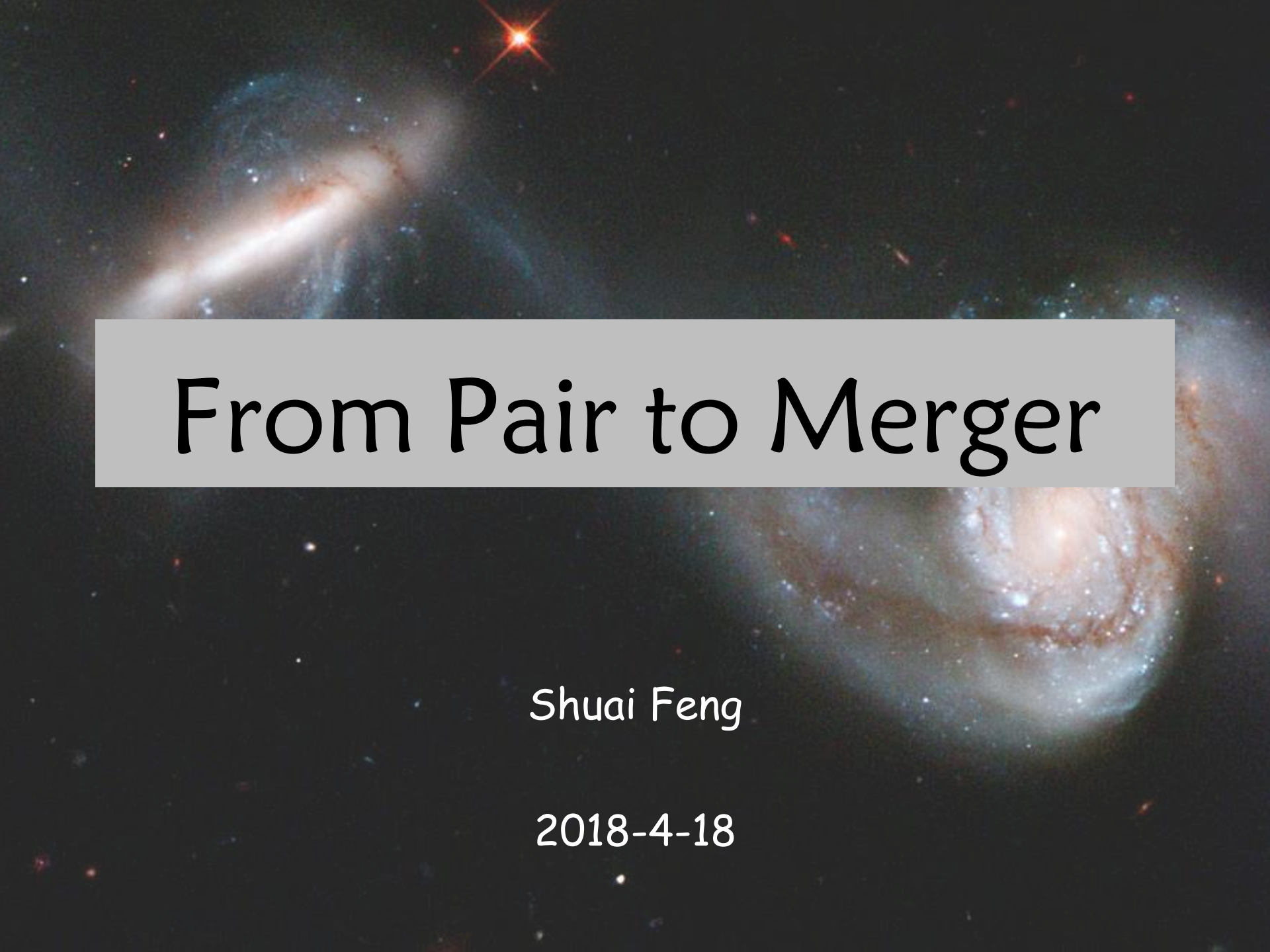
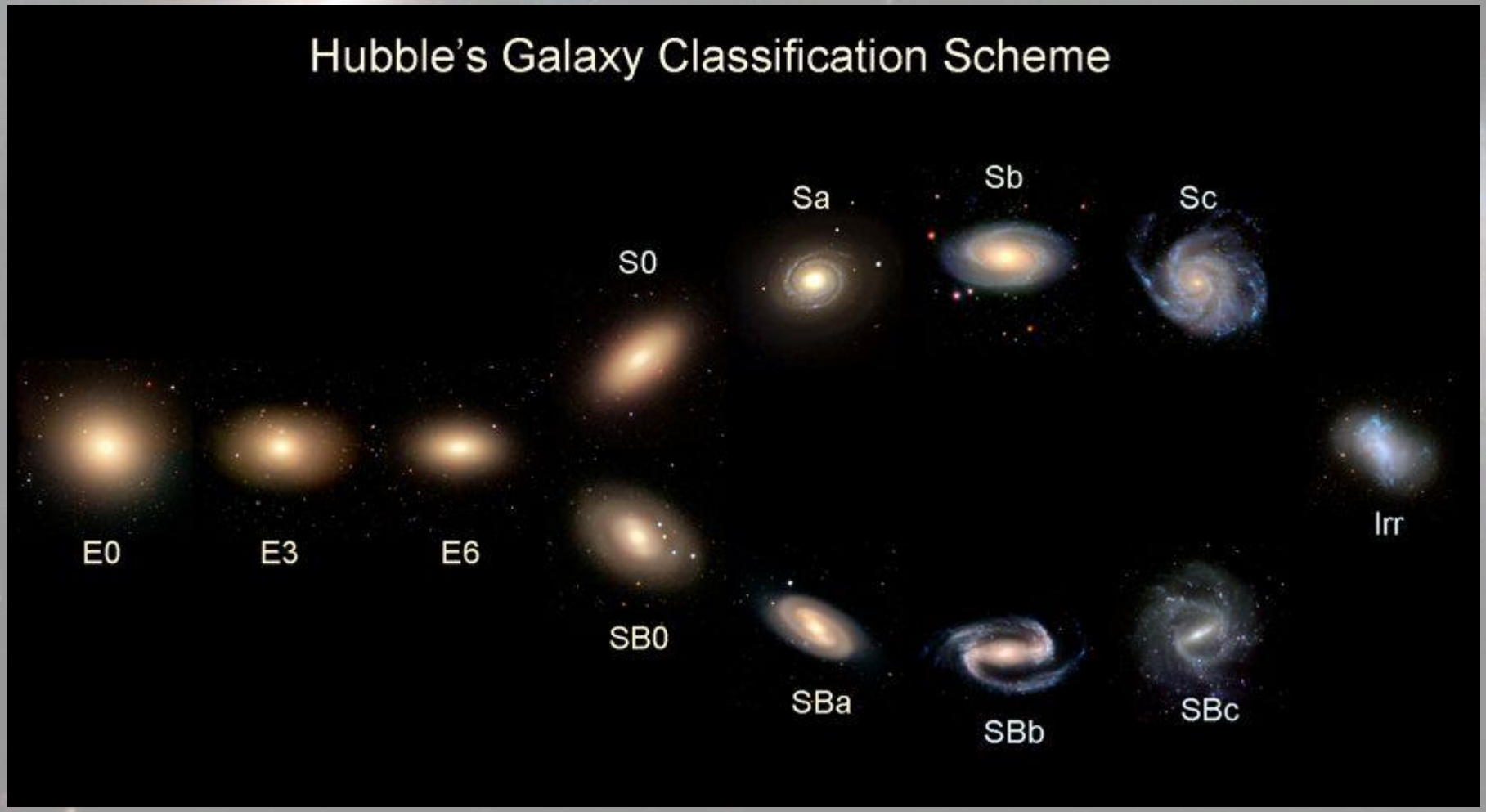


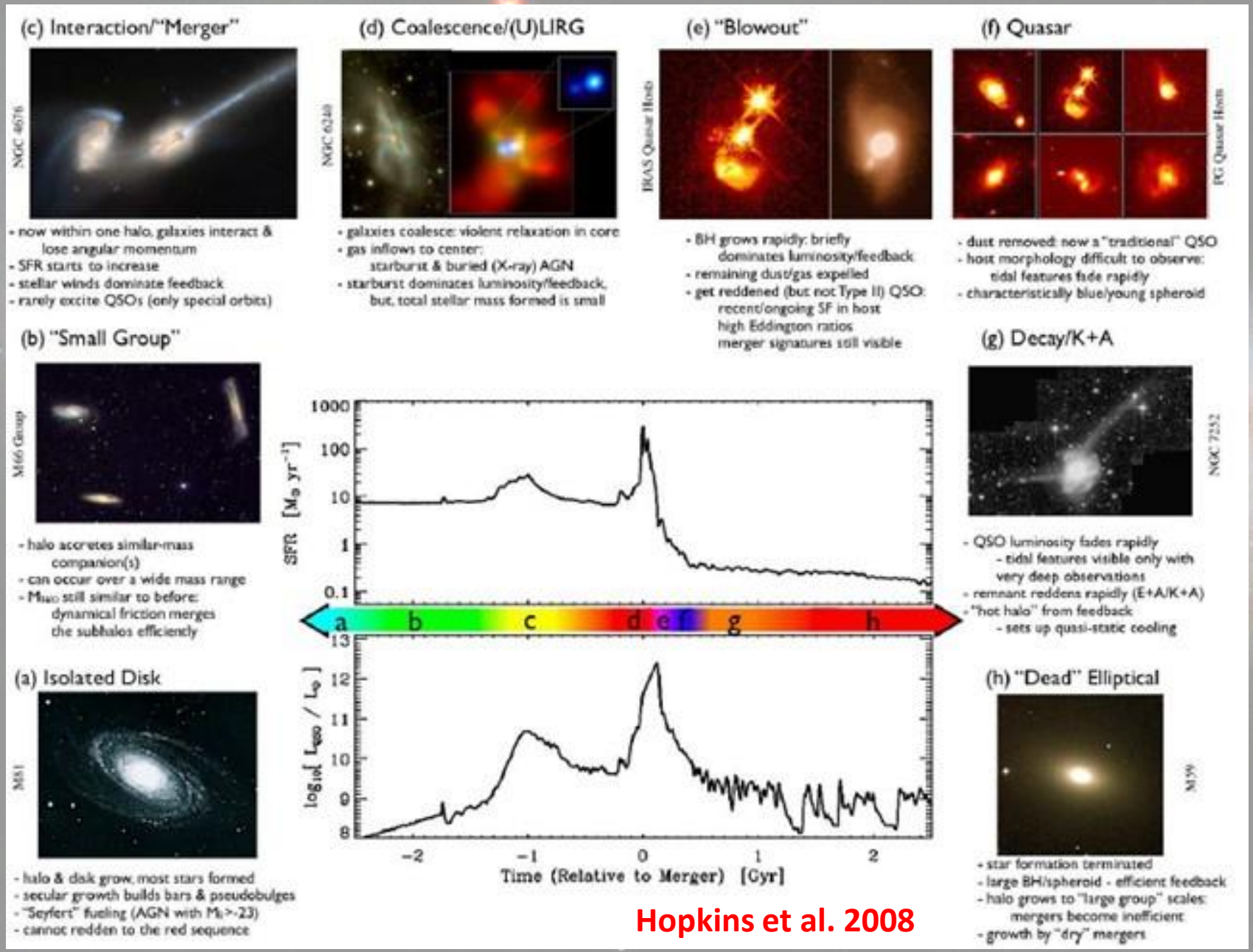
# From Pair to Merger

Shuai Feng

2018-4-18

# Hubble Sequence

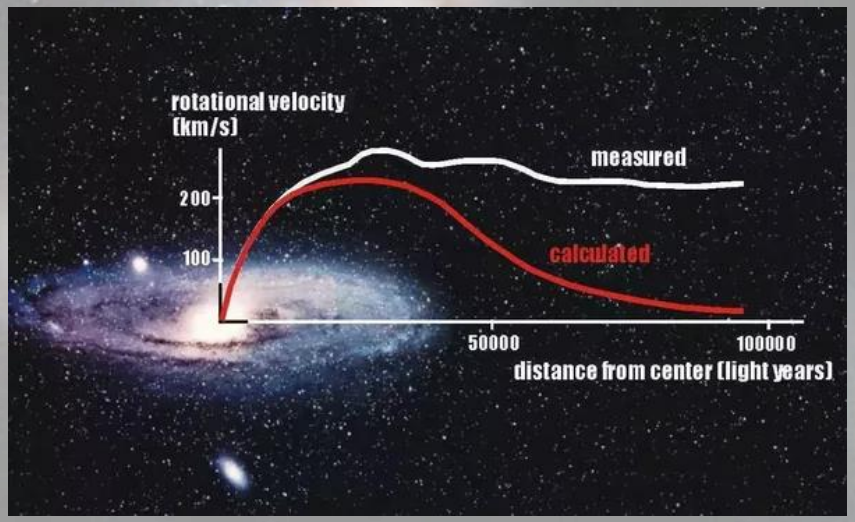


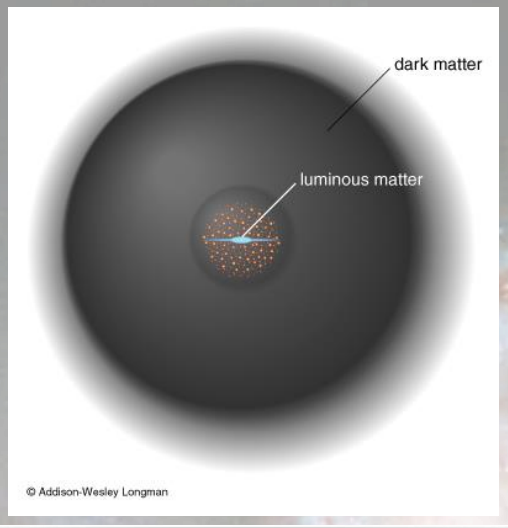

(c) Interaction/"Merger"
NGC 4676
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)
(d) Coalescence/(U)LIRG
NGC 6240
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small
(e) "Blowout"
IRAS Quasar Host
- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host, high Eddington ratios, merger signatures still visible
(f) Quasar
PG Quasar Hosts
- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid
(b) "Small Group"
M66 Group
- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- $M_{halo}$ still similar to before: dynamical friction merges the subhalos efficiently
(g) Decay/K+A
NGC 7252
- QSO luminosity fades rapidly
- tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
- sets up quasi-static cooling
SFR [$M_\odot$ yr$^{-1}$]
1000
100
10
1
0.1
a
b
c
d
e
f
g
h
$\log_{10}[L_{bol} / L_\odot]$
13
12
11
10
9
8
−2
−1
0
1
2
Time (Relative to Merger) [Gyr]
(a) Isolated Disk
M51
- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with $M_i$>-23)
- cannot redden to the red sequence
(h) "Dead" Elliptical
M59
- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales: mergers become inefficient
- growth by "dry" mergers
Hopkins et al. 2008

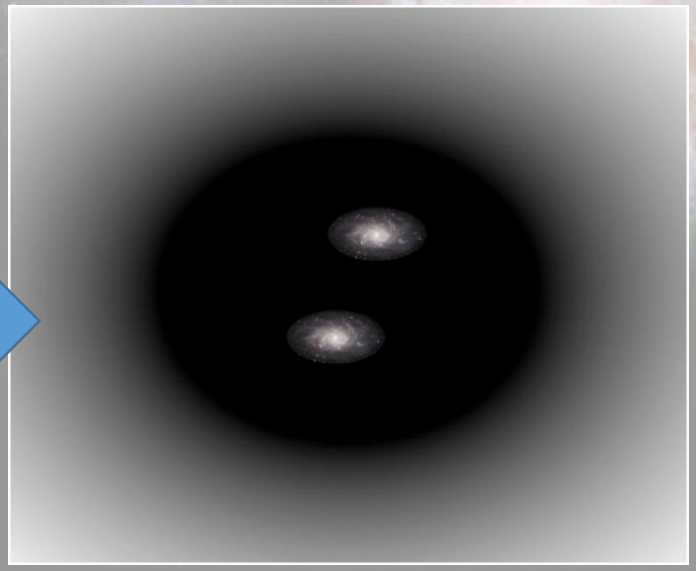
# Galaxy Pair

- Theoretical view:
  - Gravitational bounded system (enclosed by a common dark matter halo)
- Observation view:
  - Projected distance (close enough)
  - Redshift difference (remove overlapping pair)

# Host Halo


rotational velocity
(km/s)
200
100
measured
calculated
50000
100000
distance from center (light years)

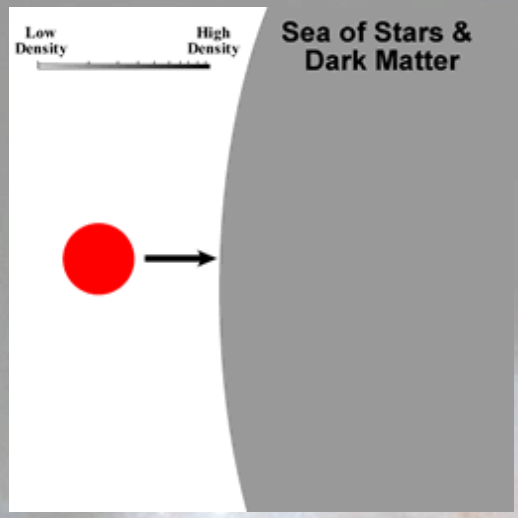

dark matter
luminous matter
© Addison-Wesley Longman



# Dynamic Friction

- Chandrasekhar formula

$$\frac{d\boldsymbol{v}_s}{dt} = -16\pi^2 G^2 m(M_s + m)\log\Lambda \frac{\int_0^{v_s} f(v_m)\, v_m^2\, dv_m}{|\boldsymbol{v}_s|^3}\boldsymbol{v}_s$$




- Main mechanism of dynamic energy dissipation

➔Sink into the center of dark matter halo

➔Merge!

# Timescale of Dynamic Friction

- N-body simulation
- Mainly depends on mass ratio of pair member and mass of primary galaxy (e.g. Colpi et al. 1997, Boylan-Kolchin et al. 2008, Jiang et al. 2014)

$$T \sim (\frac{m_1}{m_2})^a {m_1}^b$$

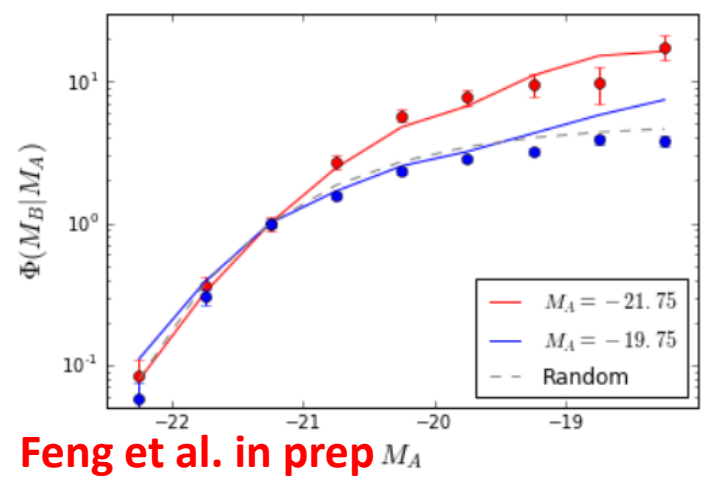
- a>0, minor merger spends longer time to merge
- b<0, massive pairs merge more rapidly

# Observational Evidence of Dynamic Friction

- Timescale of dynamic friction is too long to be observed directly(~1Gyr)
- Life time of galaxy pair (~dynamic friction timescale) depends on mass ratio

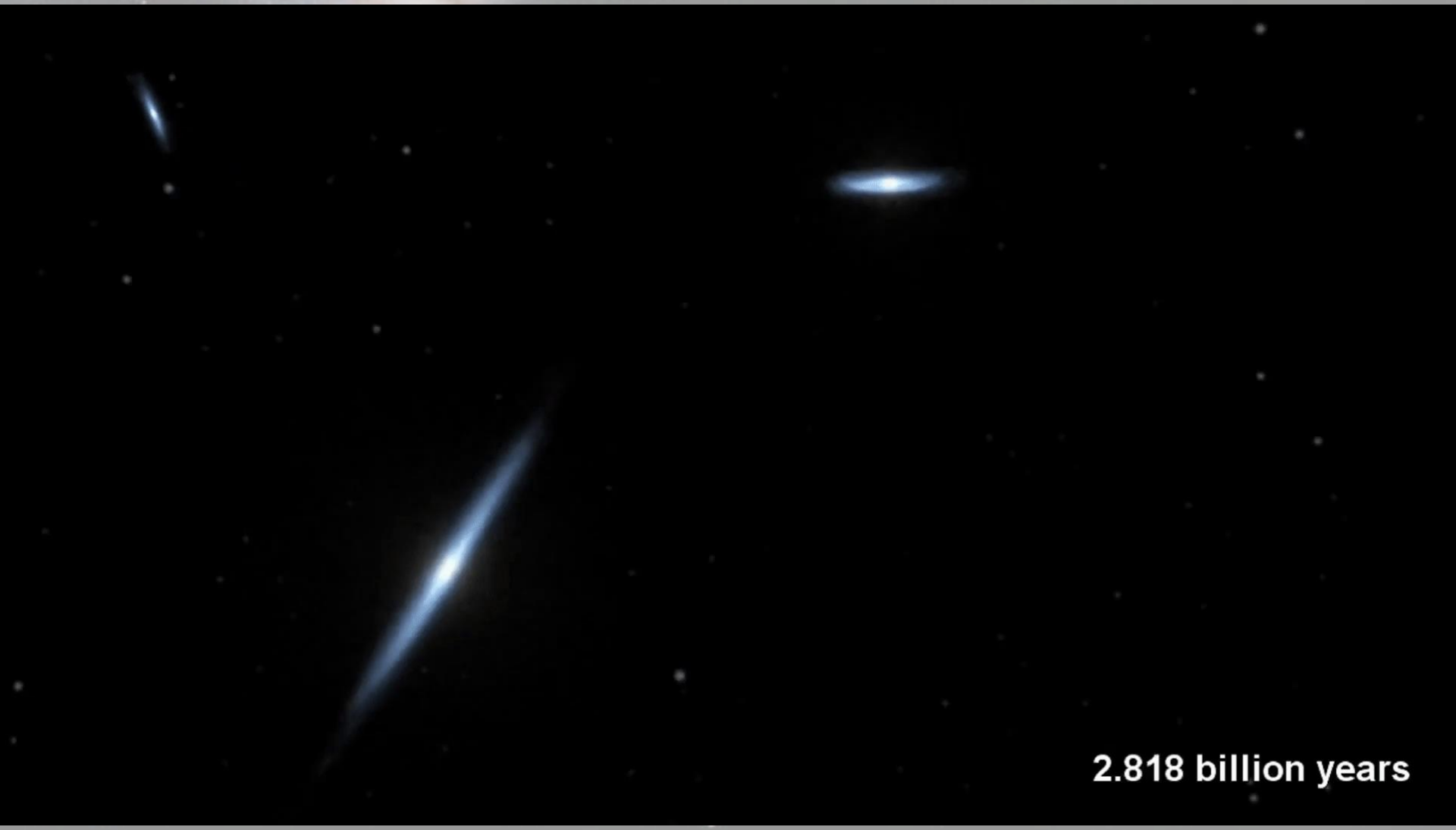
➔Observing probability depends on mass ratio

➔ Luminosity (mass) function of pair member depends on neighbor mass




Feng et al. in prep

# From Close Interaction to Merge

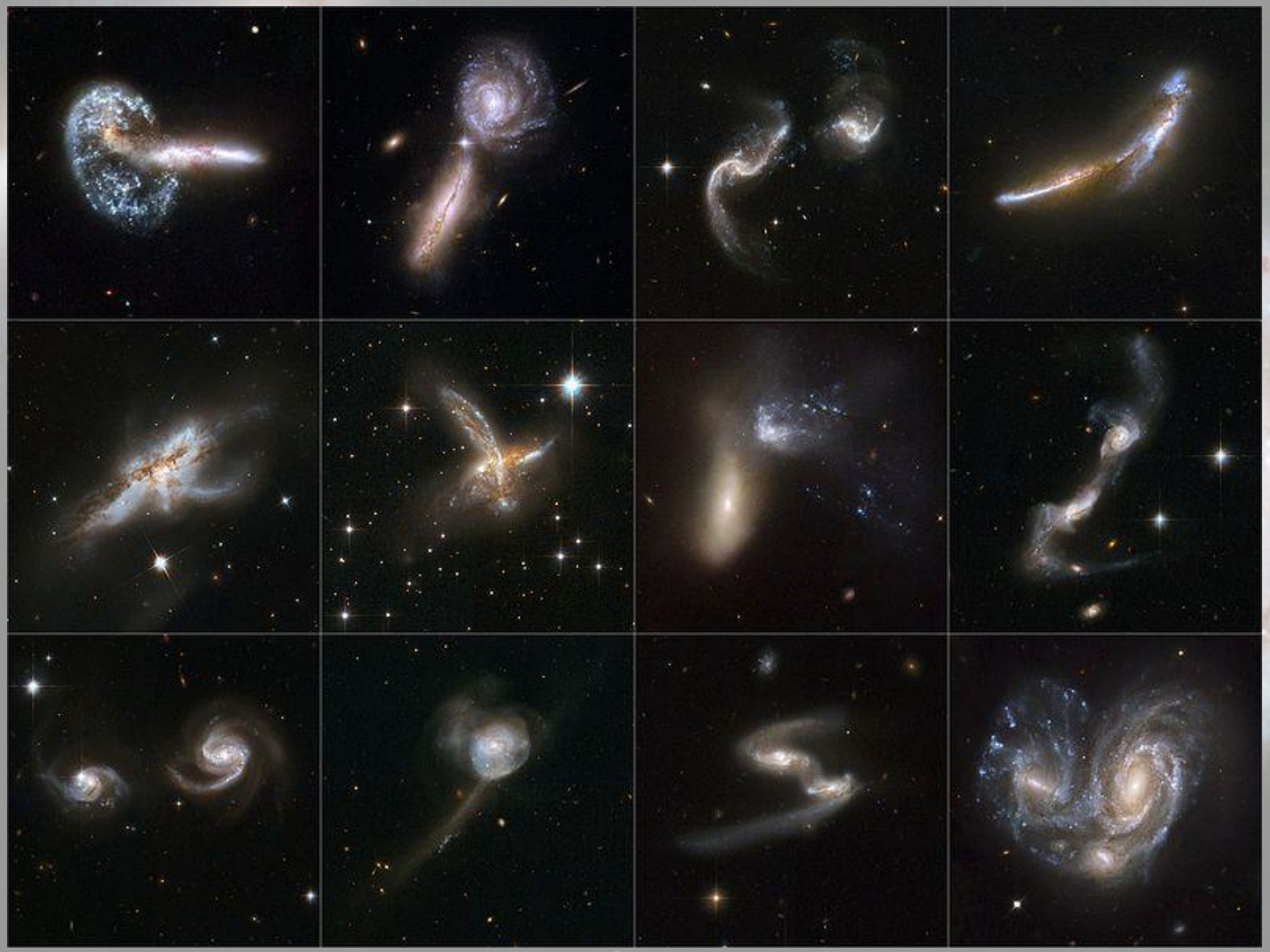


# Classification of Merger

- Mass ratio
- $m_1/m_2 < 3$ : Major merger pair
- $m_1/m_2 > 3$ : Minor merger pair

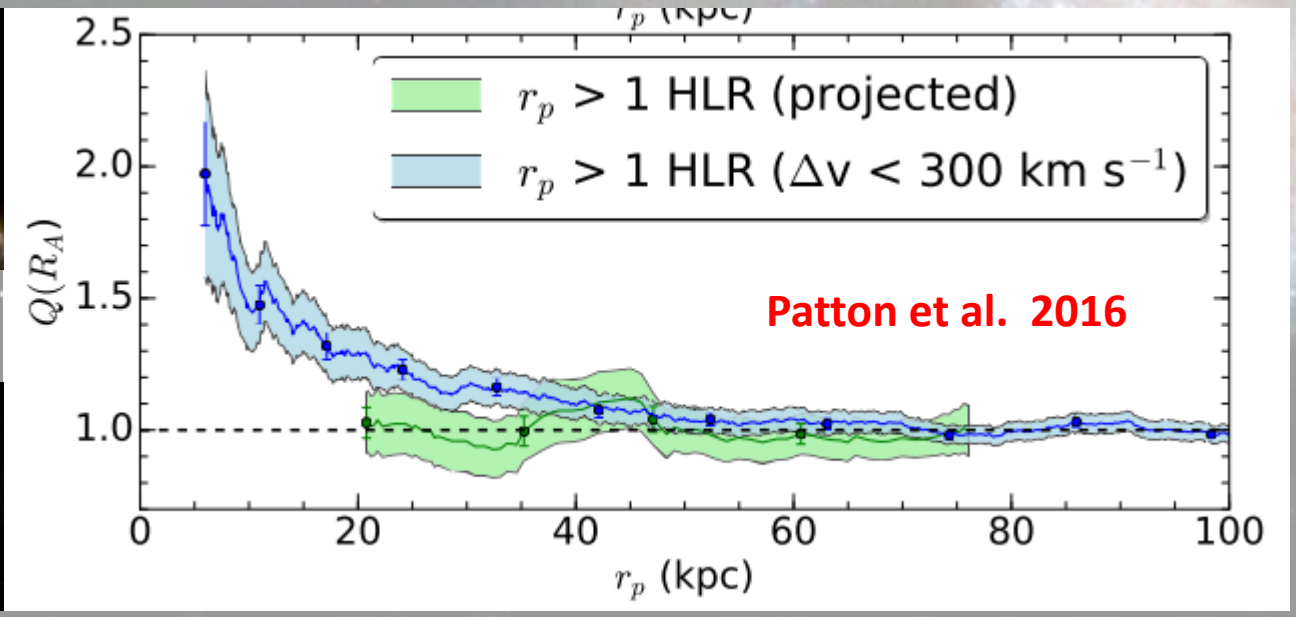
- Gas content
- Gas rich: Wet merger
- Gas poor: Dry merger

# Disturbed Morphology



# Disturbed Morphology

- Tidal force drives asymmetry
- Morphology asymmetry is dependence on $r_p$
  - Closer $r_p$ ➔ higher asymmetry



# Dilute Metallicity

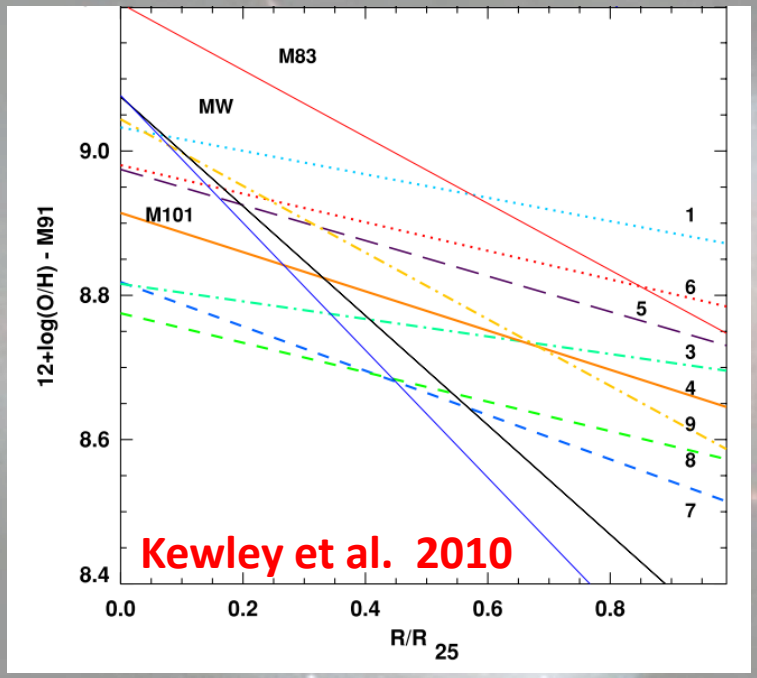
Strong interaction

➔ Instability of gas

➔ Gas inflow

➔ Gas in outer region is metal poor which is metal rich in inner region

➔ Inflow induces dilute metallicity

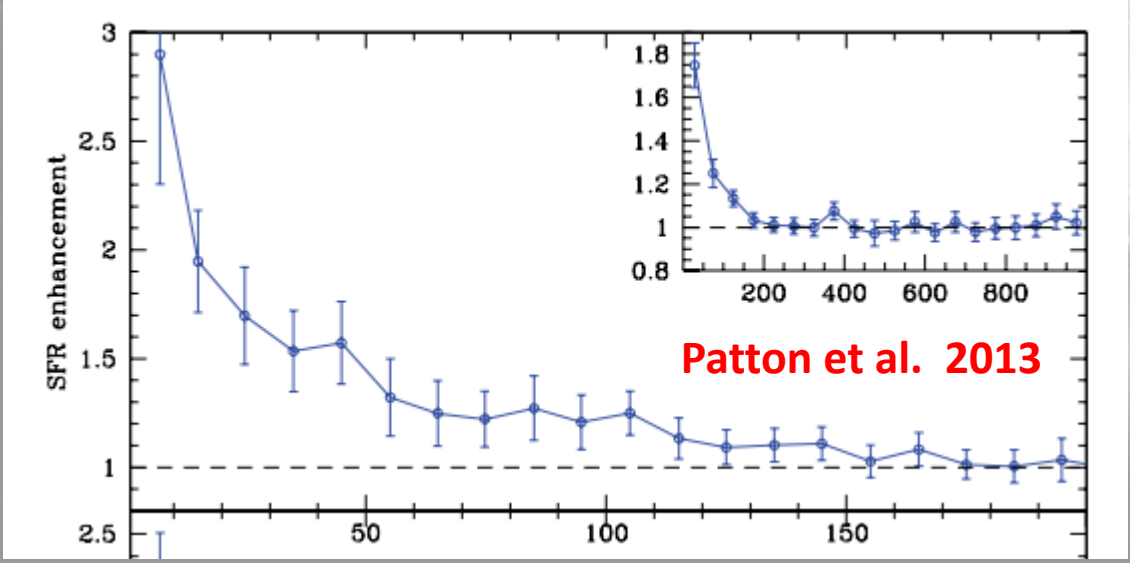


# Enhanced SFR

- Gas inflow

➔ Increased central cold gas density

➔ Fuel central star burst

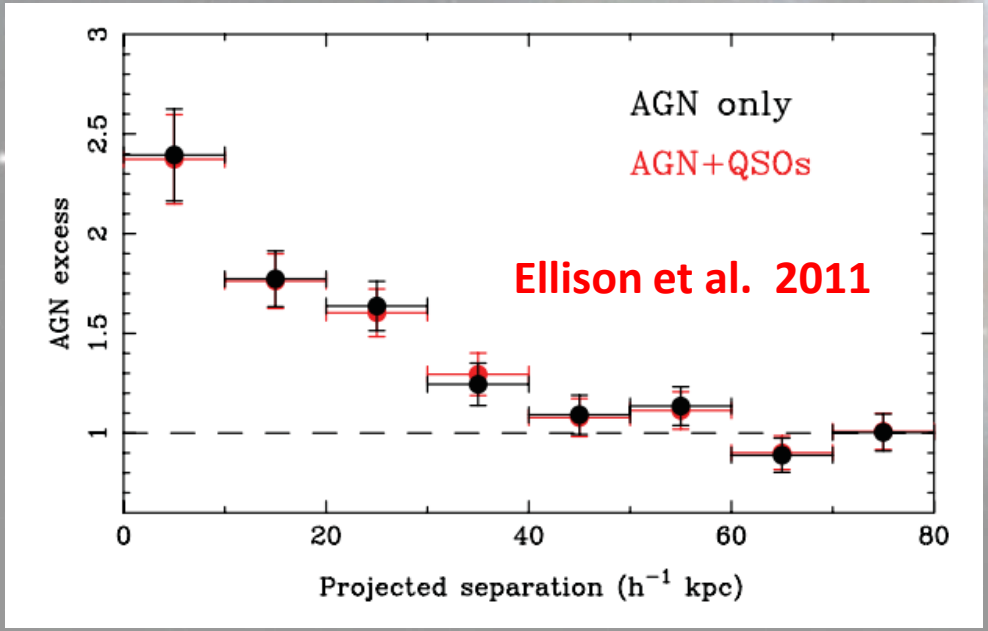


# Trigger AGN

- Gas inflow

➔ Fuel central super massive black hole

➔ Trigger AGN



# Coalescence

- Morphology
  - Single nuclear
  - Compact spheroid
  - Tidal tails

- More gas inflow

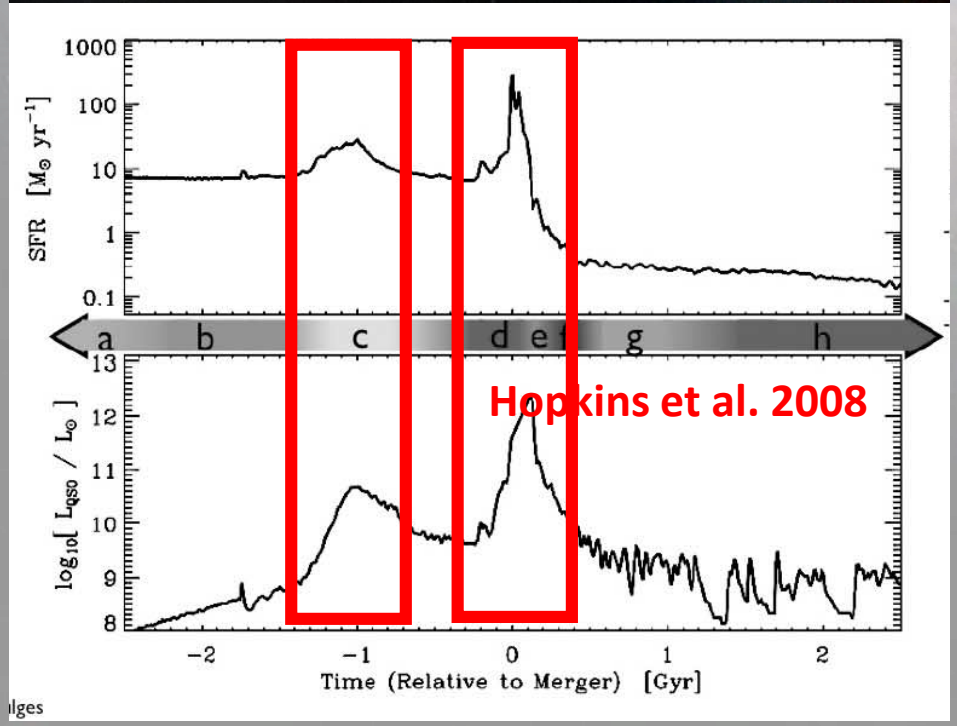
➔ Stronger star burst

➔ Large amount of young stars

➔ Supernova or AGB star generate dust

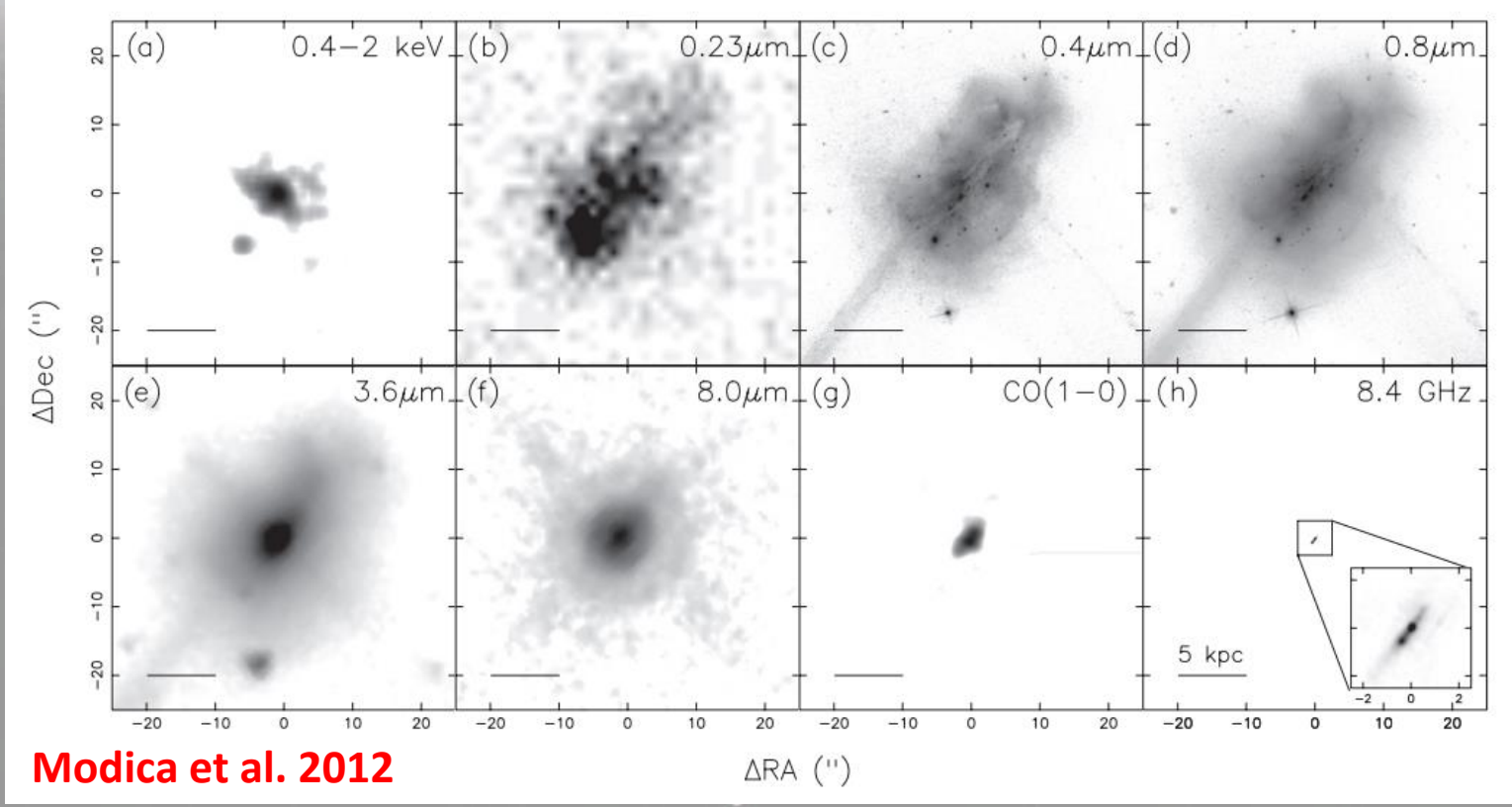
➔ Obscure star forming region or AGN

➔ High infrared luminosity



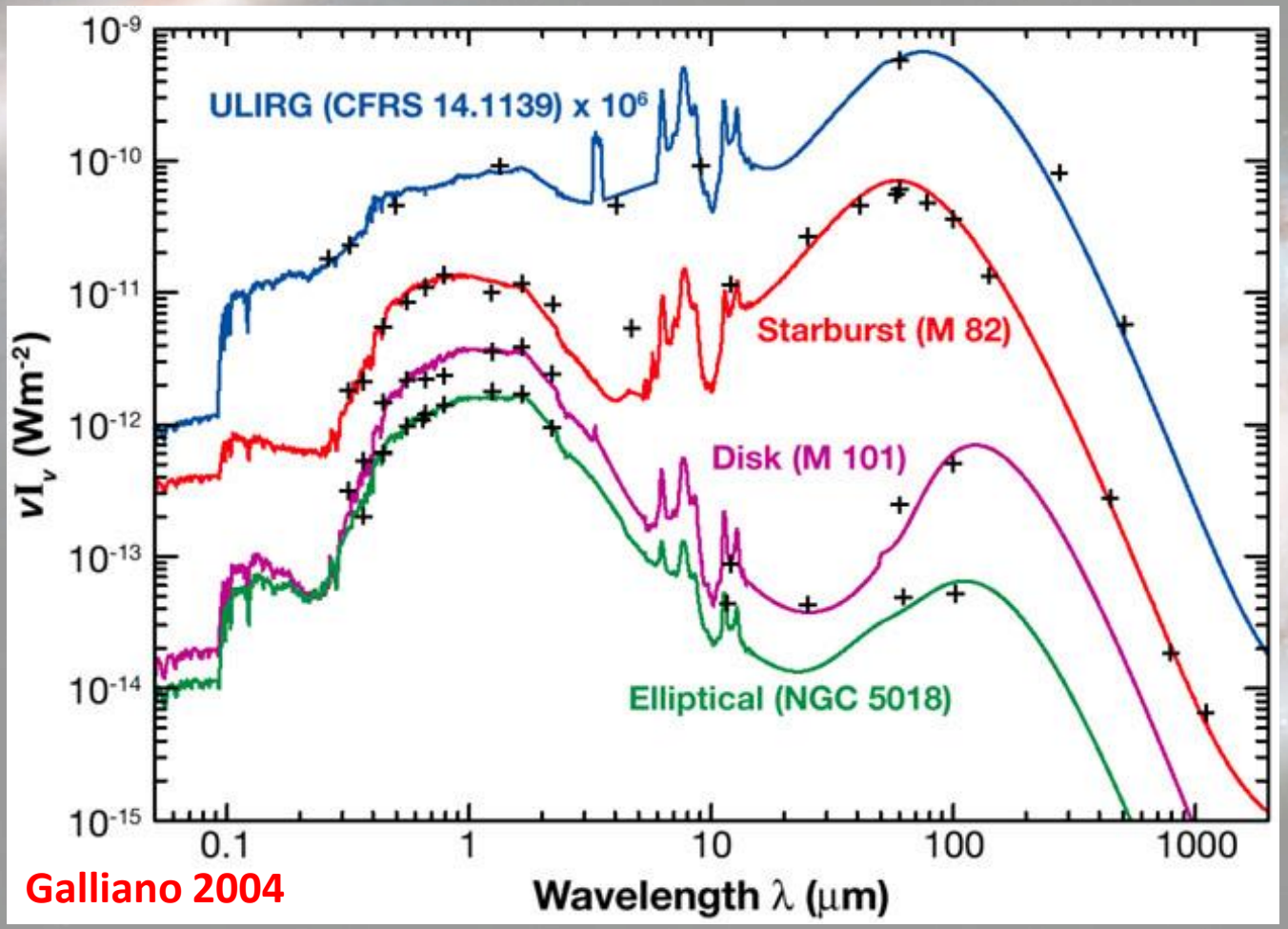
# Luminous Infrared Galaxy (LIRG)

- LIRG: $L_{IR}[8-1000\mu m] > 10^{11} L_{\odot}$
- ULIRG: $L_{IR}[8-1000\mu m] > 10^{12} L_{\odot}$



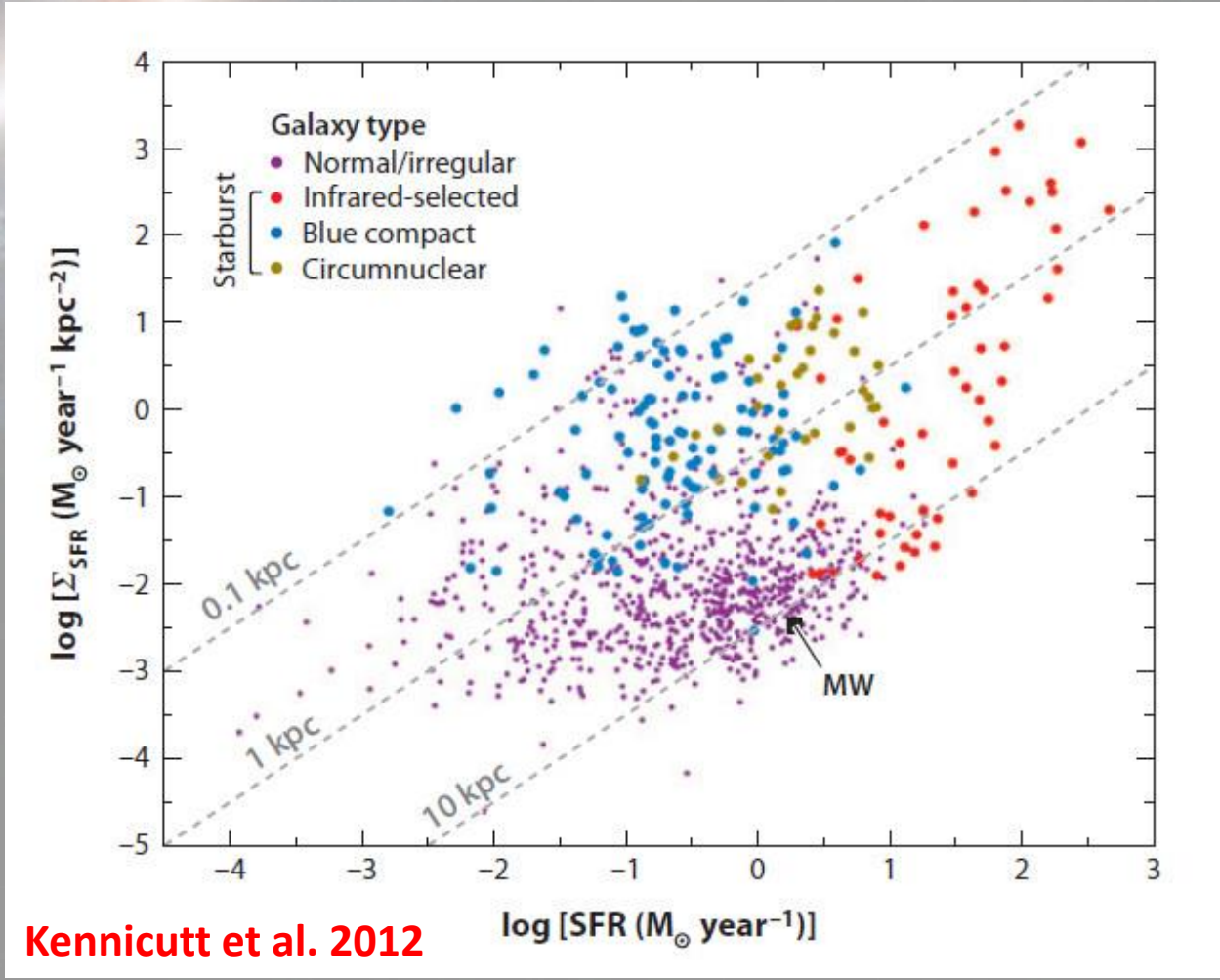

Modica et al. 2012

# Luminous Infrared Galaxy (LIRG)

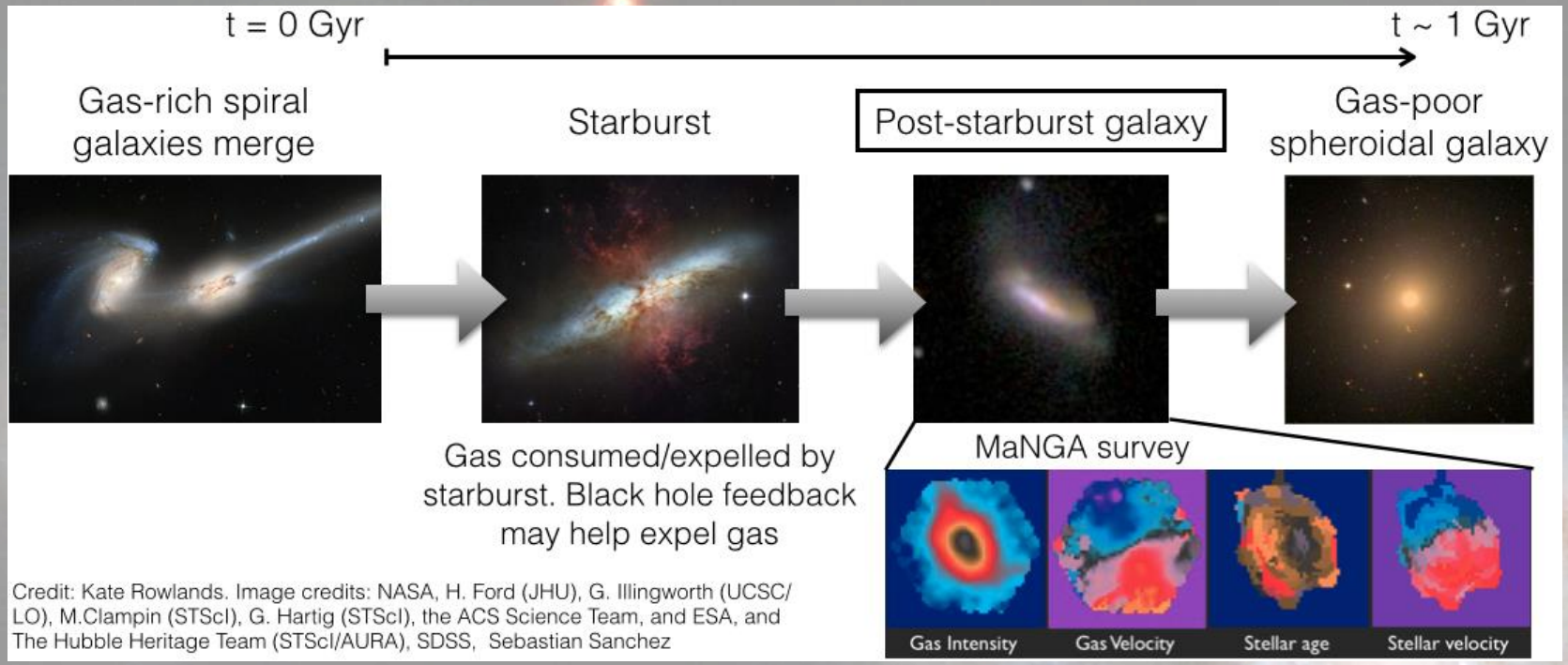



Galliano 2004

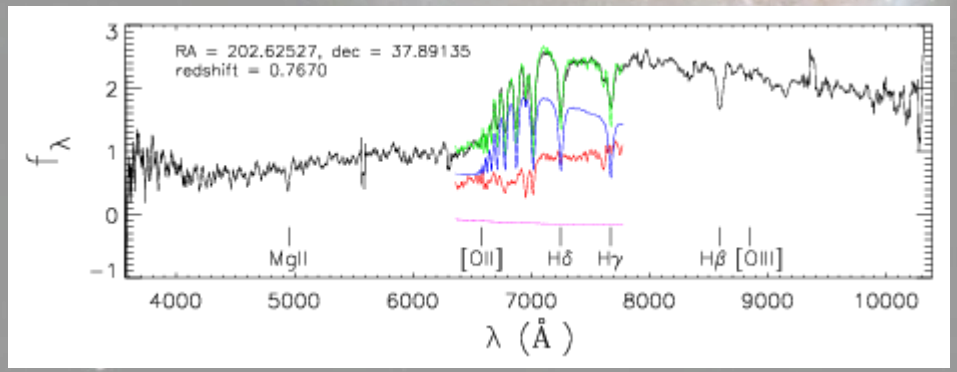
# Luminous Infrared Galaxy (LIRG)




Kennicutt et al. 2012



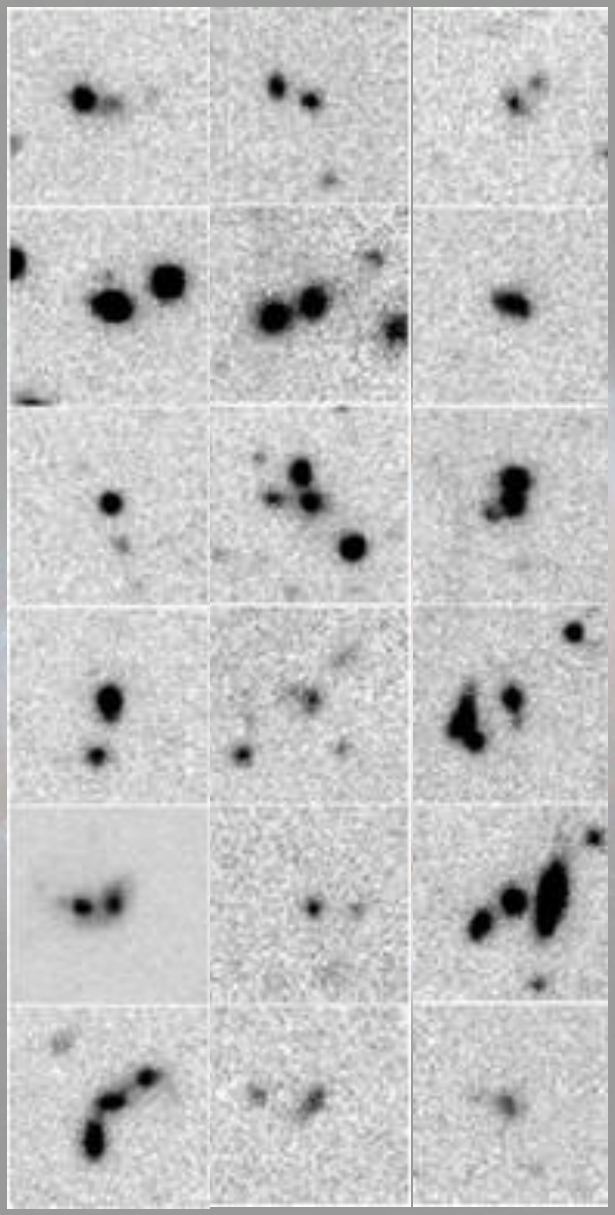

- Post starburst galaxy (E+A galaxy)
  - Balmer absorption (recent star formation within 1 Gyr), A type star
  - Elliptical spectra



# Merger Rate

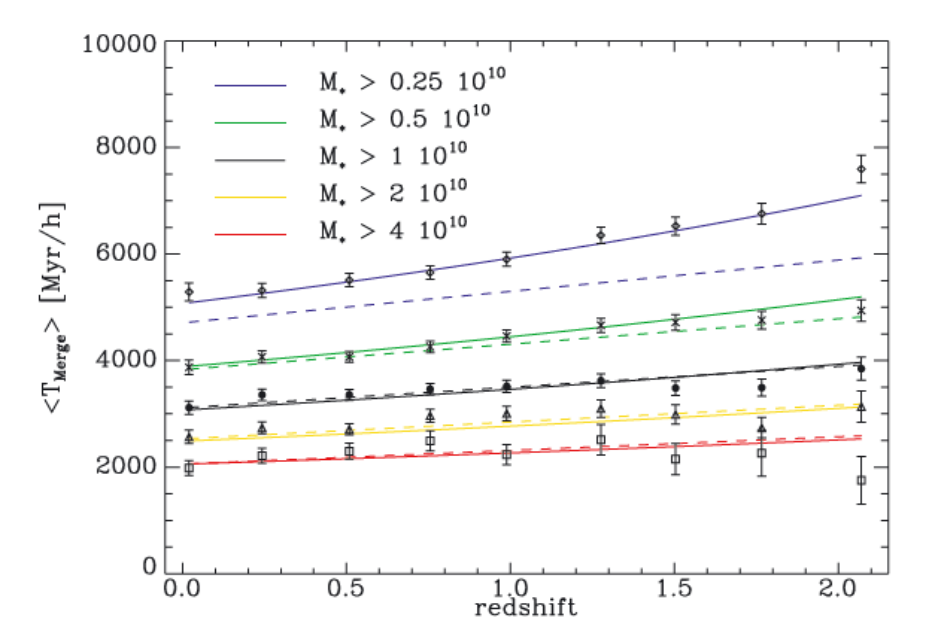
- Method
  - Pairs of galaxies (priori)
  - Merger remnants, shapes (posteriori)
- Both methods require a time scale
  - Timescale for the pair to merge (vs. mass and separation)
  - Timescale for features visibility (vs. redshift, type of feature …)
- At high redshift z>1: pairs
  - Faint tails/wisps lost to (1+z)4

  Surface brightness dimming



# Merging rate from pair fraction

- Kitzbichler & White (2008) merge timescale of close pair (major merger)

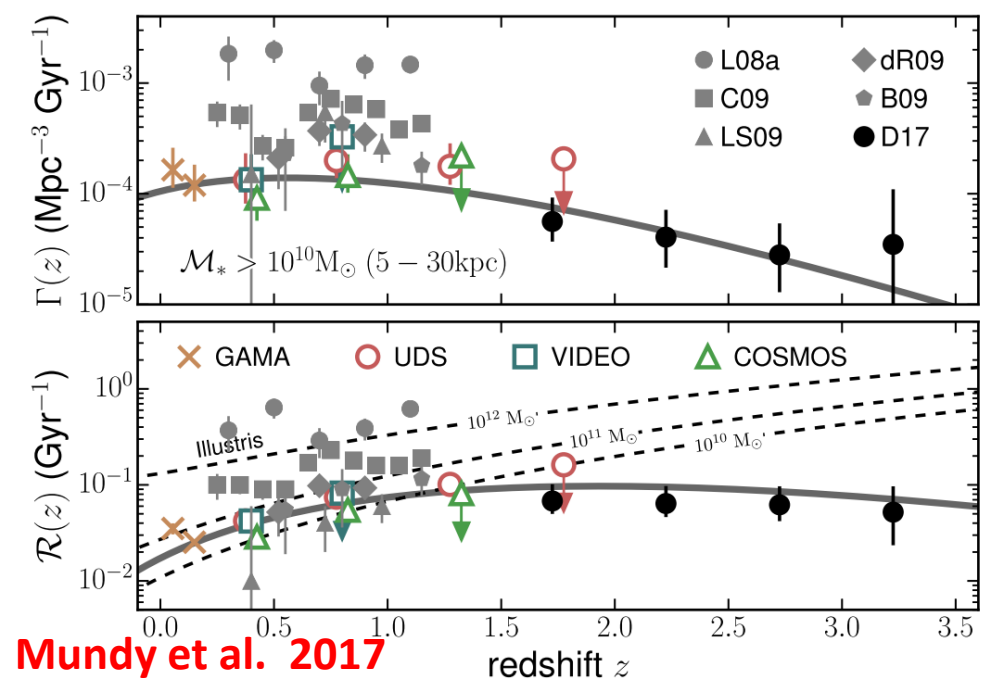



$$\langle T_{\rm merge}\rangle = 2.2\,{\rm Gyr}\frac{r_{\rm p}}{50\,{\rm kpc}}\left(\frac{M_*}{4\times10^{10}\,h^{-1}\,{\rm M}_\odot}\right)^{-0.3}\left(1+\frac{z}{8}\right)$$

# Evolution of Merge Rate

$$\Gamma_{\rm merg}(z) = \frac{\phi_{\rm merg}(z)}{\langle T_{\rm obs}\rangle} = \frac{f_{\rm merg}(z) n_1(z)}{\langle T_{\rm obs}\rangle} \quad ({\rm Mpc}^{-3}\ {\rm Gyr}^{-1})$$

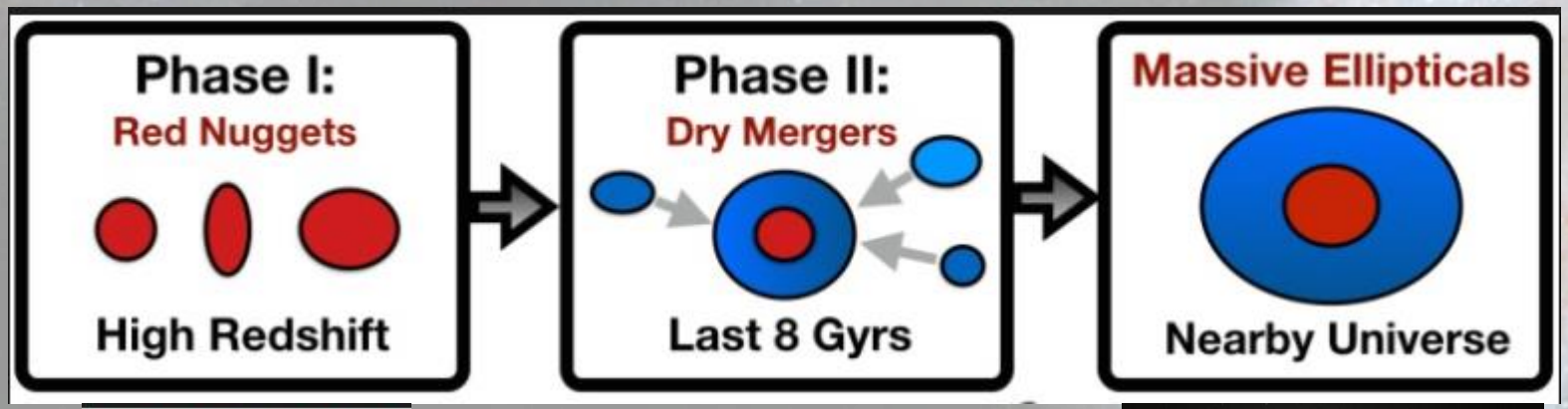
$$\mathcal{R}_{\rm merg}(z) = \frac{f_{\rm merg}(z)}{\langle T_{\rm obs}\rangle} \quad ({\rm Gyr}^{-1})$$




Mundy et al. 2017

# Formation of Massive Elliptical

- Phase I: Gas rich major merger ➔ Compact red galaxy (Red Nuggets)
- Phase II: Gas poor minor merger ➔ Compact core + Extend envelop




Huang et al. 2016