The bivariate luminosity function of galaxy pairs

Shiyin Shen (沈世银), Shuai Feng(冯帅)

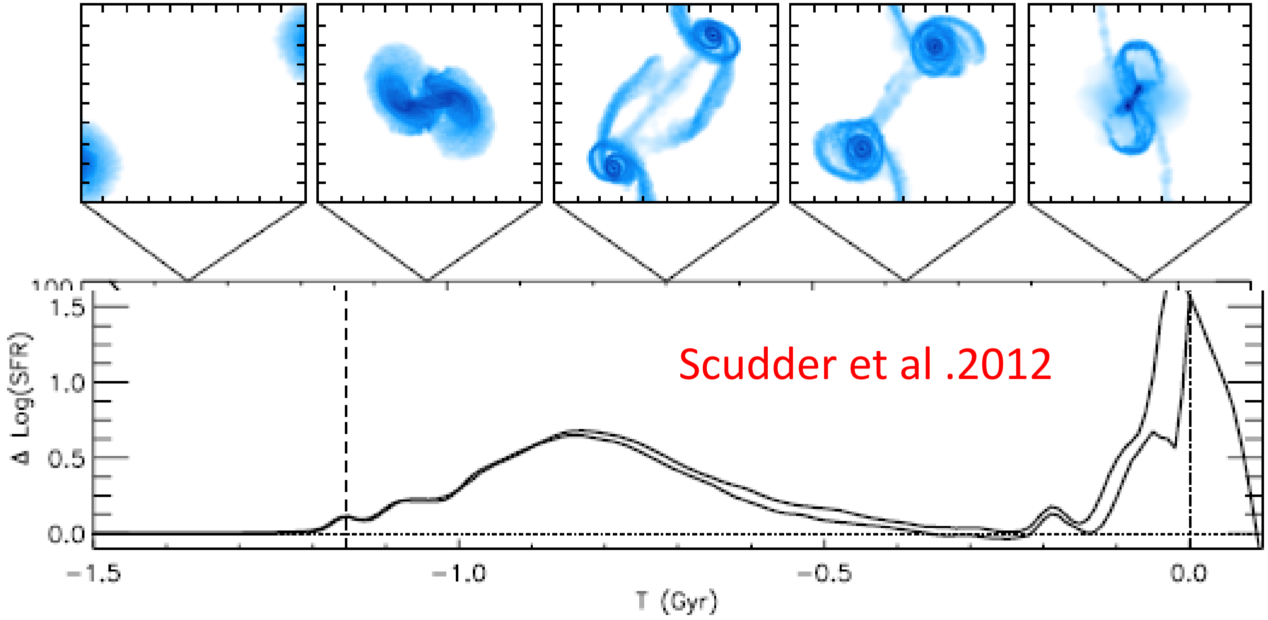
Shanghai Astronomical Observatory (上海天文台)

Outlines

- **Why measure bivariate LF of galaxy pairs?**
- **Measure it.**
- **Interpret and model it.**

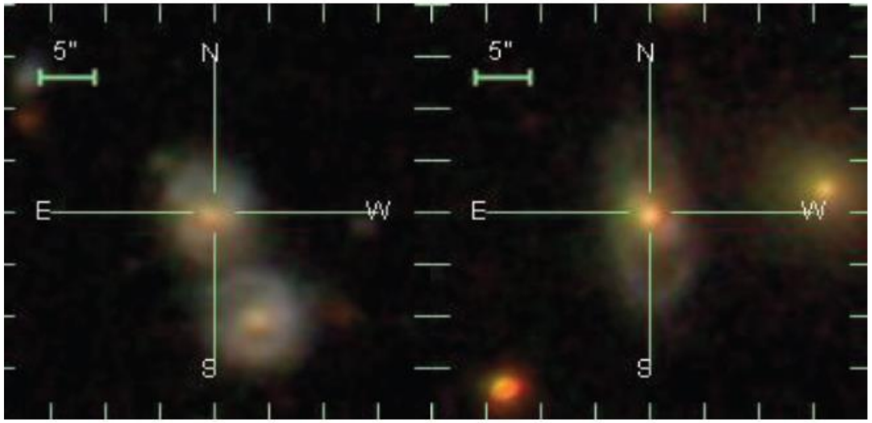
Galaxy merging

- One of the main channel of galaxy formation and evolution
- global merging time scale 1-2 Gyr
  - Depends on many physical parameters(e.g. mass ratio, orbit….)
  - time mainly in the phase of galaxy pairs



Galaxy pairs

- Close enough
  - $d_p < \sim 100$ kpc



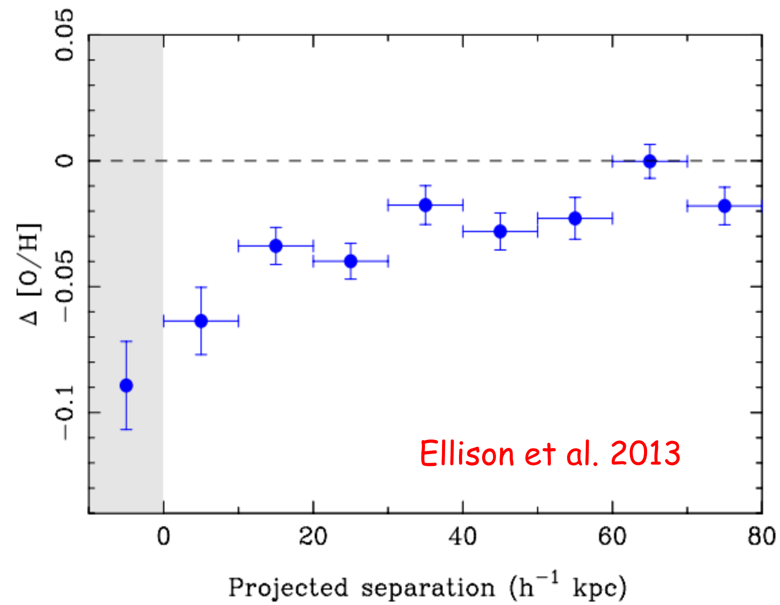
- Dynamical bound?
  - dV < ~ 500 km/s

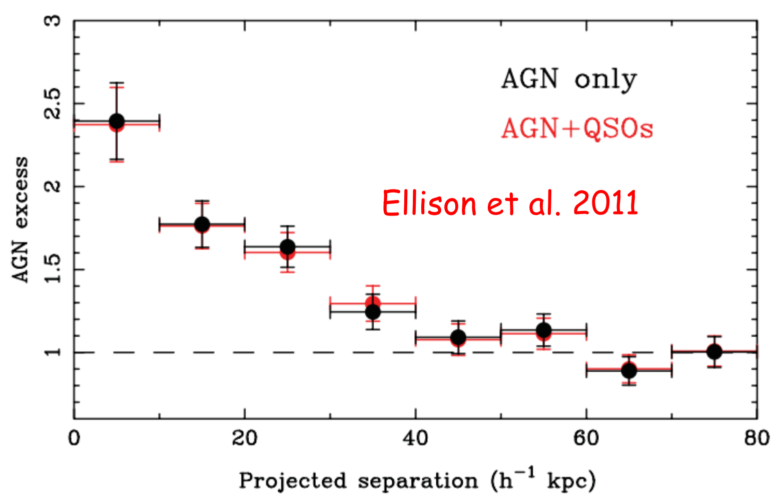
- Compare with field galaxies
  - Control sample (e.g. M*, Morphology etc.)
  - At what distance, pairs start to show strong interactions?
    - $d_p < 50$kpc (close pairs)
    - $d_p > 50$kpc (wide pairs)

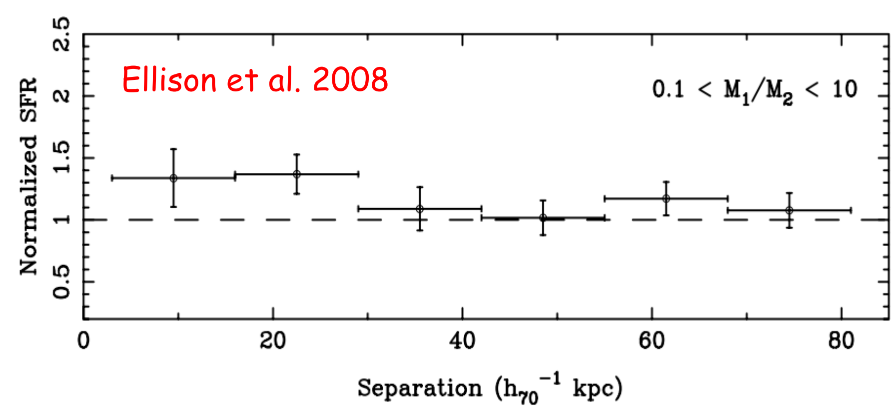
Galaxy-galaxy interaction

Compare with field galaxy, galaxies in close pairs (d_p < 50kpc) show

- Enhanced star formation rate
- Diluted nuclear gas-phase metallicities
- Overabundance of AGN
- ...







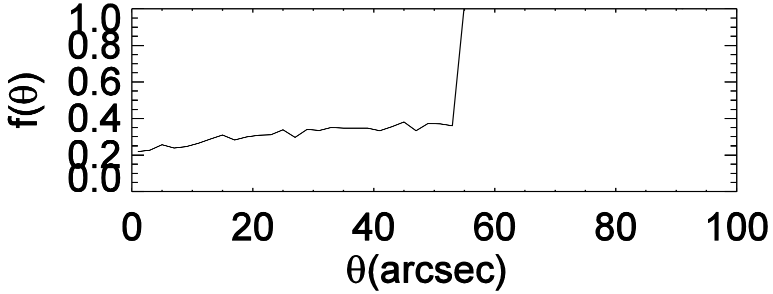
What missed in control sample studies?

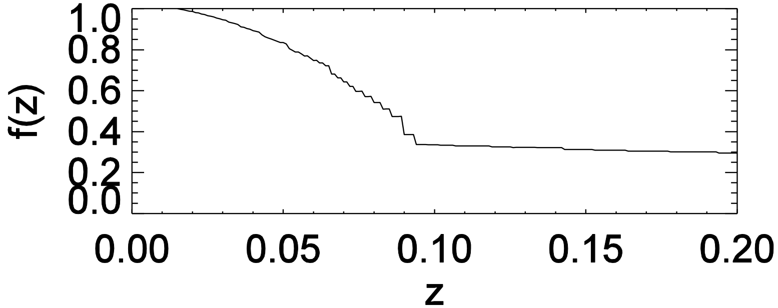
- Relative frequency of galaxies of M* in pairs
  - If high stellar mass galaxies are less frequent in pairs because of shorter merging time scale?
  - $\Phi(M*)$
- The dependence of the galaxy properties on its companion
  - $\Phi(M1 \mid M2)$

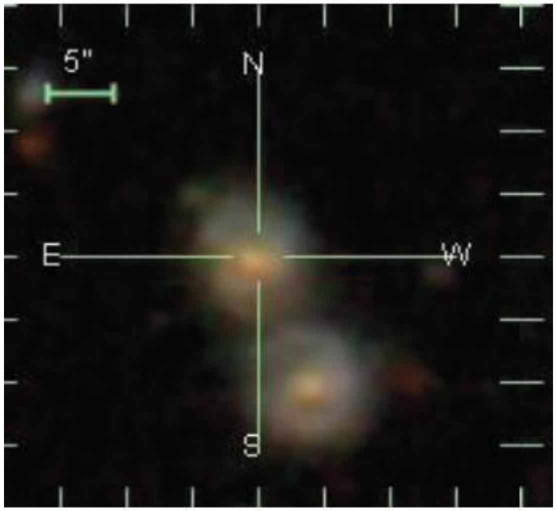
BLF of galaxy pairs $\Phi(M1, M2)$ provide a comprehensive description of galaxy-galaxy interaction

Galaxy pair sample

- SDSS legacy: main galaxy sample (r<17.77)
  - N~700,000, spectroscopy completeness: ~91%
  - Fiber collision: (θ < 55″: ~30%)
- LAMOST spectral survey
  - Complementary galaxy sample (Shen et al. 2016)
  - ~10,000 new redshifts till LAMOST DR5
- Other redshifts (~20,000)
  - SDSS DR14 , GAMA, 2dfRs …
- Final sample
  - 10kpc < d_p < 200kpc and |Δv|<500km/s
  - Each galaxy have only one neighbor (Isolated)
  - 56,808 galaxy pairs







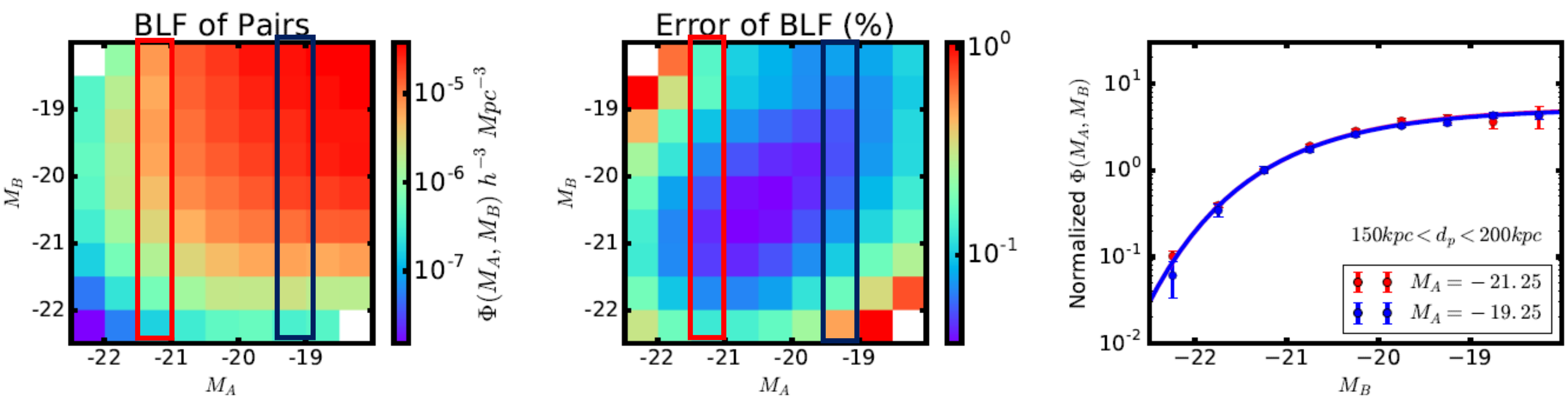
Bivariate Luminosity Function

- Method: Step-wise maximum likelihood (Efstathiou+1998, Sodre+1993)

$$p_i = \frac{\Phi(A_i, B_i) C_{\rm pair}(\theta_i)}{\int_{A_{\max}(z_i)}^{A_{\max}(z_i)} \int_{B_{\min}(z_i)}^{B_{\max}(z_i)} \Phi(A, B) C_{\rm pair}(\theta) dA dB} \qquad \mathscr{L} = \prod^{N_{\rm p}} p_i$$

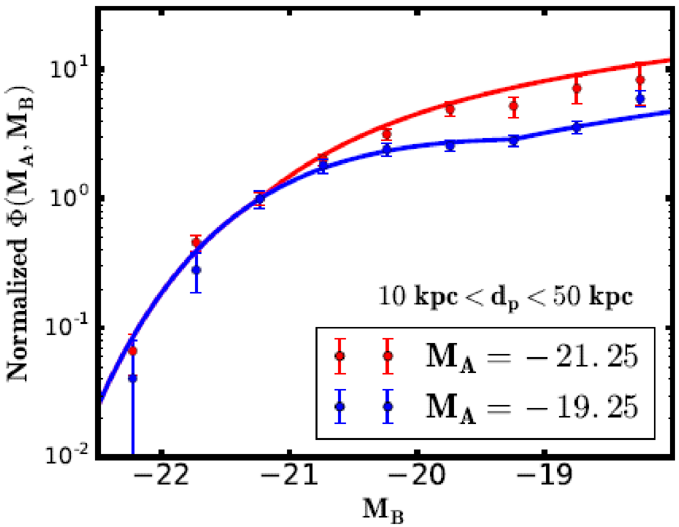
- BLF map and error map

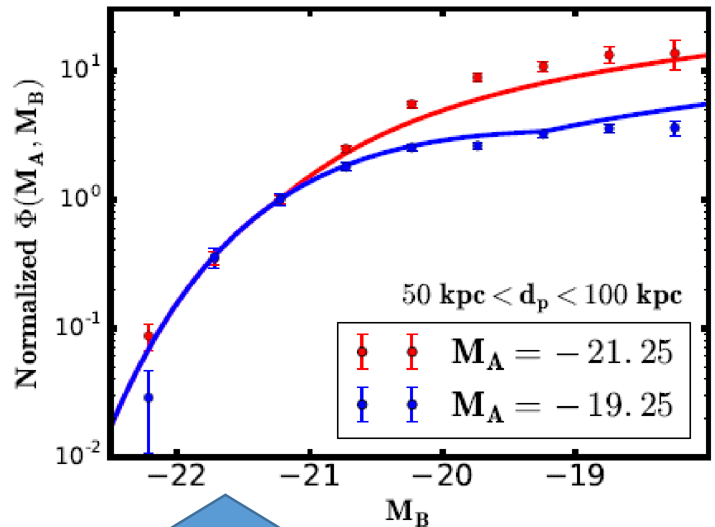
  ➔Conditional Luminosity Function



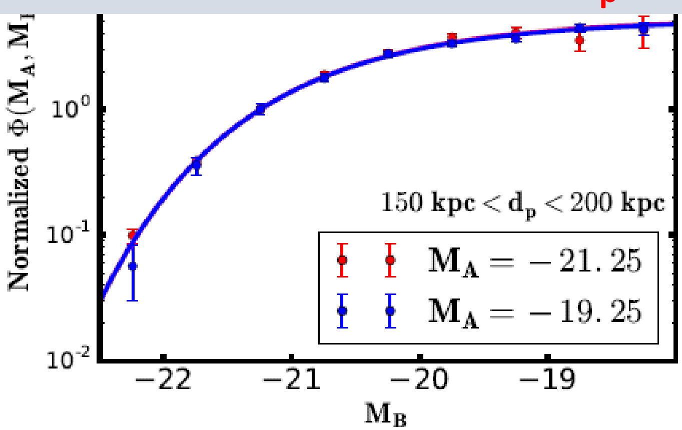
BLF Result

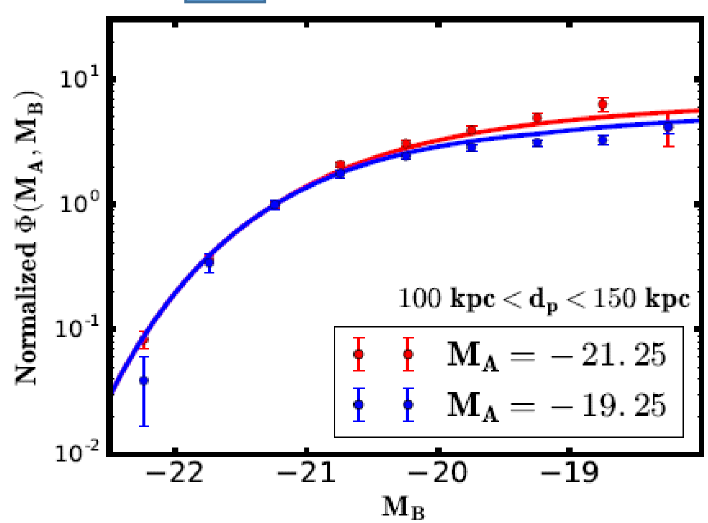
Conclusion II: At d_p~50 kpc, major merger pairs are less frequently than random assembly prediction





Conclusion I: there is no interaction between pair members at d_p>150kpc





Why major merger pairs are less frequent?

- Dynamic friction: driving two bounded galaxies getting close until merge.
- Numerical simulation
  - Mass ratio

$$T_{\rm df} \sim (\frac{M_{\rm host}}{M_{\rm sat}})^a$$

    - 0.4 < a < 1.3 (Colpi+1997, Kitzbichler+2008, Jiang+2008)
  - Host halo mass (Jiang+2014)

$$T_{\rm df} \sim M_{\rm host}^{-1/3}$$

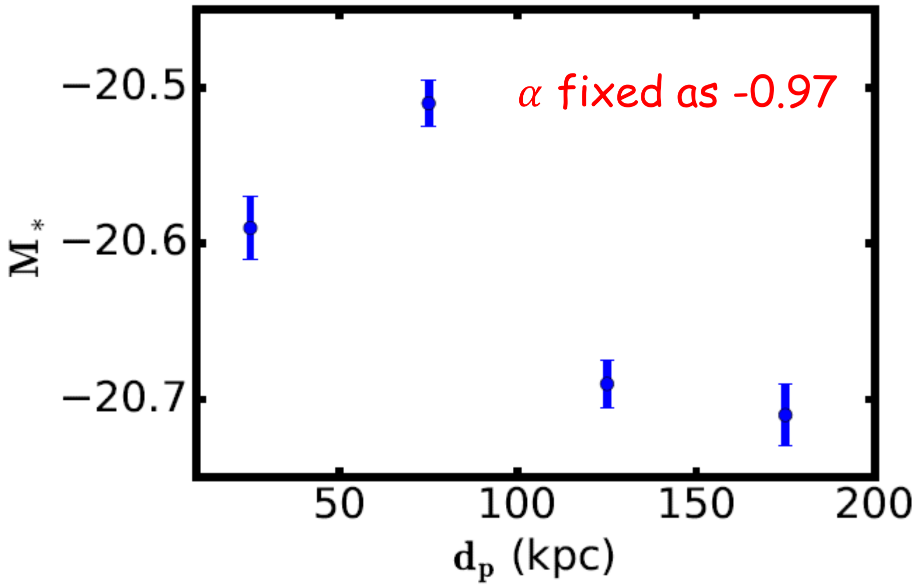
- Life time of massive major merger pairs is shorter.
  - therefore less frequent in statistical studies

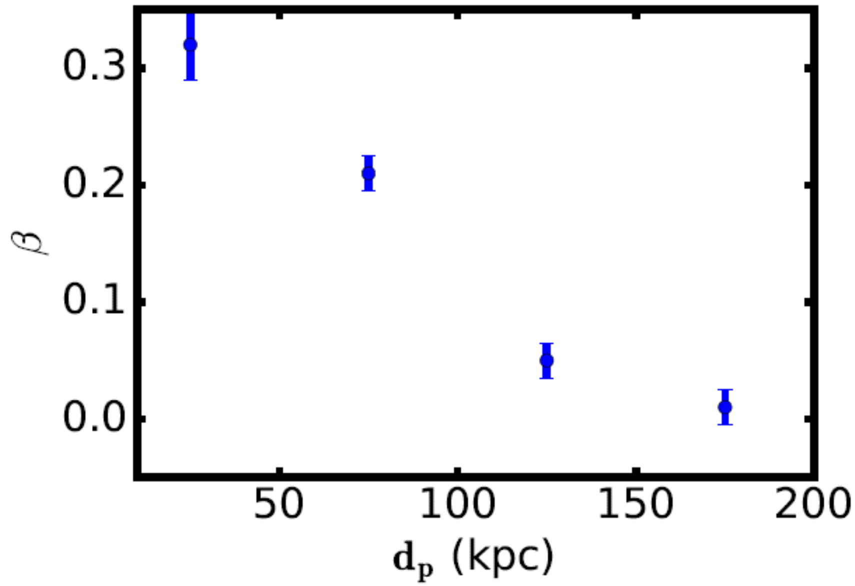
Parameterization of BLF

$$\Phi_{Pair}(M_A, M_B) \propto \Phi_{Sch}(M_A)\Phi_{Sch}(M_B)10^{0.4|M_1 - M_2|\beta}$$

- Interaction term: β (dynamical friction)
  - $\beta = 0$: random assembly
  - $\beta > 0$: favorite more minor mergers

- What happens to M*?



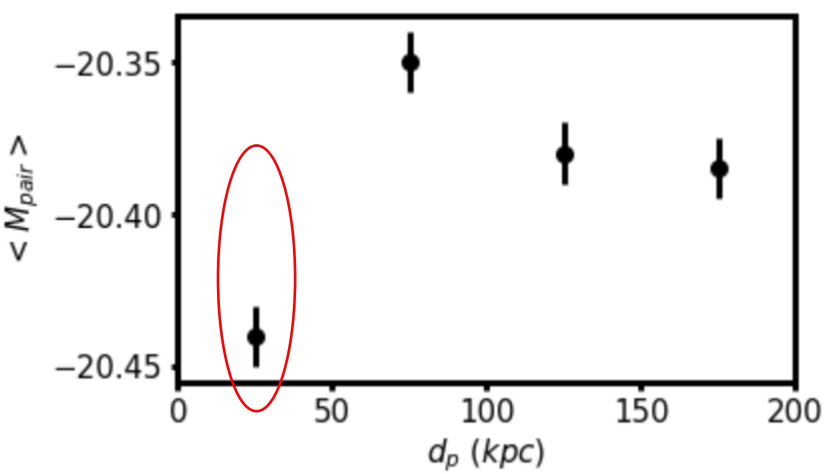


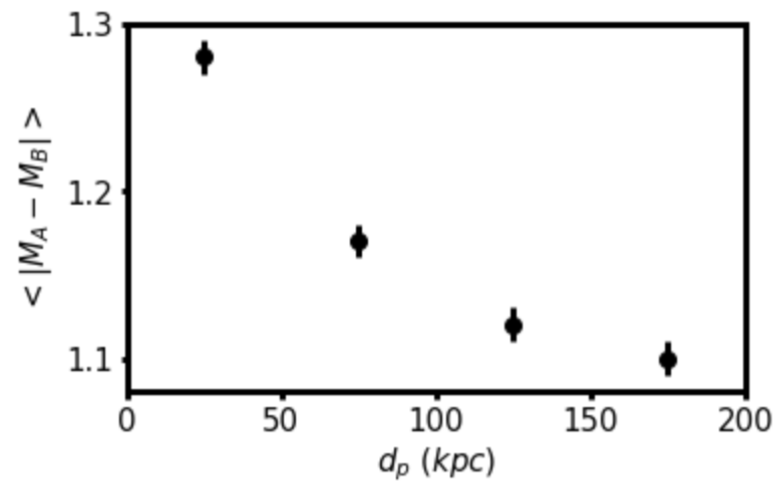
Another simpler parameterization

- M_{pair}: global pair luminosity
- $|M_A - M_B|$: magnitude difference

} (M_A, M_B)

- Merging time scale effect
  - Decreasing fraction of major merger pair ($< |M_A - M_B| >$ ↑)
  - Decreasing fraction of massive pair ($< M_{pair} >$ ↑)
- $< M_{pair} >$ becomes brighter at d_p~30kpc
  - Enhanced star formation!





Modelling merging time scale effect

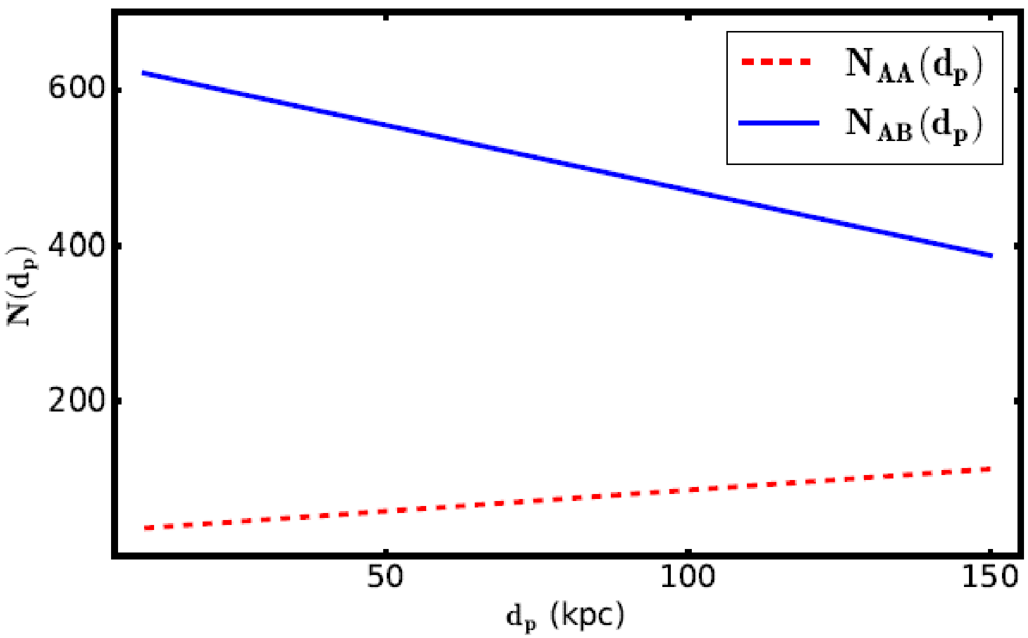
- Pair birth rate: randomly assembly

$$\dot{\Phi}(L_A, L_B) \propto \Phi_0(L_A)\Phi_0(L_B)$$

- Observed number density of pairs

$$N(L_A, L_B) \propto \Phi_0(L_A)\Phi_0(L_B)T_m(L_A, L_B)$$

$$T_m(L_A, L_B) \sim T_m(L_1, L_2) \sim (\frac{L_1}{L_2})^a (L_1 + L_2)^b$$



Boundary conditions:

1. Pairs born at d_p=150 kpc

$$N(L_A, L_B, d_{max}) \propto \dot{\Phi}_{L_A, L_B}$$

2. d_p distribution of the global pair sample is flat

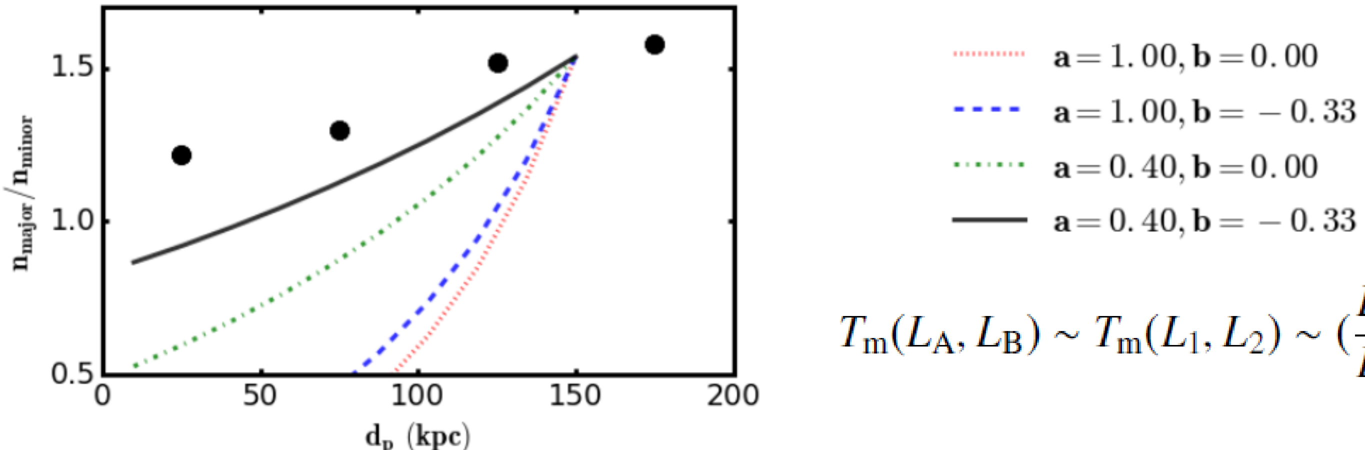
From Numerical simulation: merge timescale depends on:

- Mass ratio

$$T_{\rm df} \sim (\frac{M_{\rm host}}{M_{\rm sat}})^a$$

  - 0.4 < a < 1.3 (Colpi+1997, Kitzbichler+2008, Jiang+2008)
- Host halo mass (Jiang+2014)

$$T_{\rm df} \sim M_{\rm host}^{-1/3}$$



$$T_{\rm m}(L_{\rm A}, L_{\rm B}) \sim T_{\rm m}(L_1, L_2) \sim (\frac{L_1}{L_2})^a (L_1 + L_2)^b$$

a~0.4, b~-0.3

First observational evidence on merging time scale of galaxy pairs

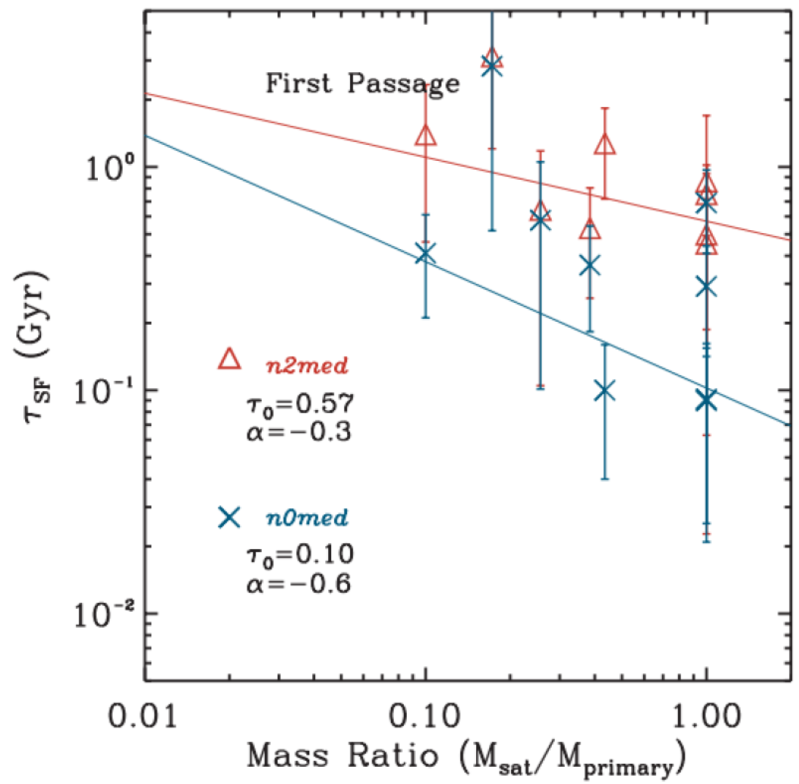
Enhanced star formation at d_p~30 kpc

- Extra young stars → Brightening
- Only happens on gas-rich galaxies
  - Enhanced star formation efficiency: (f_Δ ~ 1-2 ?)

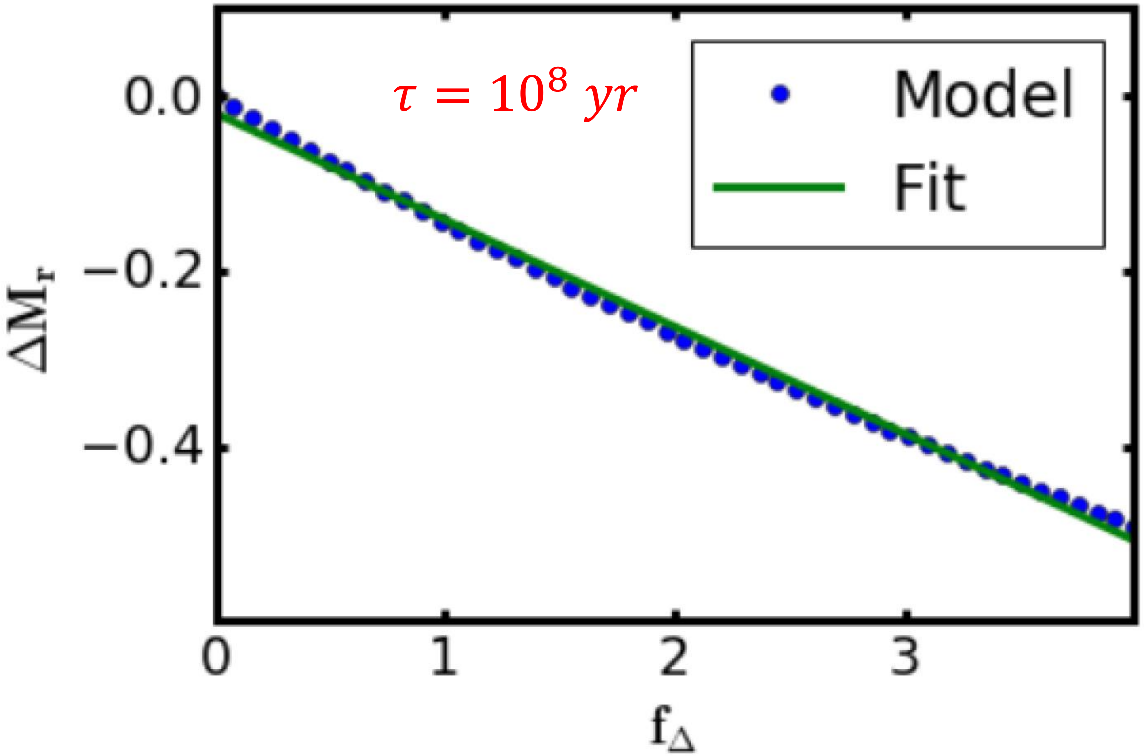
$$\mathrm{SFR} = \mathrm{SFR}_0 + \Delta\mathrm{SFR} = (1 + f_\Delta) * \mathrm{SFR}_0$$

  - time scale of enhanced star formation phase
    - τ ~10% percent of the merging time scale: ~ 10^8yr

Cox et al. 2008

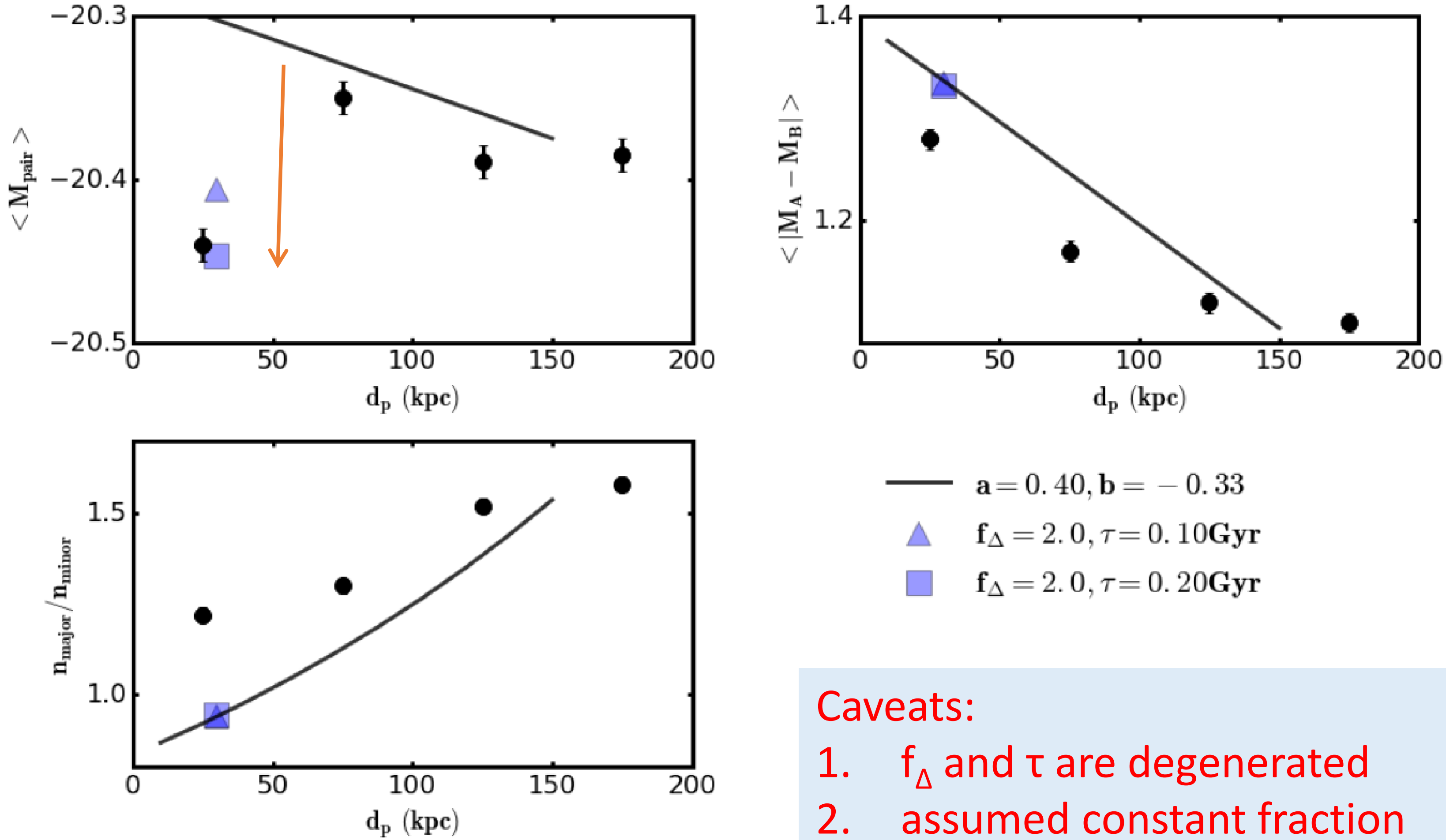


Parametrization of enhanced star formation



$$\Delta \bar{M}_r \sim -0.12(\frac{f_\Delta}{1})(\frac{\tau}{10^8 yr})(\frac{\Upsilon_{r,0}}{1.35})(\frac{0.13}{\Upsilon_{r,n}}) - 0.02\,.$$

How brightening reshapes BLF?



Caveats:

1. f_Δ and τ are degenerated
2. assumed constant fraction of gas-rich galaxies

Ingredients of galaxy pair evolution

I: Galaxies start to show interactions from d_p ~150kpc

II: Dynamic friction drives massive and major merger pairs merging more rapidly.

- $|M_A - M_B|$ ↑ & M_{pair} ↑ with decreasing of d_p

III: Enhanced star formation happens only when galaxies are close enough d_p~ 30kpc

Summary (Feng et al. 2019, in preparation)

- We first time measure and parameterize the bivariate luminosity function(BLF) of galaxy pairs
  - which provides one of the most comprehensive description of the galaxy-galaxy interaction in pairs.

- From BLF of galaxy pairs, we show
  - galaxies start to have interaction from d_p ~150kpc, larger than previous thoughts;
  - observation evidence that galaxy merging time scale is shorter for massive and major merge pairs;
  - galaxies at very close galaxy pairs ($d_p \sim 30$ kpc) are brightened by enhanced star formation
    - efficiency $f_\Delta \sim 3$ and time scale ~2×10^8 yr.