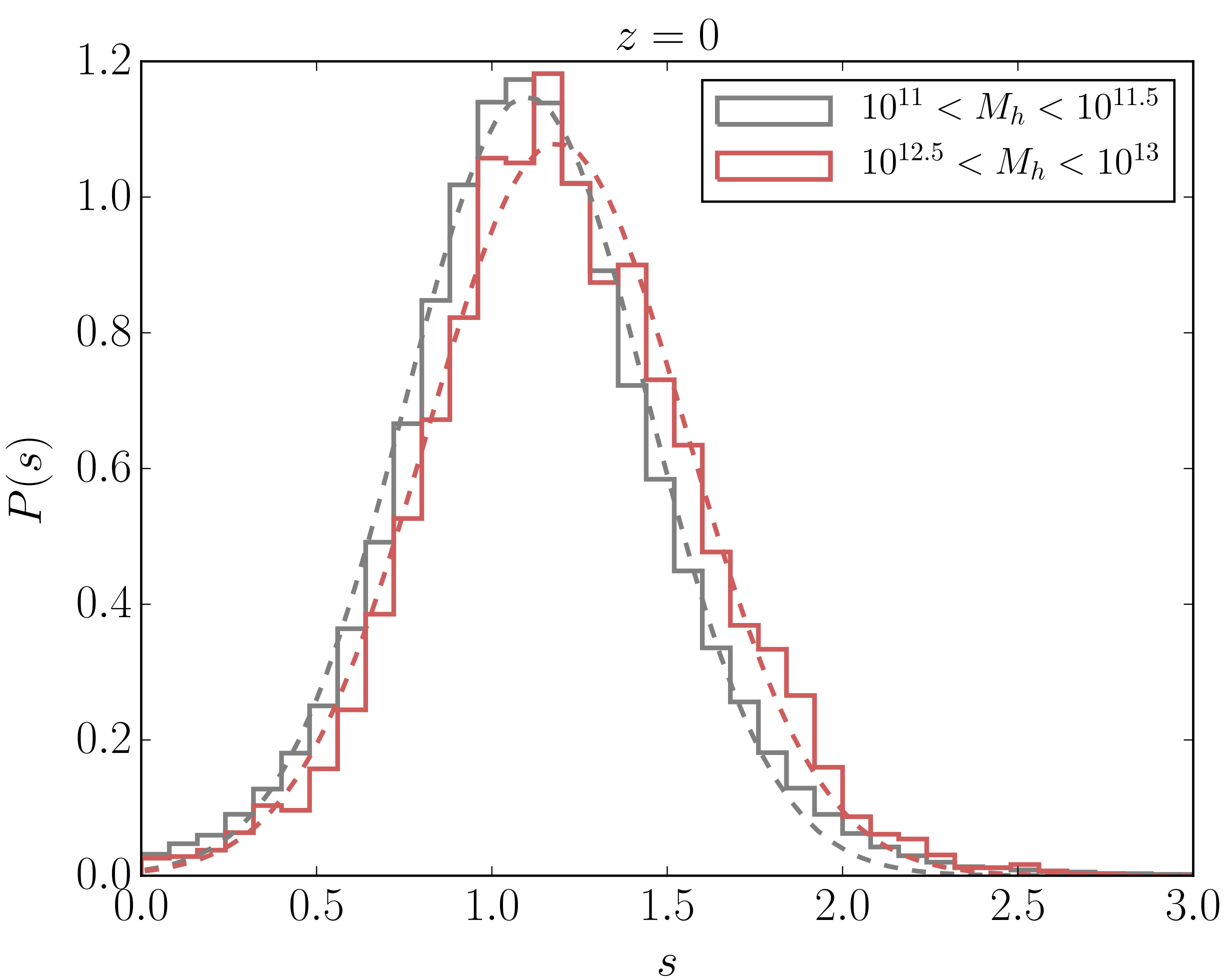
Summary

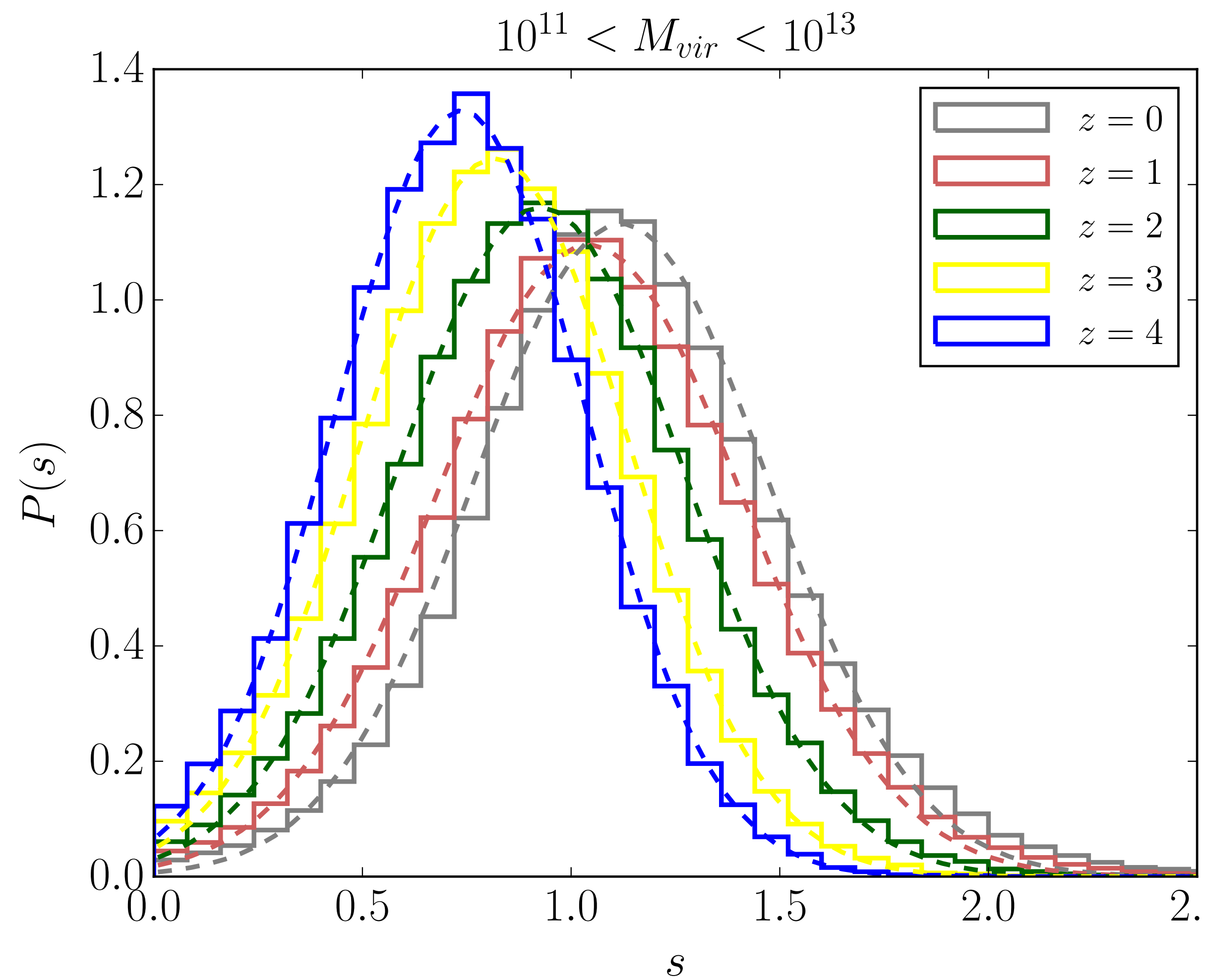
1. infall fraction $f_{\rm inf} \sim 1$ for LTGs and $f_{\rm inf} \sim 0.4$ for ETGs
2. the retention fractions $f_j \equiv j_\star / j_{\rm inf}$ are $f_j \approx 1.1^{+0.75}_{-0.44}$ for LTGs, $f_j \approx 0.64^{+0.2}_{-0.16}$ for ETGs
3. $f_\star$ and $Z_\star$ conspire to make $j_\star \propto f_\star^{-2/3+s} Z_\star^{-s}$ weakly dependent on the $M_\star$, with an overall shape close to $j_\star \propto M_\star^{2/3}$
4. the scatter in the observed $j_\star$ vs. $M_\star$ relationship for ETGs and LTGs mainly comes from the intrinsic variance in the halo spin parameter λ
5. our results suggest biased collapse plus mergers scenario.

Stellar mass - Specific angular momentum



$$j(<r) \propto M(<r)^s$$

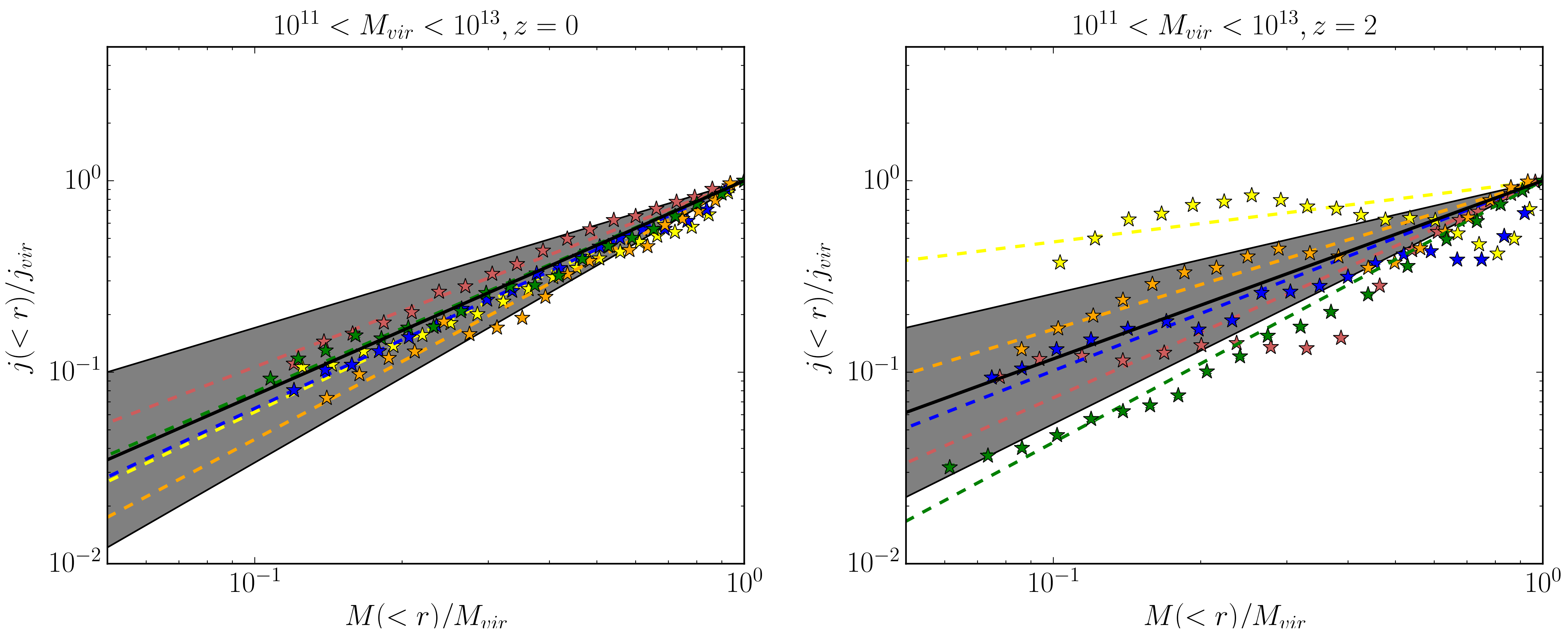




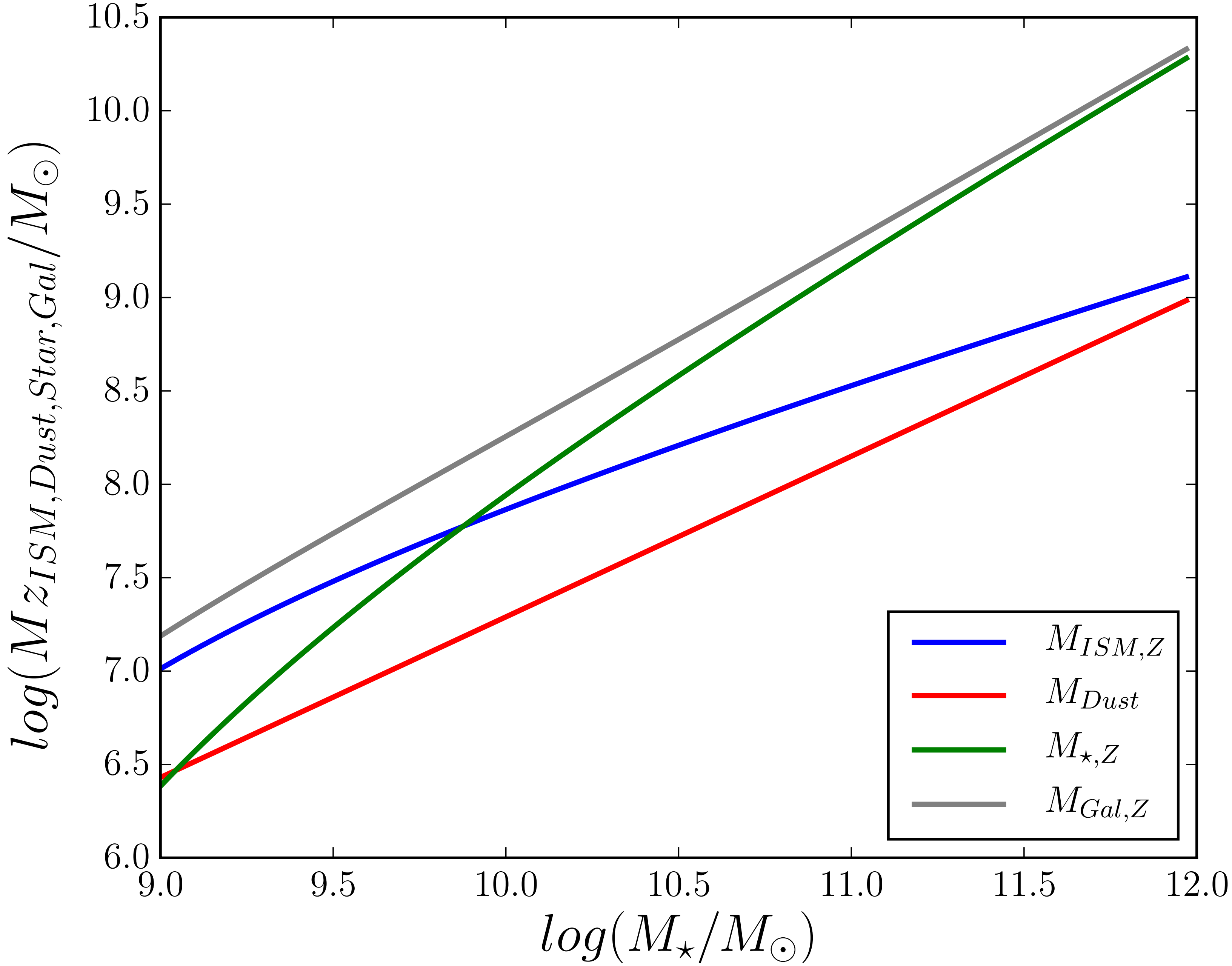
$$s = 1.3 \pm 0.3$$

Bullock et. al 2001

$$j(<r) \propto M(<r)^s$$



Metal budget in LTGs



Peeples et al 2014