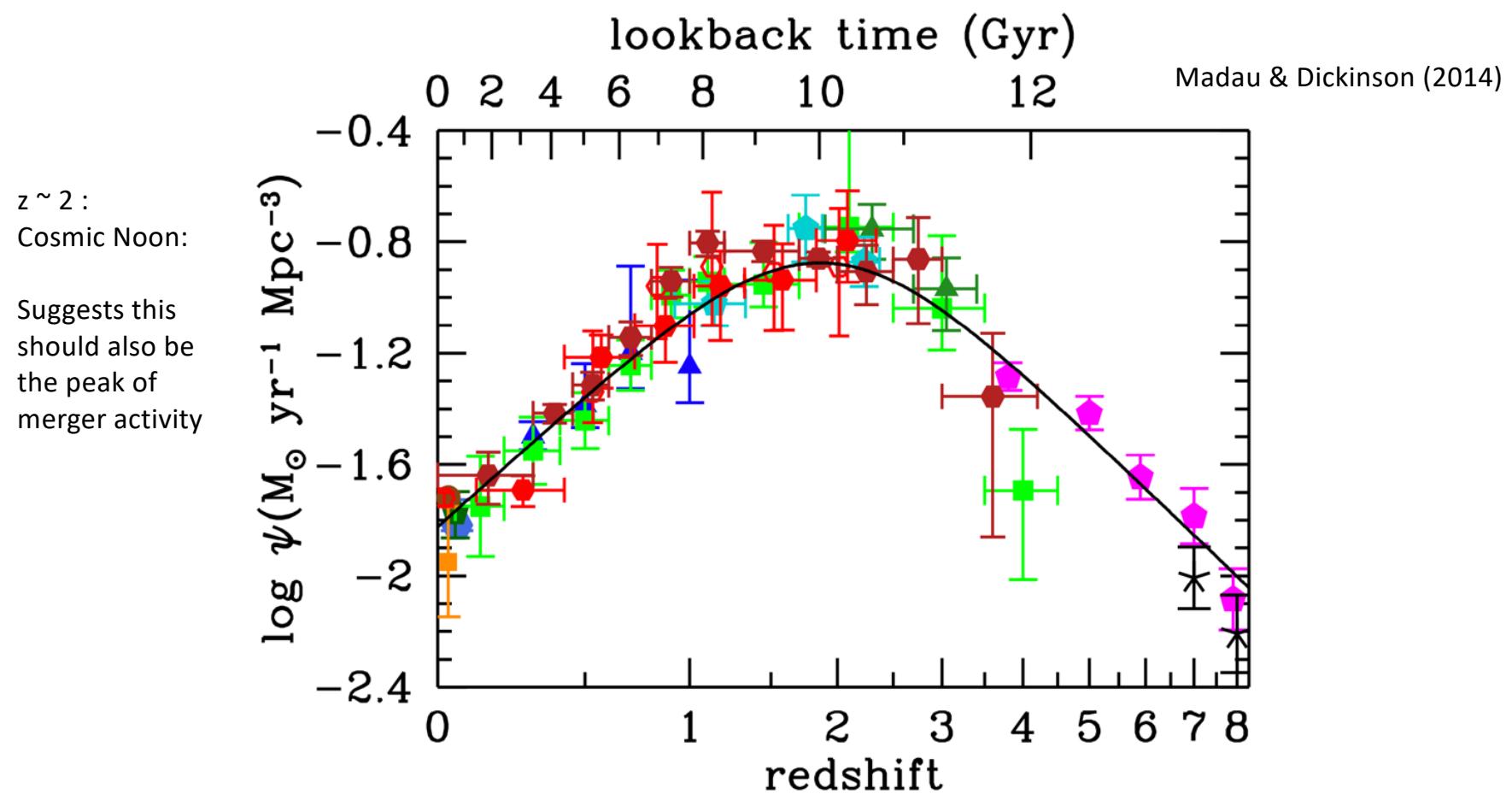
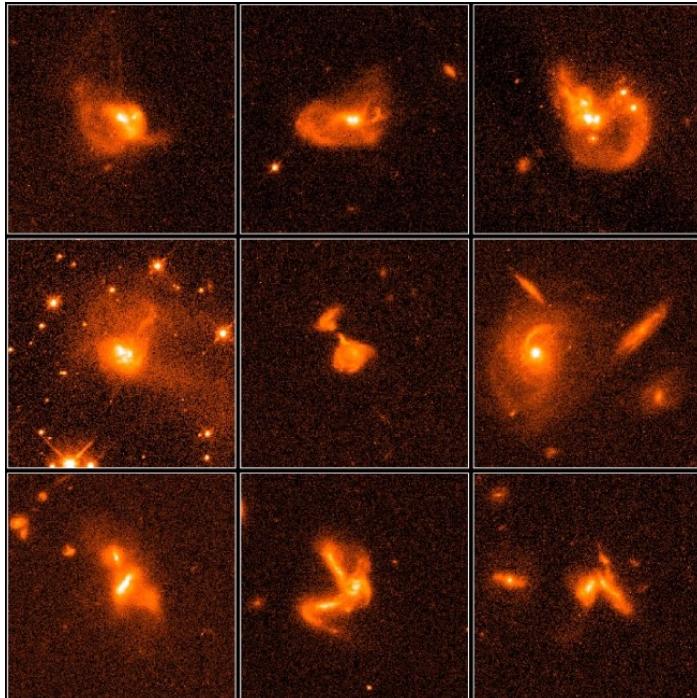


$z \sim 1 - 3$: Peak Epoch of Cosmic Star Formation Activity

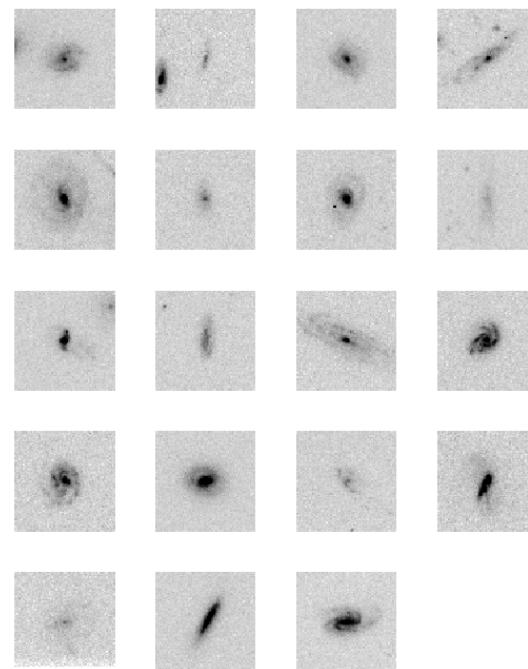


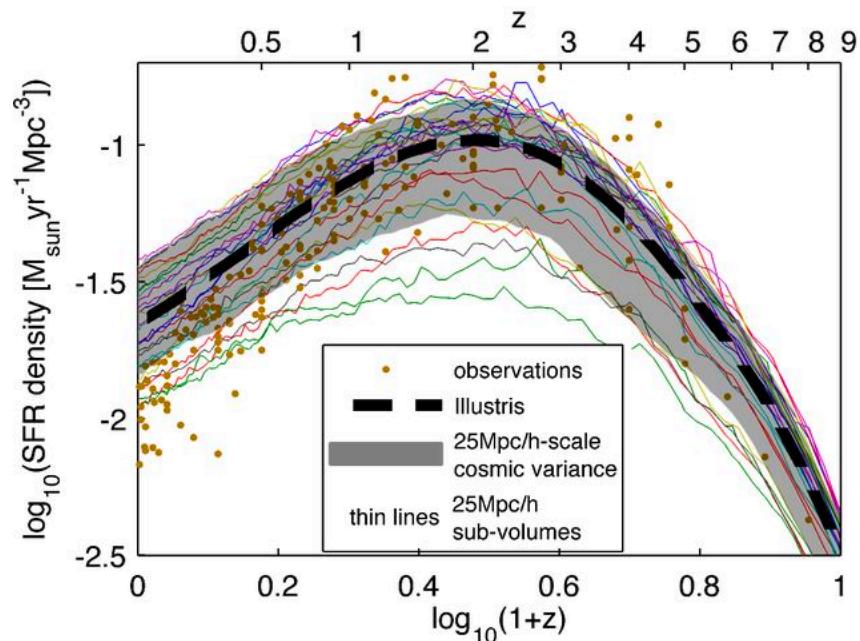
Galaxy Evolution

Galaxies at $z > 2$ are multiple with evidence of merging



Assembly of large Galaxies was evidently completed at $z < 1$

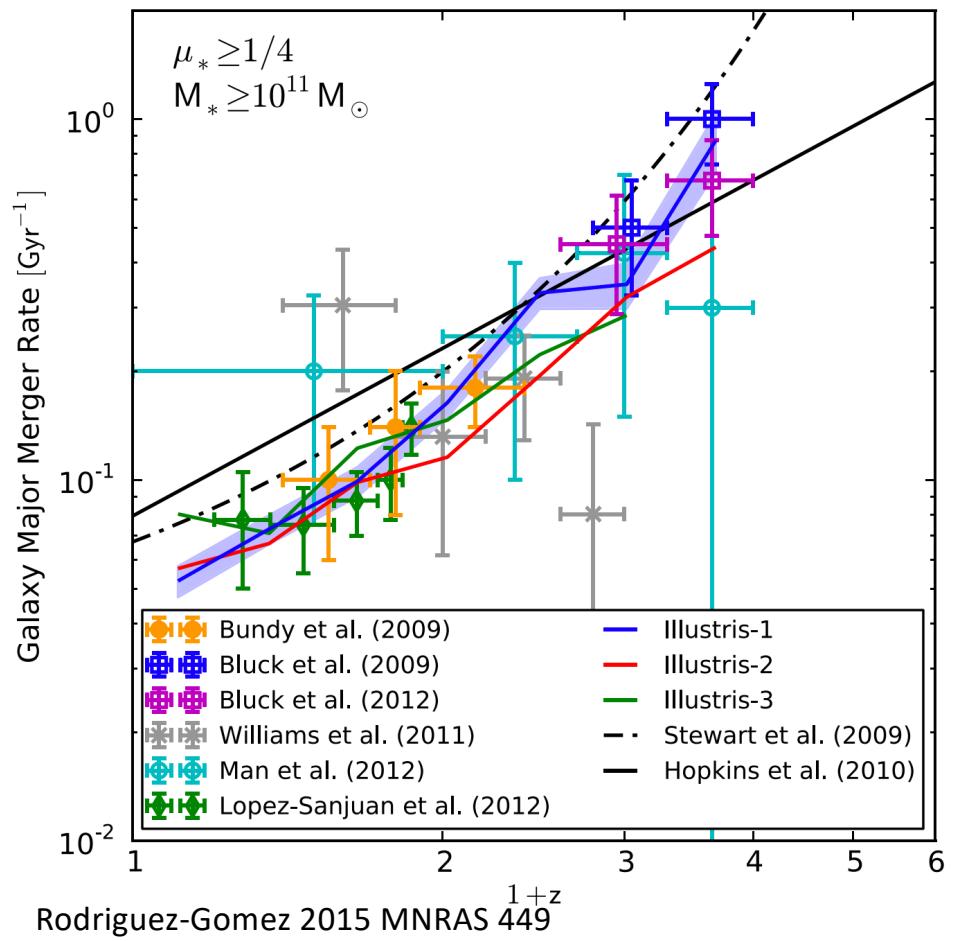




(a) Cosmic SFR density, 35.5 Mpc cosmic variance

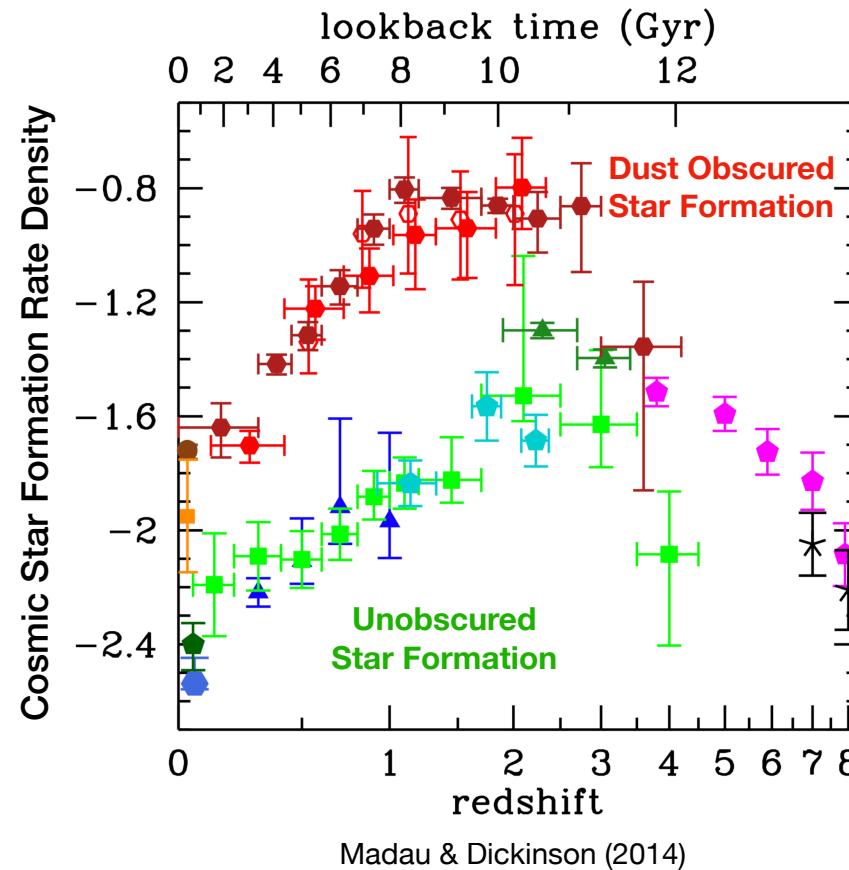
Genel+2014. MNRAS 445

Illustris



Illustris

SIGNIFICANT FRACTION OF STAR FORMATION IS DUST OBSCURED AT HIGH REDSHIFTS



Madau & Dickinson (2014)

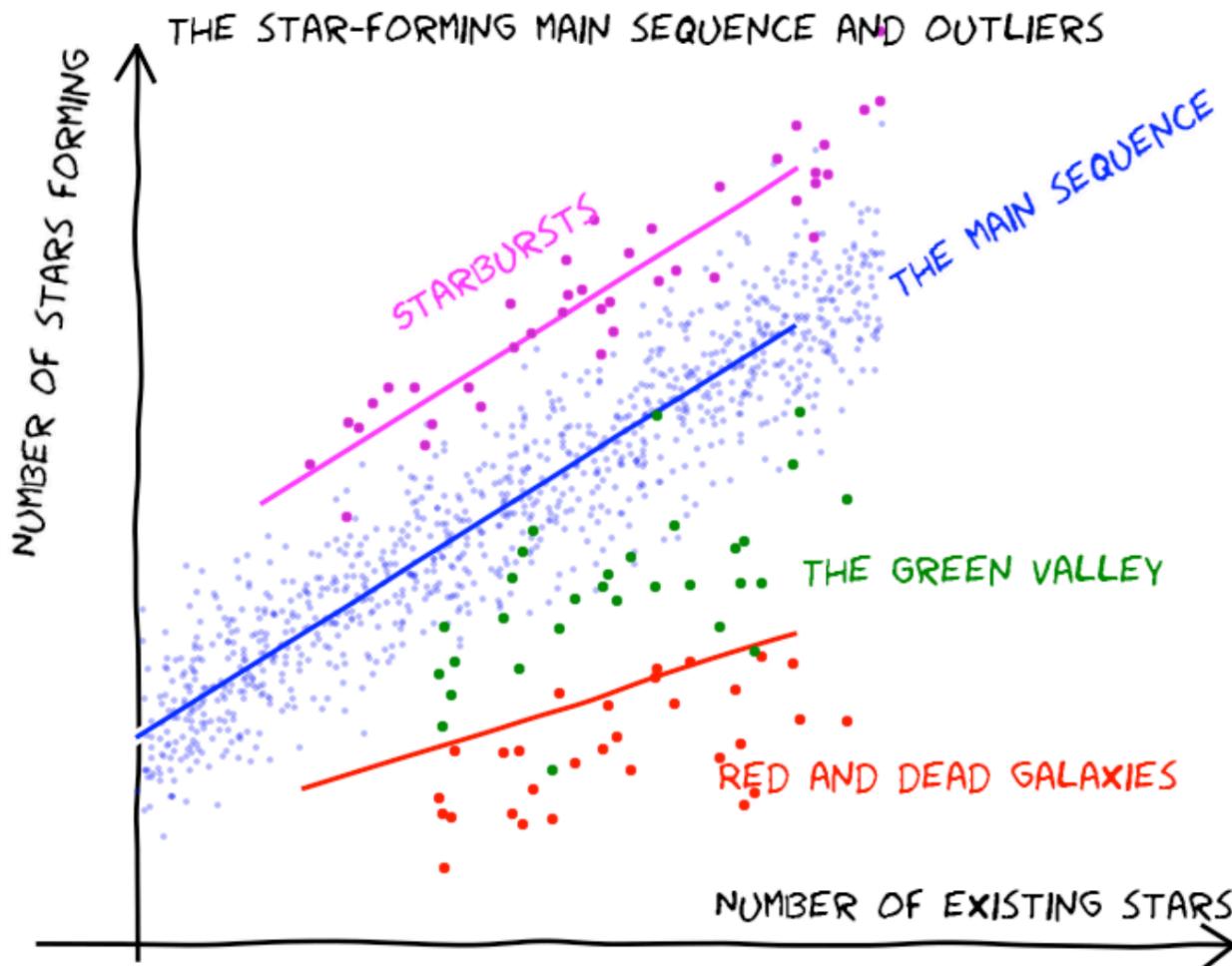


Starburst galaxies

Starburst measured by infrared luminosity 8-1000 μm :

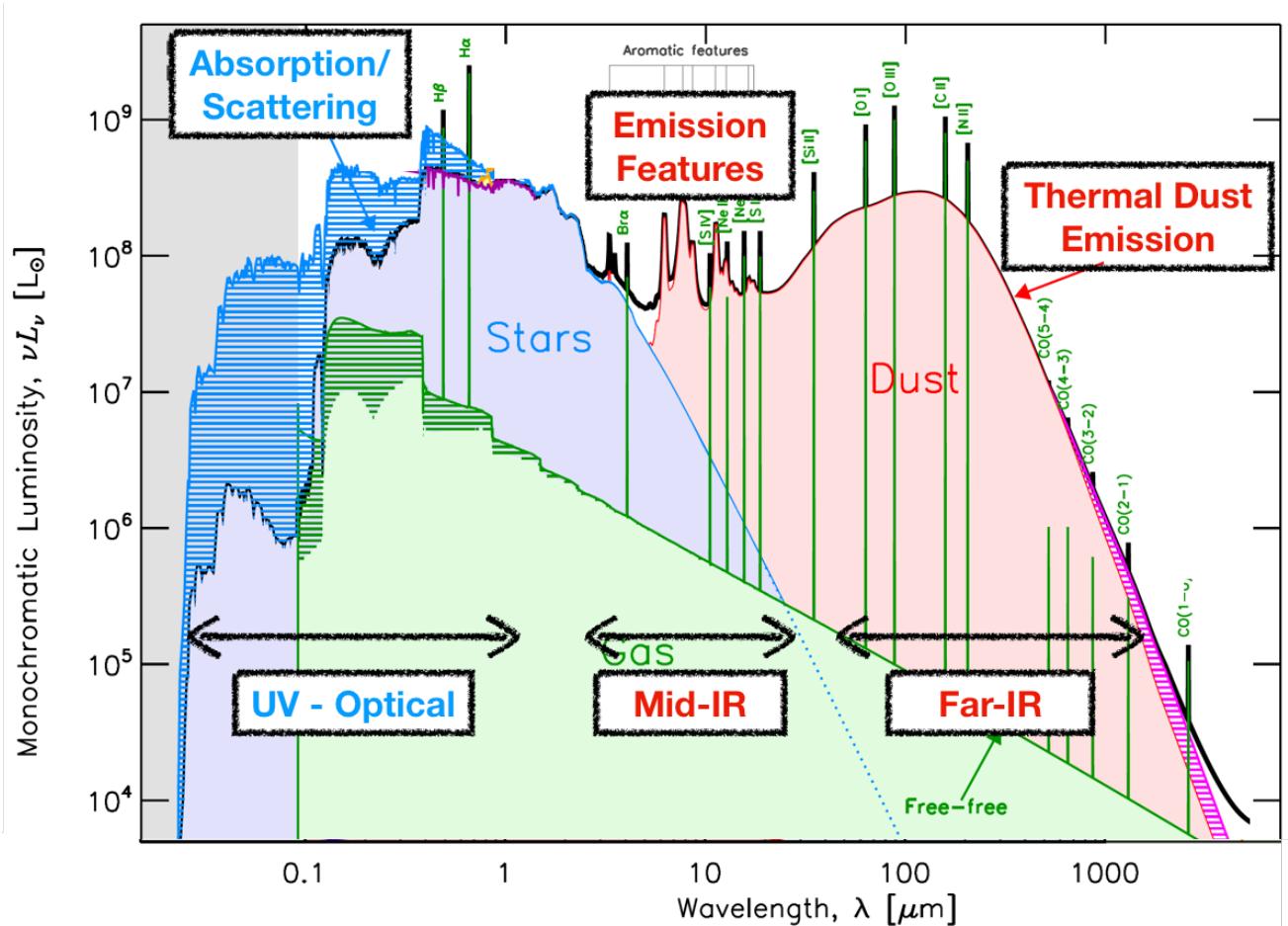
LIRG = Luminous infrared galaxies

Name	$L_{\text{ir}} [L_{\odot}]$	$M(H_2) [M_{\odot}]$	SFR (Msun/year)
normal	10^{10}	10^8	
LIRG	10^{11}	10^9	
ULIRG	10^{12}	10^{10}	
HLIRG	10^{13}	10^{11}	



Veronique Buat

SED of an LIRG



Dust modifies our view of galaxies

Absorbs and scatters UV and optical
Re-emits in IR

We don't see these commonly at low redshift, but they are present at $z > 1$.

Slide: Irene Shvai

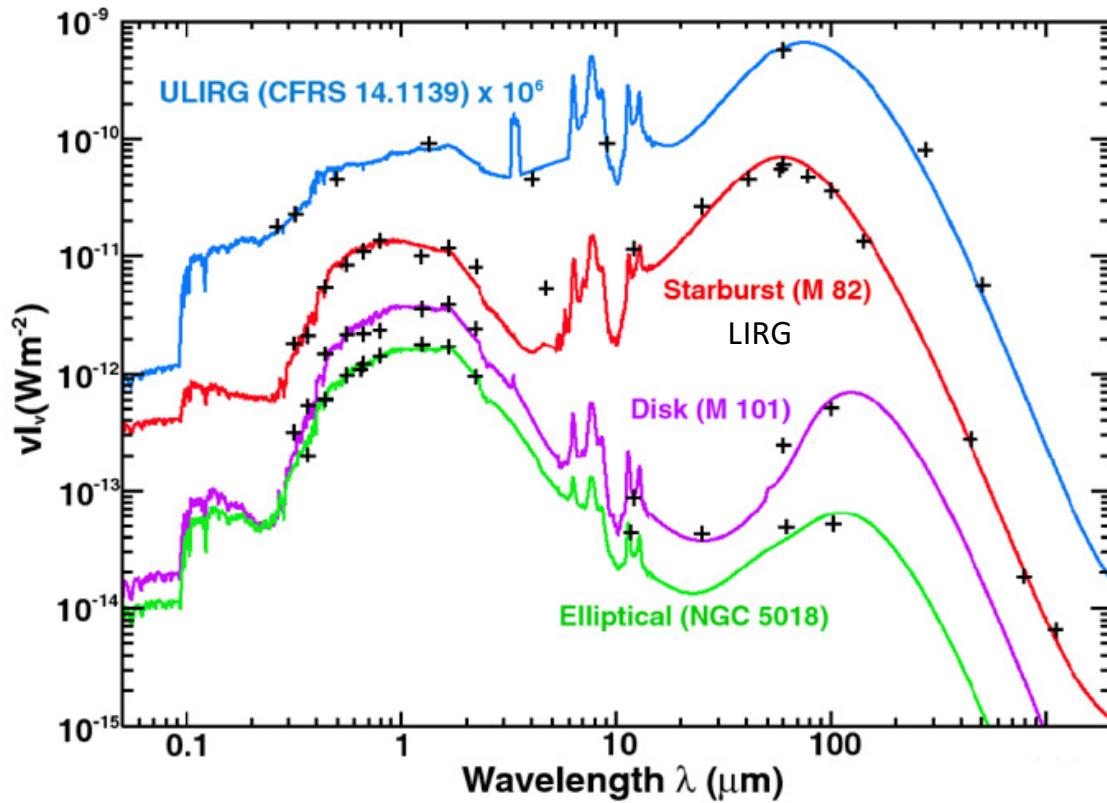
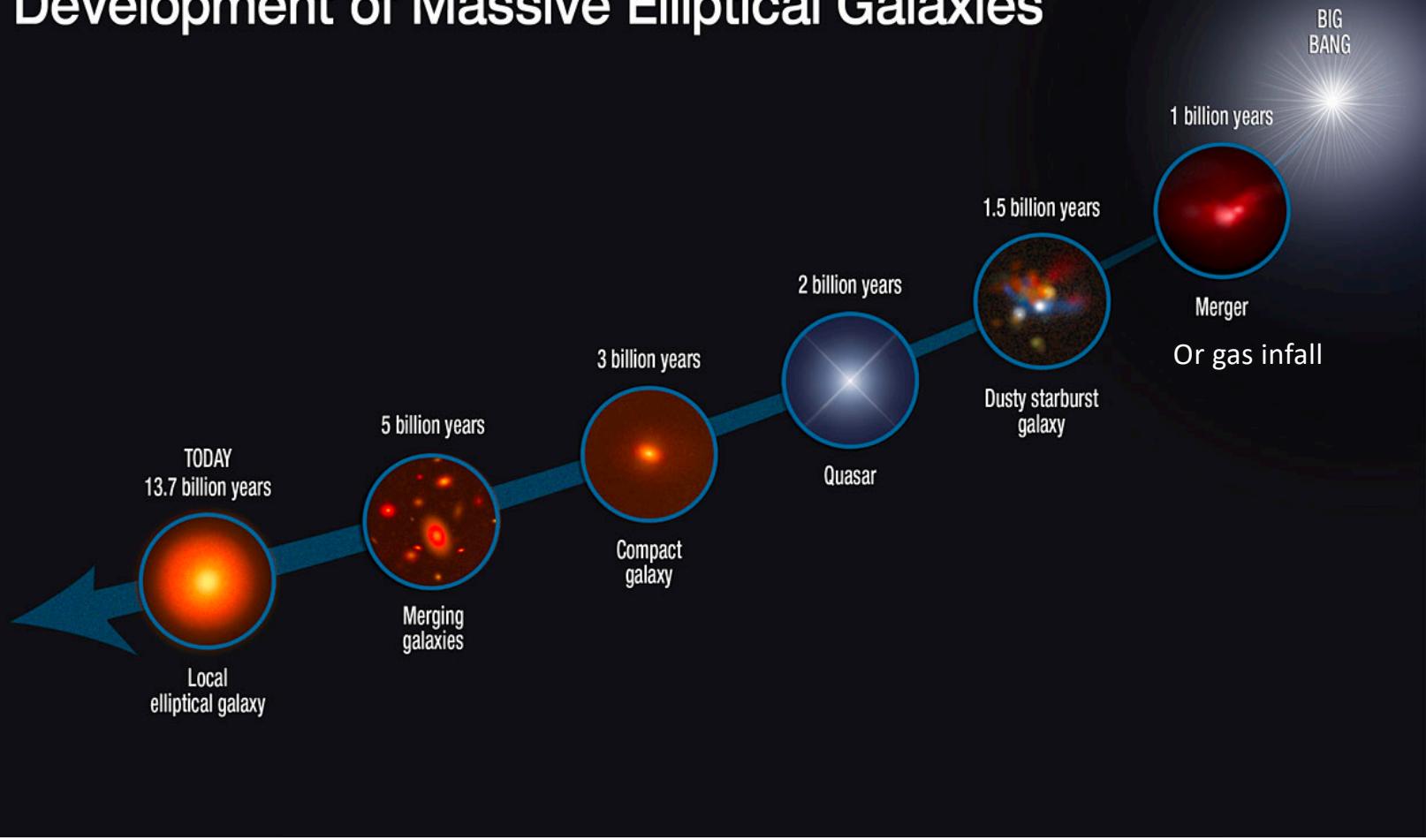


Fig 7.7 (P. Chanial, G. Lagache) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Normal elliptical and disk galaxies are brightest in the visible and near-infrared, at wavelengths less than 2 micron. Most dust grains are cooler than 30 K, and their emission peaks beyond 100 micron. In the starburst M82 and the ultra luminous infrared galaxy (ULIRG), dust intercepts far more of the light, and it is hotter, radiating mainly at less than 100 micron.

Development of Massive Elliptical Galaxies



Submillimeter Galaxies

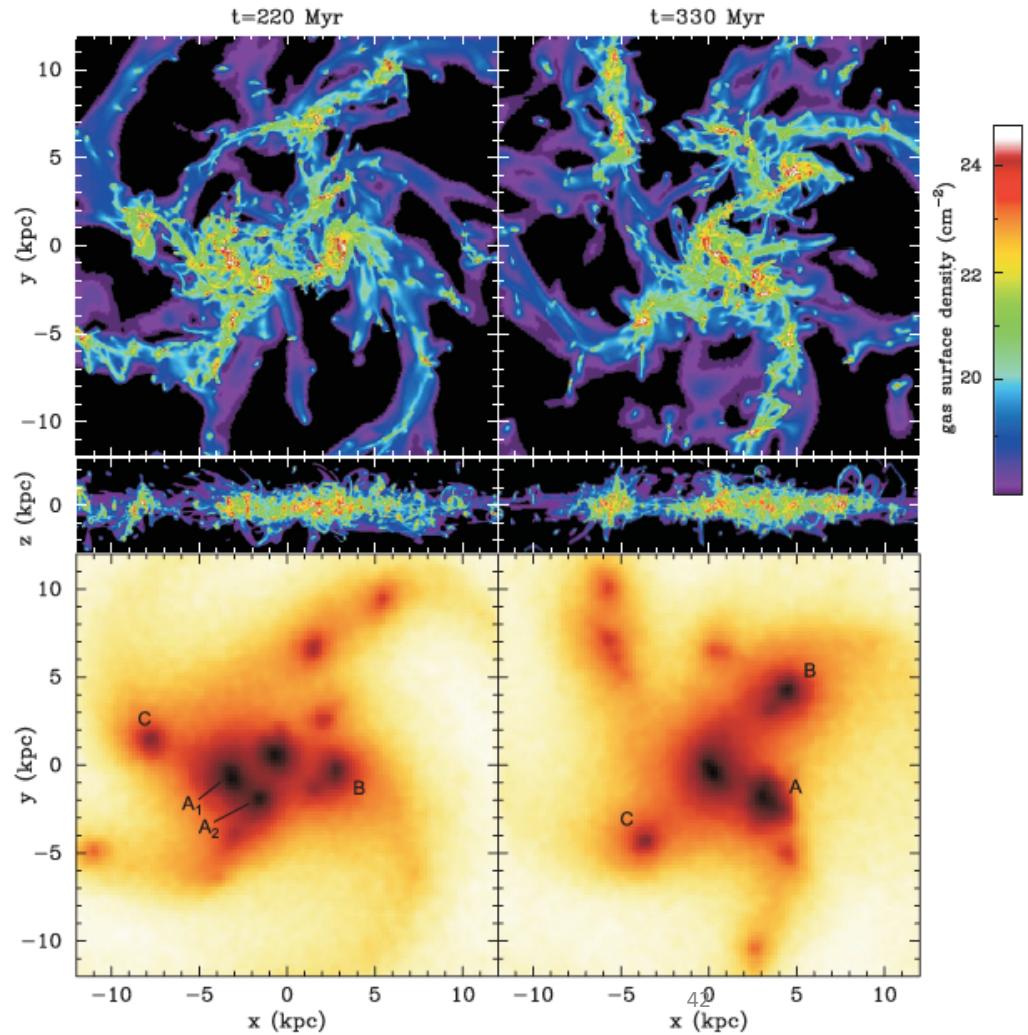
- A class of very bright ULIRGs observed at high z
- Defined as SMG if detected in the sub-mm: 850 μ m flux density > 3-5 mJy (Blain+2002, Smail+1997)
- Required $L_{IR} > 10^{12}$ Lsun \sim ULIRG
- $L_{bol} \sim 10^{12-13}$ Lsun ; Kovacs+2006
- Massive H₂ reservoirs (10^{10-11} Msun; Tacconi+2008)
- Believed to be driven by dust-enshrouded starbursts at $z \sim 1-4$

Origin of Starbursts: Gravitational Instabilities?

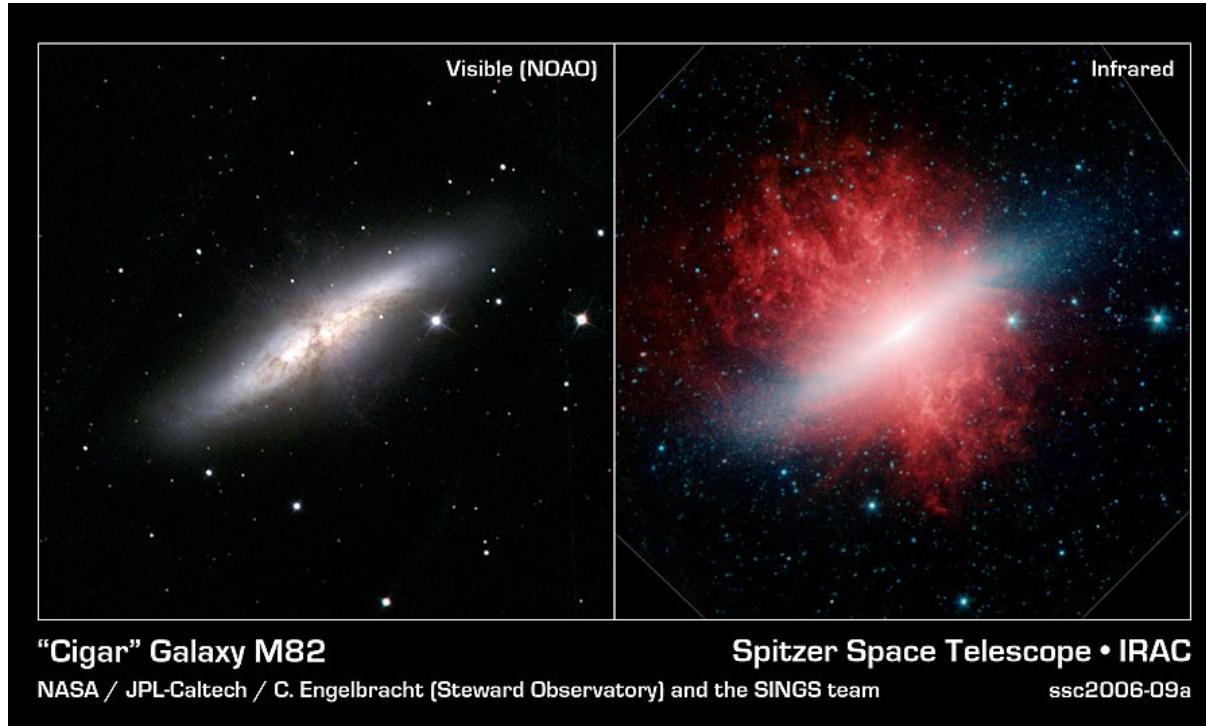
Toomre Q < 1

$$Q = \frac{\Omega\sigma}{\pi G \Sigma}$$

Bournaud (2011), Dekel (2009)



M82 – a nearby starburst



“Cigar” Galaxy M82

NASA / JPL-Caltech / C. Engelbracht (Steward Observatory) and the SINGS team

Spitzer Space Telescope • IRAC

ssc2006-09a

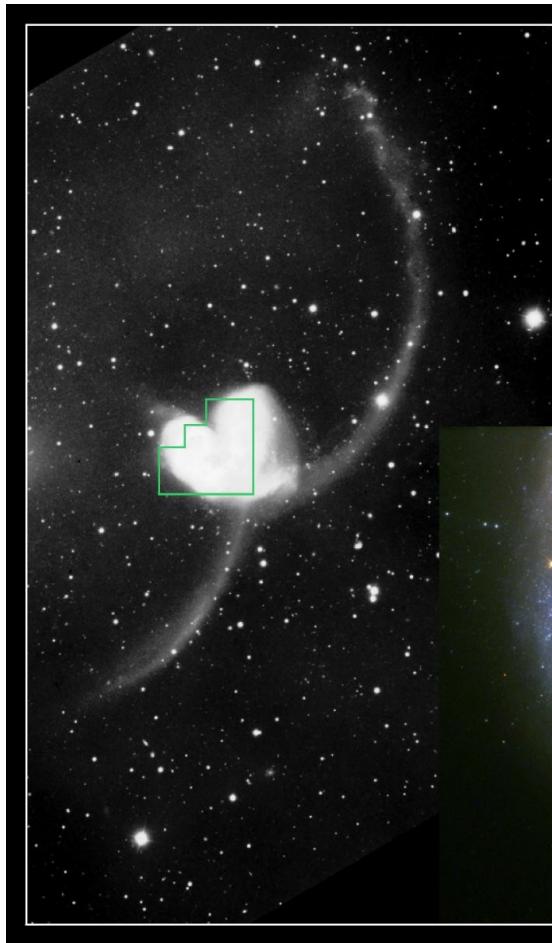
M82 – a nearby starburst



Red: Spitzer IR, Blue: Chandra X-ray

Starbursts: Merger Connection?

Antennae – a massive starburst



Optical image

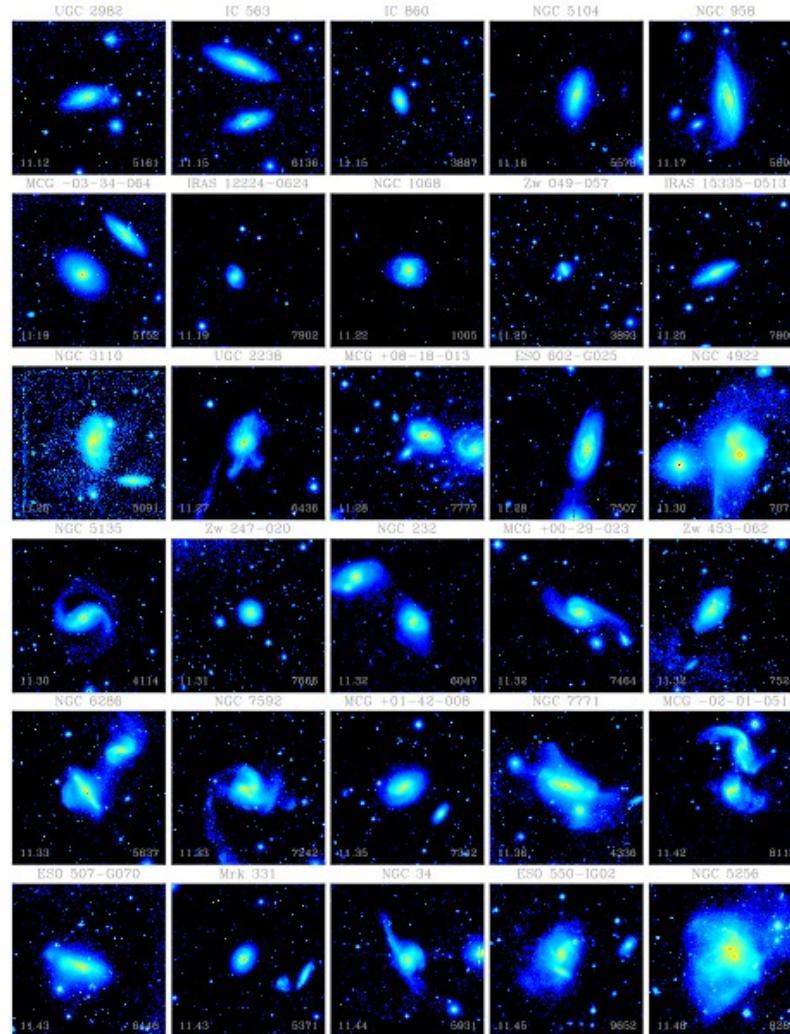


Mid-Infrared

Optical Images of LIRGs

IRAS selected:
 $\log L_{\text{IR}} = 11 - 12$

- Confirm merger origin of most star bursts



Ishida, ApJL (2003)

Brightest: Combination of all things ...

- Narayanan+2015 (Gizmo, cosmological zoom)
- Sub-mm luminous phase is associated with significant mass buildup in early Universe proto-clusters – composed of numerous unresolved components
- SMGs would trace major overdensities

“Submillimeter-emission region probed in surveys typically encompasses a central galaxy in a massive halo that is undergoing a protracted bombardment phase by numerous sub-halos” Flux is dominated by central, but 30% from other galaxies in region.

