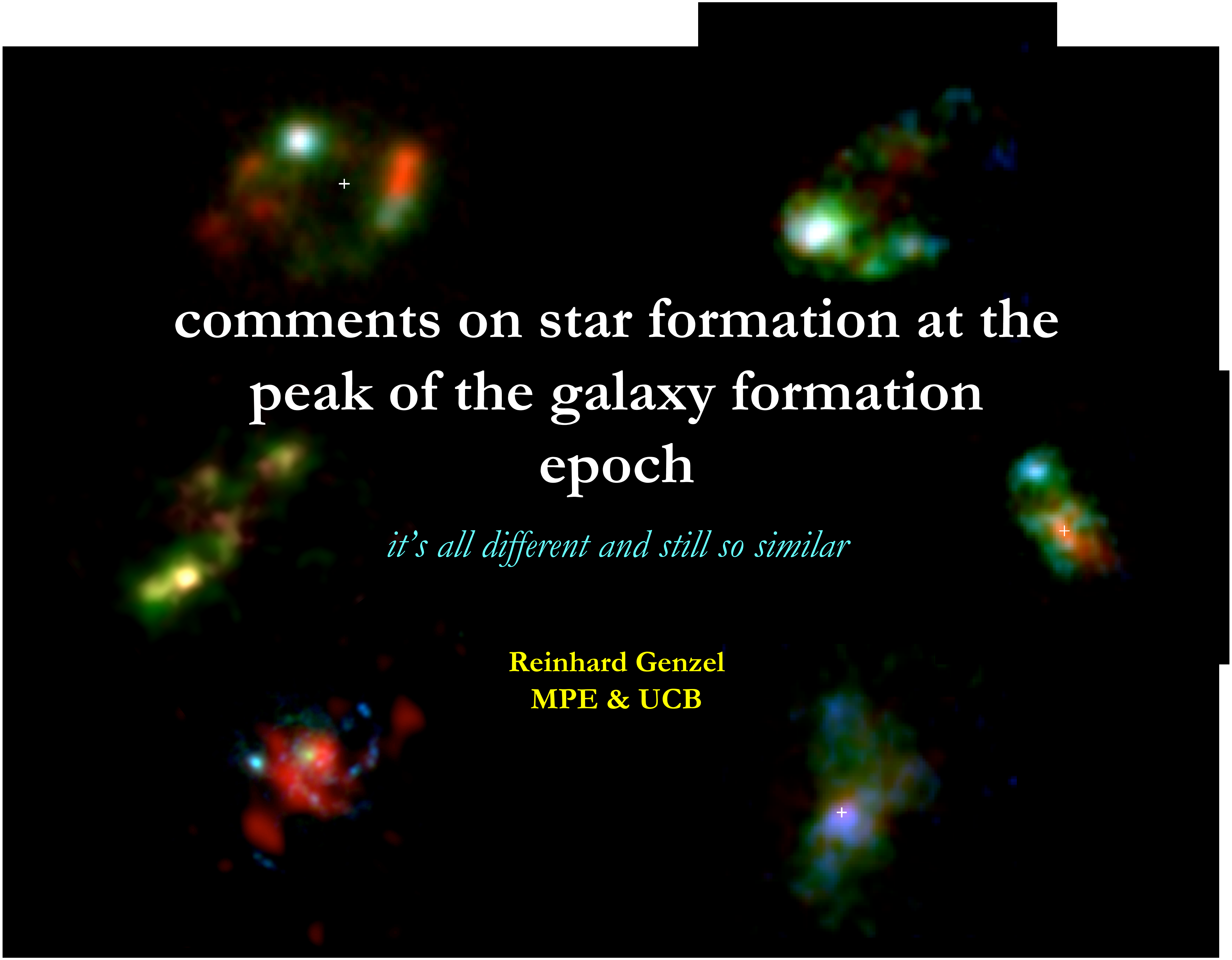
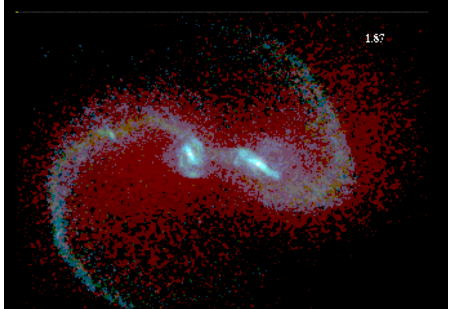


comments on star formation at the peak of the galaxy formation epoch

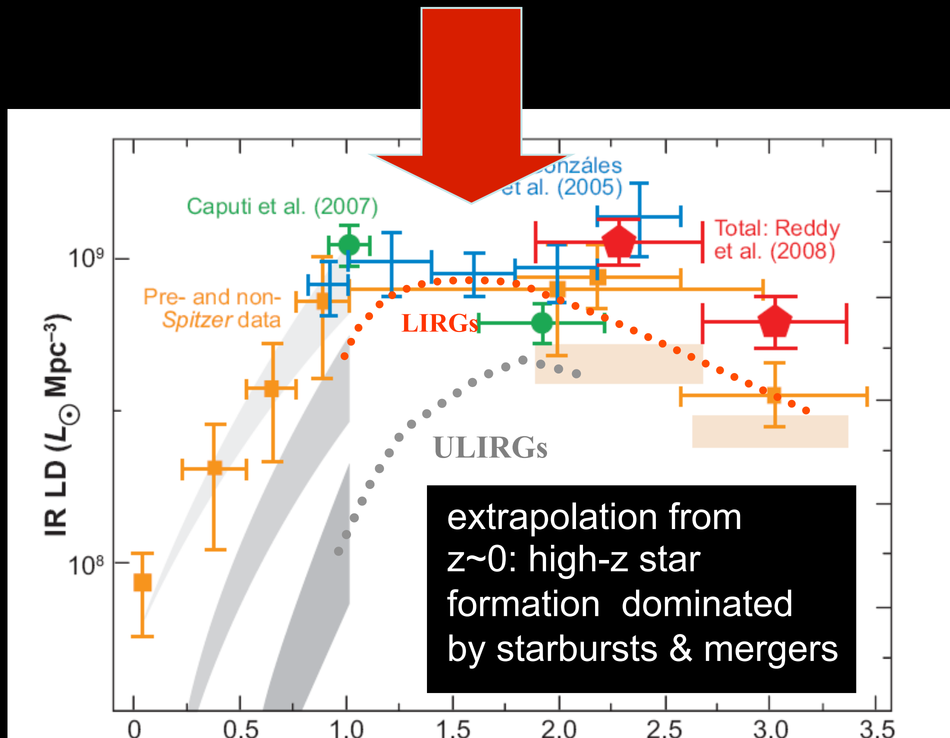
it's all different and still so similar

Reinhard Genzel
MPE & UCB

star formation and feedback at the peak of the galaxy formation epoch

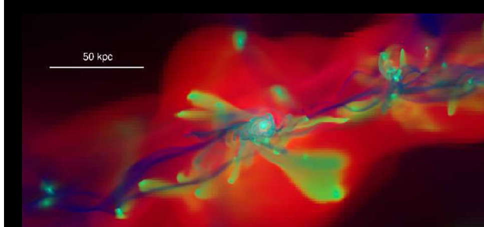


(major) mergers & starbursts



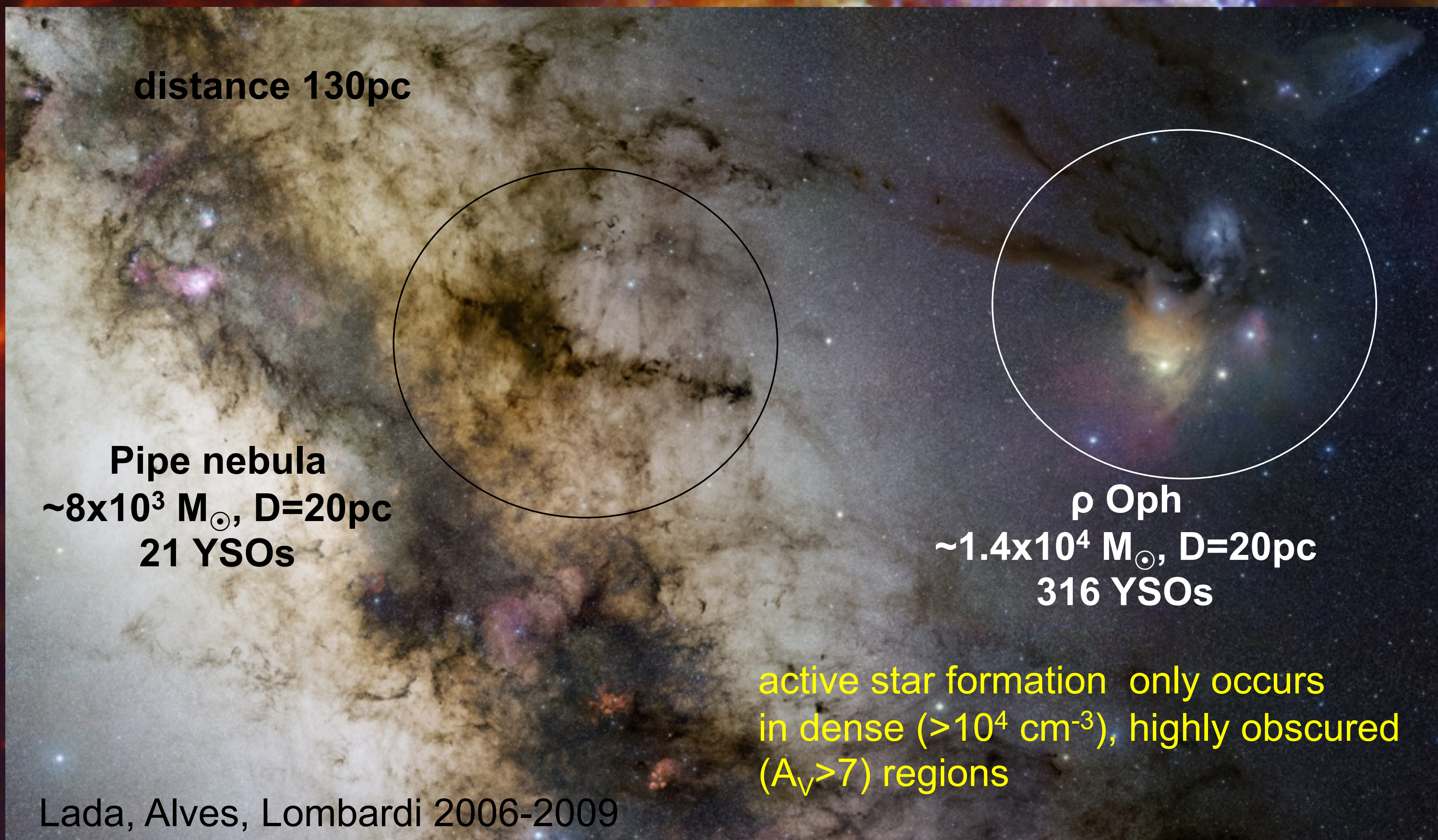
Soifer et al. 2008

continuous accretion from halo & disk instabilities



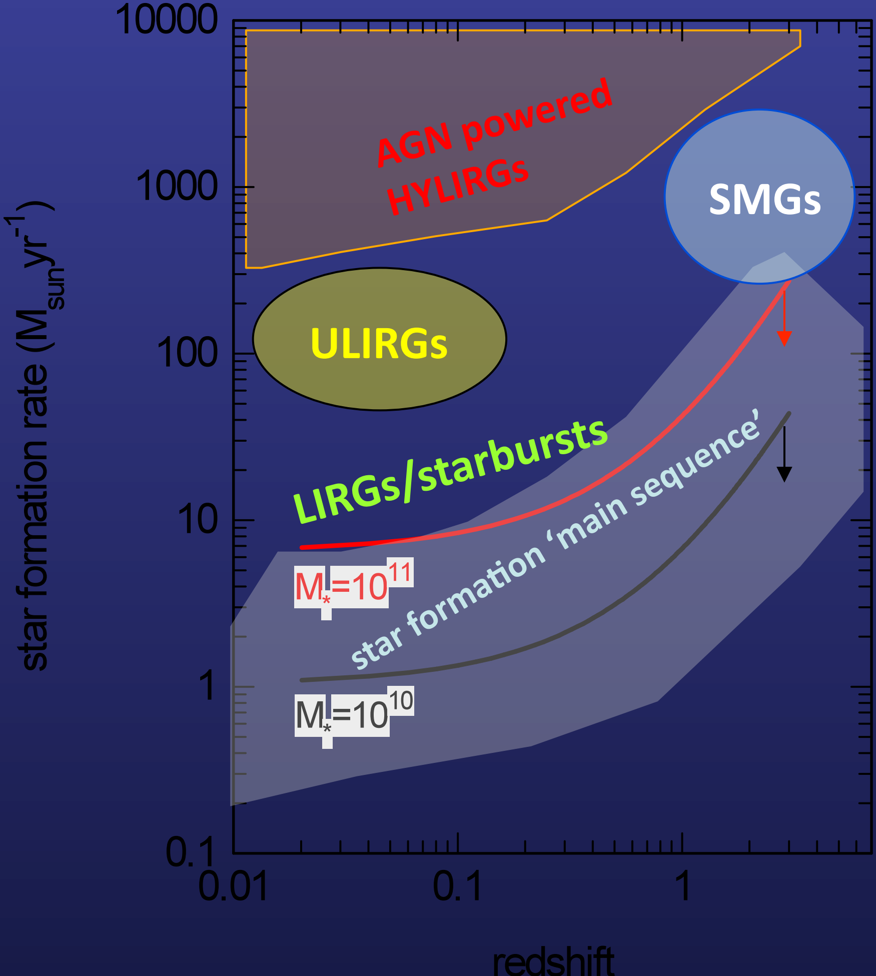
Lilly et al. 1996, Steidel et al. 1996, Hopkins & Beacom 2006, Soifer et al. 2008, Rees & Ostriker 1977, Silk 1977, White & Rees 1978, Kauffmann et al. 1993, Steinmetz & Navarro 2003, Hernquist, Springel, di Matteo, Hopkins et al. 2003-2009, Robertson & Bullock 2008, Sanders & Mirabel 1996, Dekel & Birnboim 2003,2006, Keres et al. 2005, 2009, Nagamine et al. 2005, Davé 2007, Kitzbichler & White 2007, Naab et al. 2007, Governato et al. 2008, Ocvirk et al. 2008, Dekel et al. 2009, Agertz et al. 2009, Guo et al. 2009, Teyssier et al. 2010, Bournaud 2010, Davè et al. 2011a,b, Kauffmann et al. 2010

star formation in z~0 disk galaxies is inefficient & occurs in dense, extincted gas

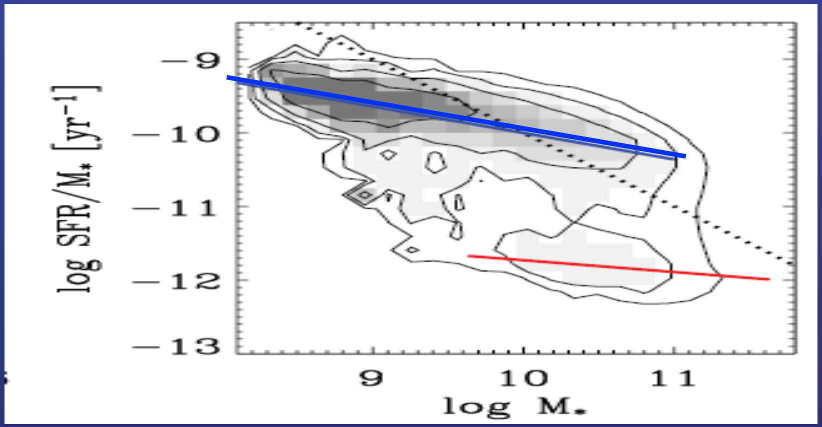


Rosetta cluster GMC: PACS & SPIRE

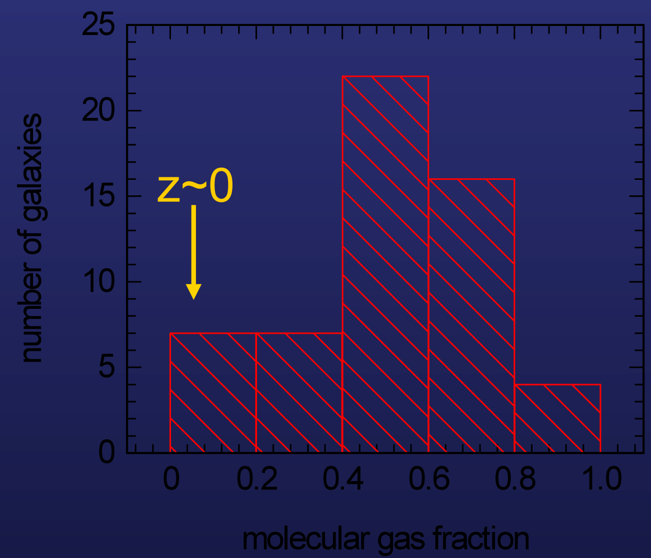
star formation rates across cosmic time



Noeske +07, Daddi+07, Elbaz+07

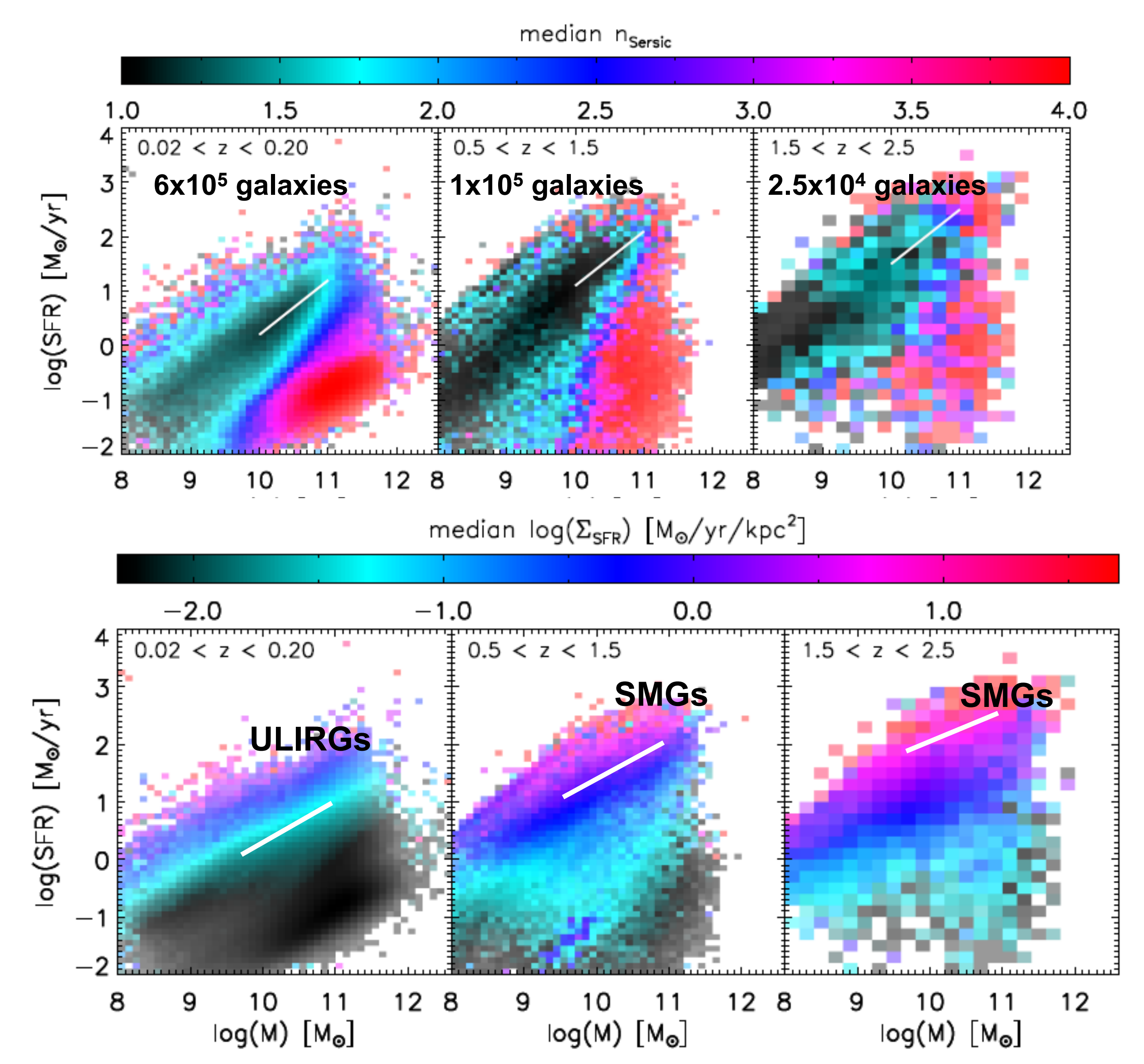


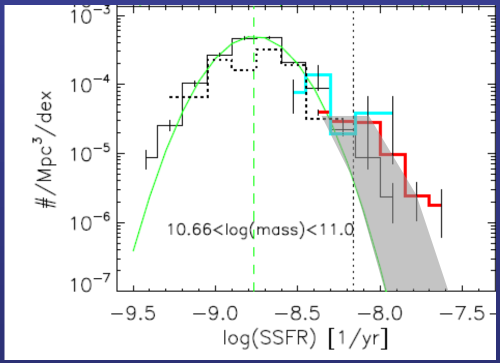
SDSS: Schiminovich et al. 2007



Tacconi, Daddi et al. 2010, 2011

galaxies on 'star forming (main) sequence' are disks with $\Sigma_{\text{star form}}$ & n_{Sersic} increasing above sequence





Rodighiero et al. 2011 (PEP):
off-ms galaxies account for ~10% of cosmic star formation at z~2

Wuyts et al. 2011 (PEP):
SDSS/GALEX,
COSMOS,GOODS

Galactic star formation in equilibrium with cosmic accretion

$$\propto M_{halo}^{1.1}\left(1+z\right)^{2.3} \qquad\qquad \dot{M}_{out} = \eta\,\dot{M}_{*}$$

$$\dot{M}_{gas} = \dot{M}_{gas,accretion} - (1-R)\,\dot{M}_{*} - \dot{M}_{out}$$

$$f_{gas} \sim 0.5\,\frac{\varepsilon_{acc}}{(1+\eta-R)}\,f_{baryon,0.18}\left(\frac{t_{depletion}}{1\,Gyr}\right)(1+z)_{3.2}^{\gamma} \quad \gamma > 0.8$$

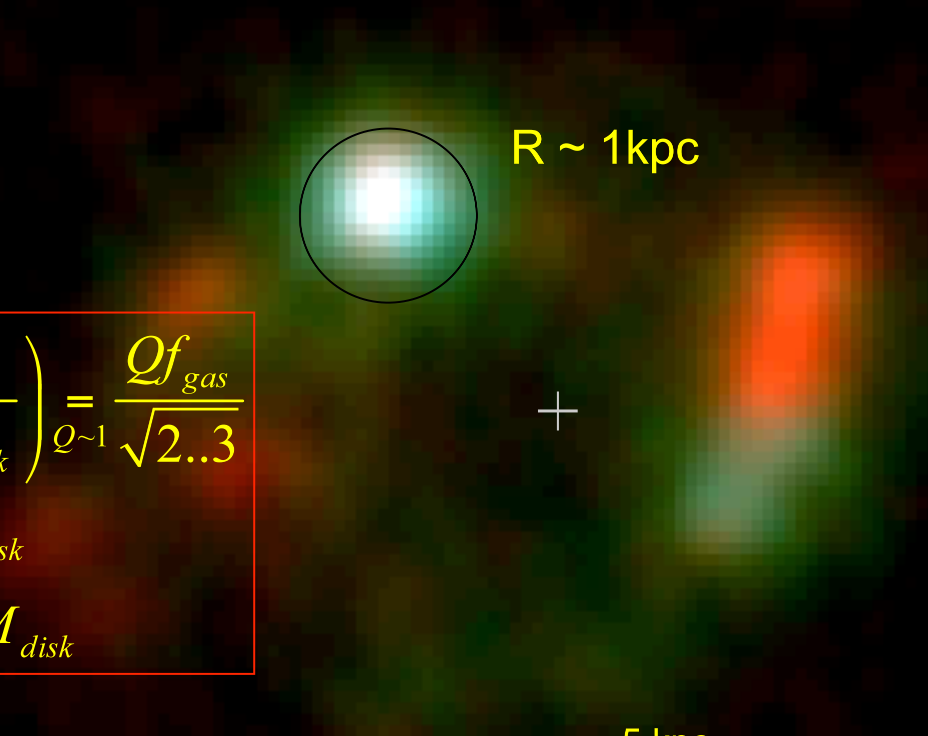
$$\dot{M}_{*} \sim 100\,\frac{\varepsilon_{acc}}{(1+\eta-R)}\,f_{baryon,0.18}\,\mathrm{M}_{*,11}(1+\mathrm{z})_{3.2}^{2.7} \quad \mathrm{M}_{\odot}\,yr^{-1}$$

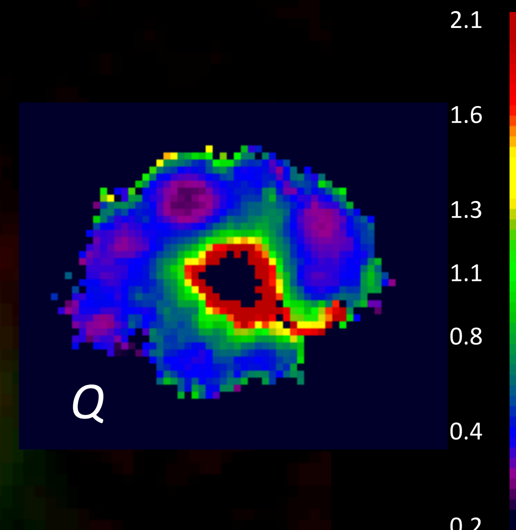
$\varepsilon_{acc} \rightarrow 1$ requires low star formation efficiency

at earlier times, when $\mathrm{M}_{*} << 10^{11}\,M_{\odot}$

Kereš et al. 2005, 2009, Neistein et al. 2006, Genel et al. 2008, Guo et al. 2009, Oppenheimer & Davè 2006, Dekel et al. 2009, Davè et al. 2010, 2011, Dutton et al. 2009, Bouchè et al. 2010

large clumps from fragmentation in gas-rich, Q ≤ 1 disks





$$\left(\frac{\sigma}{v_d}\right) = \left(\frac{h_z}{R_{disk}}\right) \underset{Q\sim1}{=} \frac{Qf_{gas}}{\sqrt{2..3}}$$

$$L_{Toomre} \sim f_{gas} R_{disk}$$

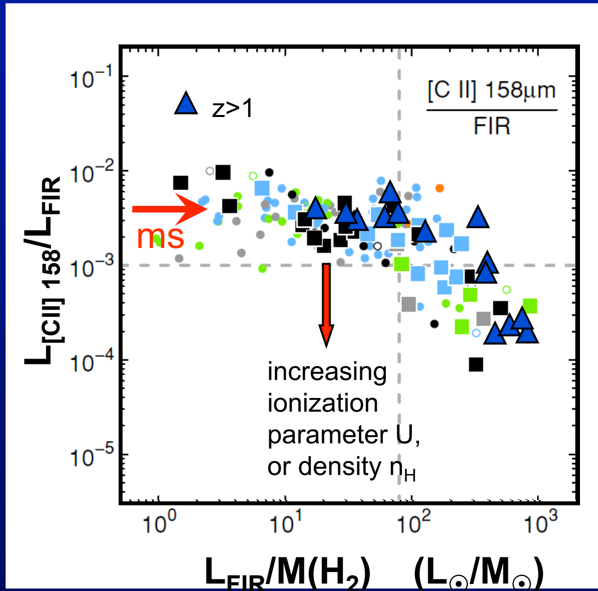
$$M_{Toomre} \sim f_{gas}^2 M_{disk}$$

largest star formation clumps in high-z 'main-sequence' disks are the largest scale of gravitational fragmentation, scaled up to the 5-10 times greater gas fraction & $10^{1.5...3}$ greater interstellar pressure than at z~0

Noguchi 1999, Immeli et al. 2004, Bournaud et al. 2007, Elmegreen et al. 2008, Dekel et al. 2009b, Genzel et al. 2008, 2011, Krumholz & Burkert 2010

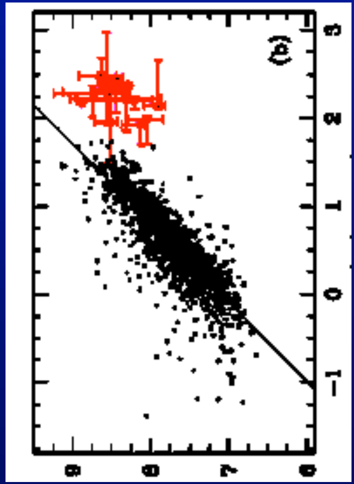
properties of SF-regions change above main-sequence

FIR line deficits



Gracia-Carpio et al. 2010

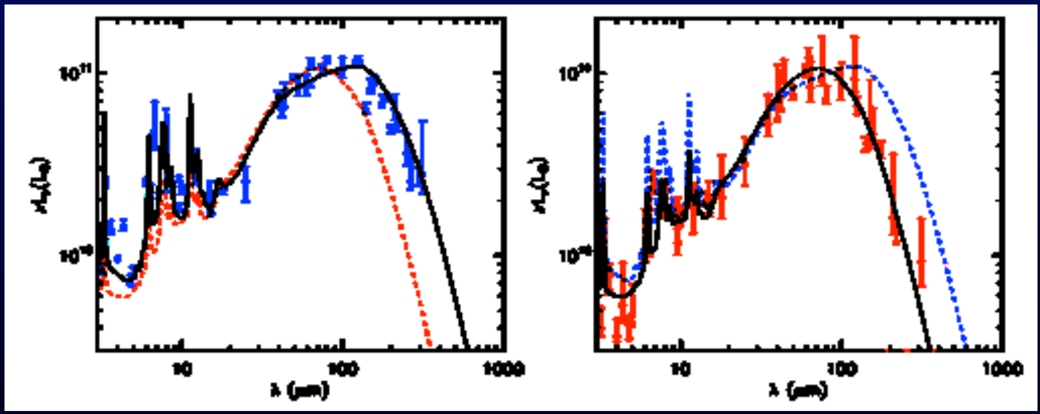
star formation rate ($M_\odot yr^{-1}$)



log (M_{dust} ($M_\odot$))

da Cunha et al. 2010

Elbaz et al. 2010, 2011,
Hwang et al. 2011,
Nordon et al. 2010, 2011



main-sequence galaxies across z have remarkably uniform infrared spectral energy distributions

off-main-sequence galaxies across z are warmer and have much lower PAH emission

star formation ‘above’ the main sequence

$$\dot{M}_* = \varepsilon_{SF,ff}\frac{M_{gas}}{t_{ff}} \underset{Q\sim1}{=} 10^2 f_{gas} M_{baryon,11} t^{-1}_{depletion,9} \quad M_{\odot} yr^{-1}$$

to be significantly above the main sequence:

requires an event bringing in fresh gas above normal

or a small dissipation time scale

(compression of the gas reservoir)