History of Mergers & Impact on SF history over 7 Gyr

Shardha Jogee

University of Texas (UT) Austin

Jogee et al & GEMS team 2008, ApJ, submitted

Jogee (2008; IAU 254 review;astroph/0810.5617)

Collaborators

- S. Miller, K. Penner , GEMS collaboration (H. W Rix, R. Skelton, R. Somerville, E. Bell, C. Wolf, Z. Zheng, M. Barden, A. Robaina) & C. Conselice
- Models from : A. Benson, P. Hopkins, S. Khochfar, A. Maller, R. Somerville
- I. Marinova, T. Weinzirl, A. Heiderman, F. Barazza

Goals

1) Provide empirical constraints on major + minor merger history out to z~1

2) Compare results from different methods

3) Compare with predictions from LCDM-based models

4) By how much is <SFR> enhanced in normal vs visibly interacting galaxies?

5) What % of the SFR density comes from visibly interacting galaxies ?

What is relative importance of different galaxy assembly modes as f(z) : major mergers, minor mergers, cold gas accretion, secular modes

Galaxy Interactions and their Impact on SF over 7 Gyr

Jogee et al & GEMS team 2008, ApJ, submitted

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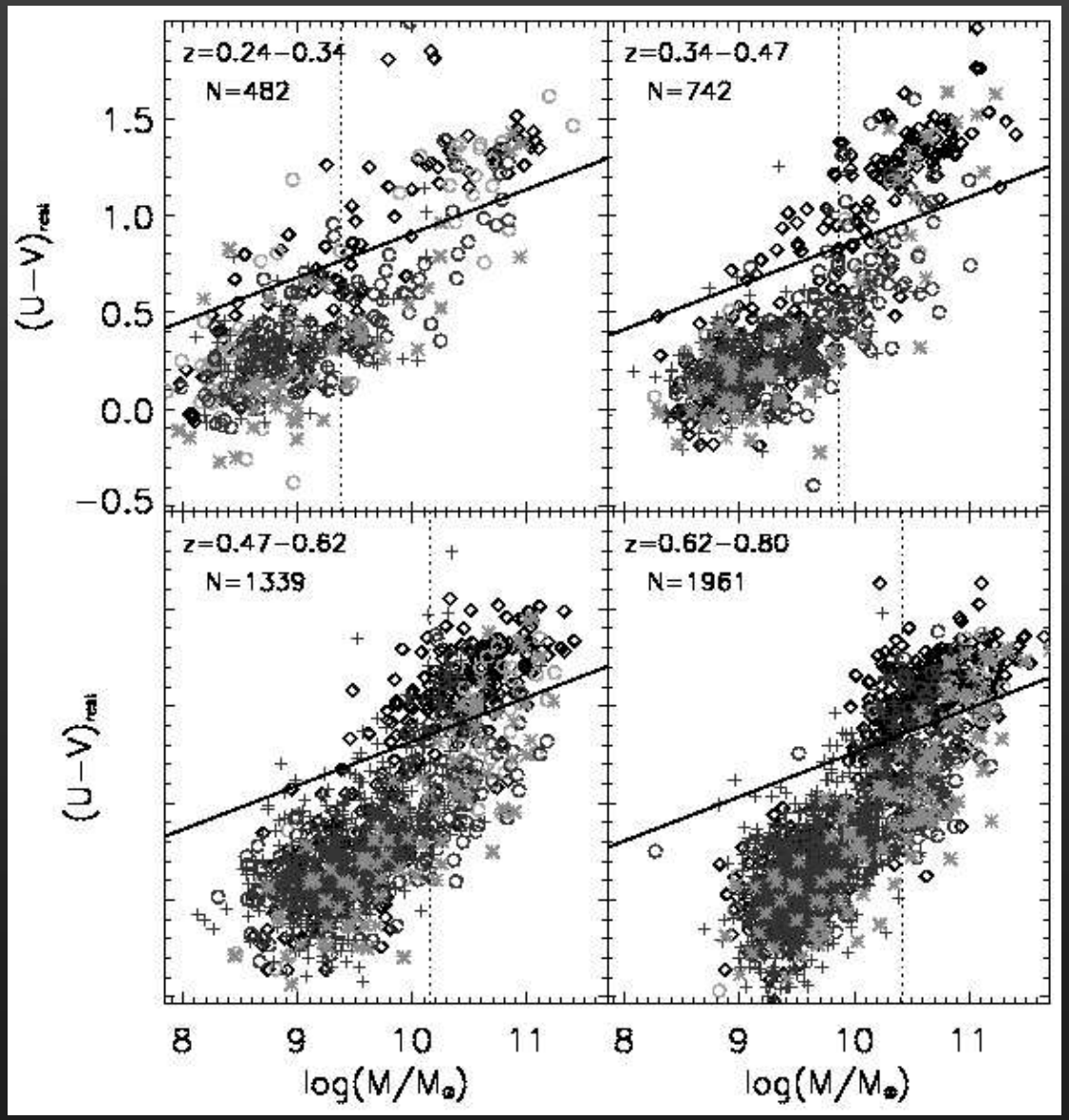
Ingredients

- 4500 galaxies (R<24) over z=0.24 to 0.80 (T_{back}~3 to 7 Gyr)
- ACS F606W high resolution images from GEMS survey (Rix et al 2004)
- Spectro-photometric redshifts ($\delta z/(1+z)$ ~0.02 down to R~24) and stellar masses from COMBO-17 (Borch et al 2006; Wolf et al 2004)
- UV and IR-based SFR from COMBO-17 & Spitzer (Bell et al 2007)

Two Samples: High Mass & Intermediate Mass



- z ~ 0.2 to 0.8 (T_{back}~3 to 7 Gyr) Divide into four 1 Gyr bins

- High mass ($M/M_0 >= 2.5x10^{10}$): Complete for red seq and blue cloud : N~800 galaxies

- Interm mass ($M/M_0 >= 1x10^9$): Complete for blue cloud only N~3700 galaxies

- Orange =interacting galaxies

Jogee et al 2008

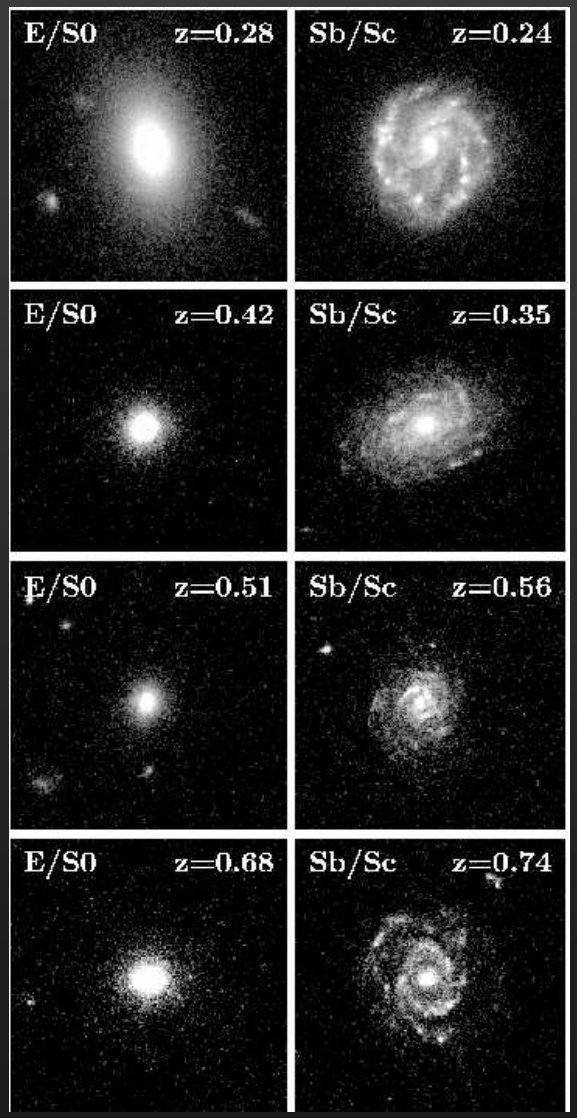
Methodology : identifying interacting galaxies

Method 1
Physically-driven visual classification of ~3700 galaxies by 3 classifiers

Method 2
Automated CAS criterion : A > 0.35 and A>S (A =asymmetry, S=clumpiness)

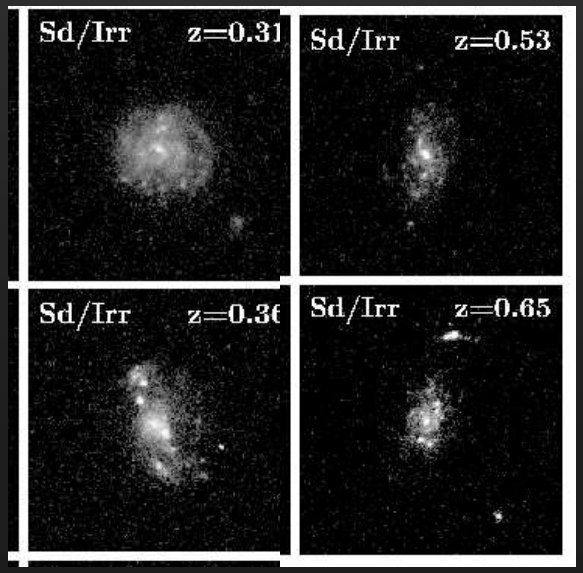
Visual classification of Interacting vs Non-Interacting Galaxies

Non-interacting E-Sd



Non-Interacting Irr1

Galaxies with small –scale asymmetries that can be internally triggered (e.g., via stochastic SF or low V/σ) without any galaxy-galaxy interactions.

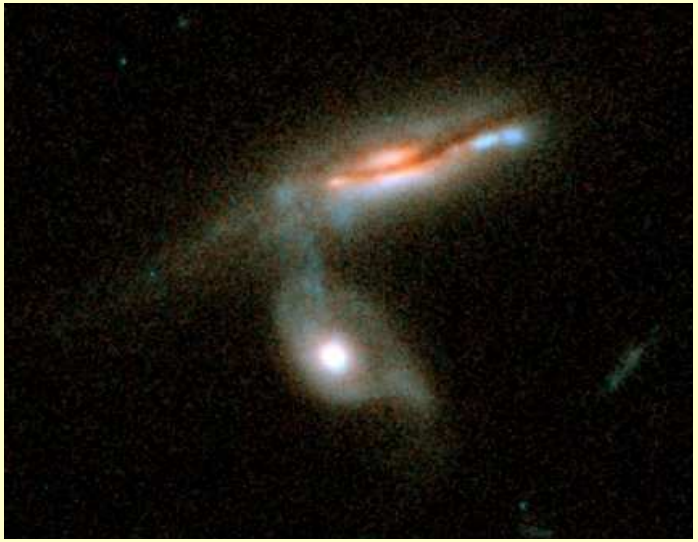


Interacting

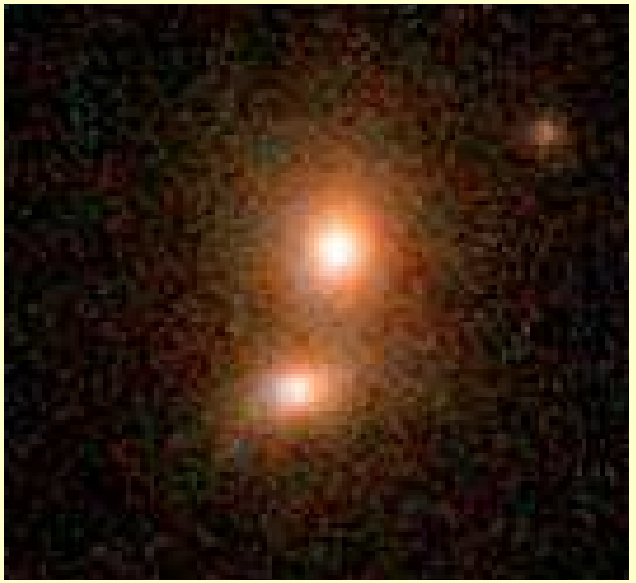
Galaxies w/ morphological distortions that require a strong external trigger, typically an interaction of mass ratio M1/M2>1/10

e.g., tidal tails, warps, strongly asymmetric arms, double nuclei, galaxies bounded by a common body or bridge

Example of interacting galaxies



2 at similar z



2 at similar z

Separate interacting galaxies into major minor, major/minor

Interacting

Galaxies w/ asymmetries and features that require a strong external trigger, typically an interaction of mass ratio M1/M2>1/10

Clear Major (M1/M2>1/4)

- Double nuclei same L
- Contact pair w/ M1/M2>1/4 and z1~z2
- Train wreck

Clear Minor (1/10 < M1/M2 <1/4)

- Contact pair with M1/M2 ~1/4 to 1/10 and z1~z2
- Single system where disk has survived, but shows a warp or strong tidal signatures

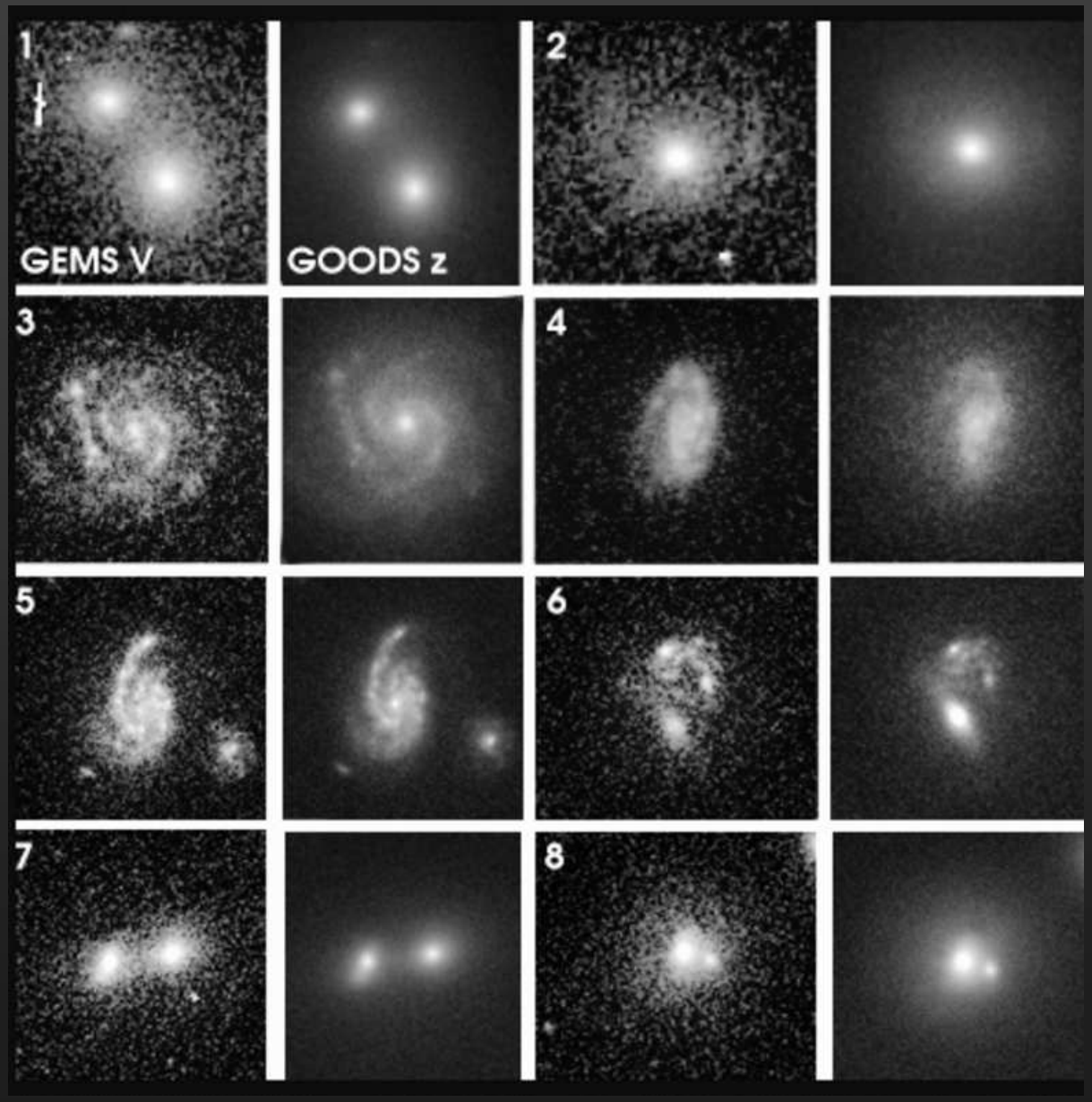
Ambiguous: Major or Minor

% of clear majors

% of clear minor

% of minor or major

Test effect of bandpass shift and SB dimming on visual f



- In last bin z =0.6--0.8
  - rest-frame λ of GEMS V image shifts to near-UV (3700-3290 A)
  - SB dimming by factor of 8

- Compare f from GEMS v vs deep, redder GOODS z

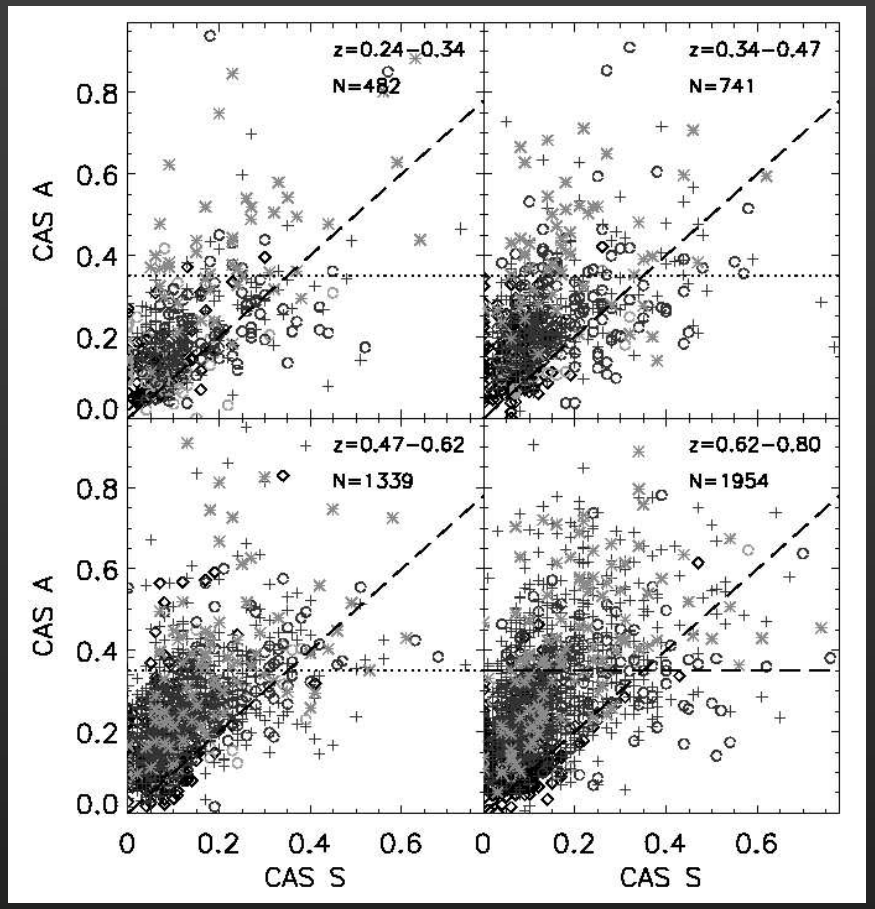
- Results changes by less than 1.07

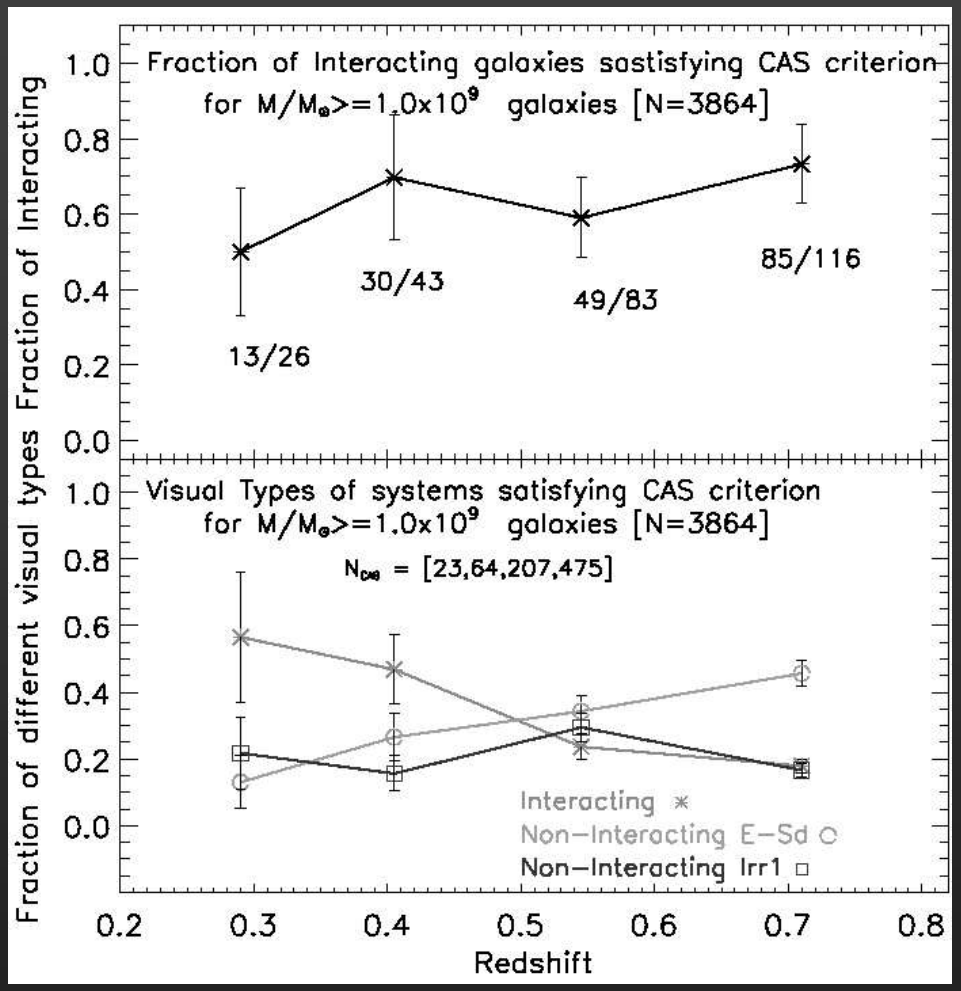
Methodology : identifying interacting galaxies

Method 1
Physically-driven visual classification of ~3700 galaxies by 3 classifiers

Method 2
Automated CAS criterion : A > 0.35 and A>S (A =asymmetry, S=clumpiness)

Interaction fraction from CAS vs visual classifications

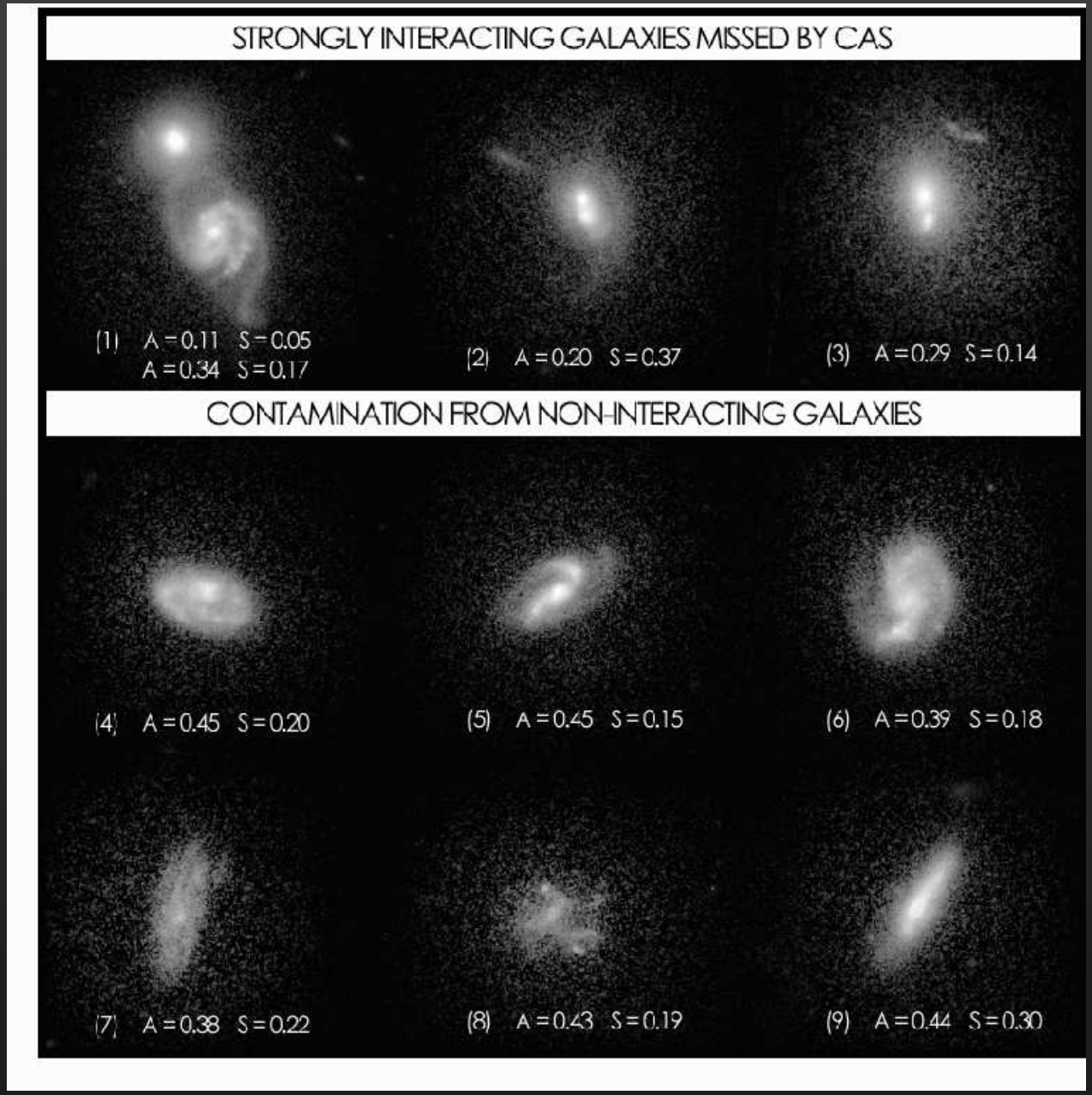




What are the visual types of the M*>1e9 systems picked by the CAS criterion (A>0.35 and A>S) ?

1) 44% (z~0.3) to 80% (z~0.7) are visually-classified <u>non-interacting</u> (Irr1, E-Sd) galaxies
   à high contamination from non-interacting systems especially at z>0.5

2) the remaining are visually-classified <u>interacting</u> systems [50% to 70% of latter are picked]

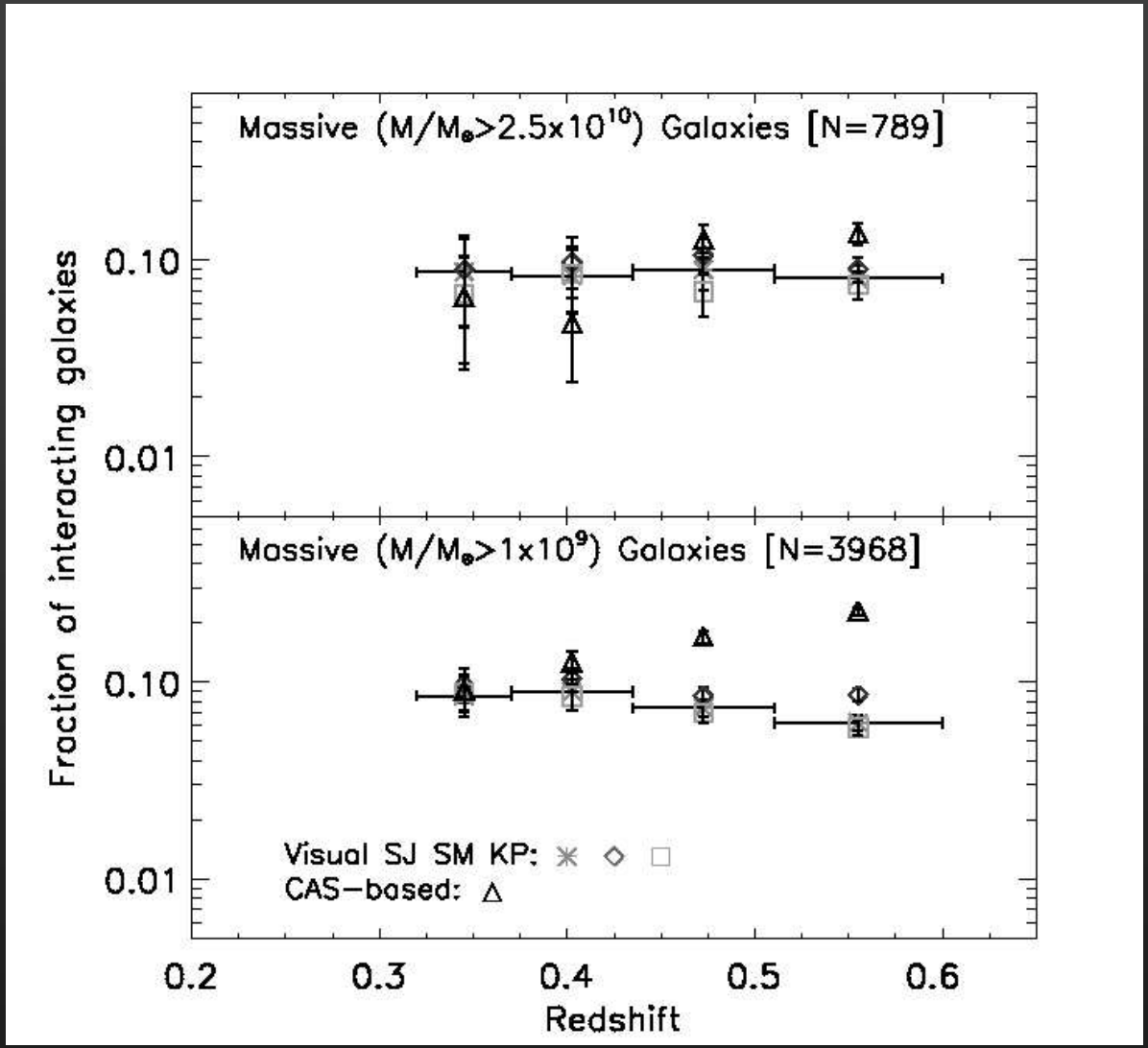


Interacting galaxies missed by CAS criterion (A>0.35,A>S)

Non-Interacting galaxies picked by CAS criterion (A>0.35,A>S)

Results

Interaction fraction from visual classifications versus CAS



Jogee et al 2008

- For high M/M$_\odot$>=2.5e10

CAS-based f agrees within a factor of less than two with visual f

- **For interm M/M$_\odot$>=1e9**

CAS method overestimates f by a factor of 3 at z>0.5… as it picks up a large number of non-interacting galaxies (E-Sd and Irr1)

Interaction history of massive galaxies since z~0.8 (last 7 Gyr)

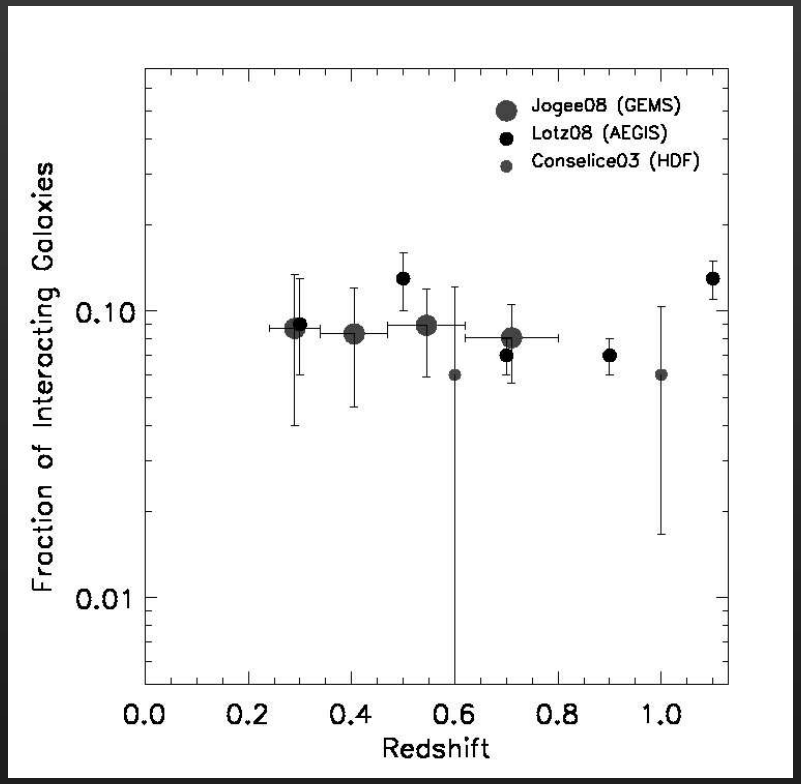
For high mass (M>=2.5e10) galaxies

Interaction fraction f (for mass ratio >1/10) ~ 8% to 9%

fraction of clear major (M1/M2>=1/4) interactions ~1% to 3%

fraction of clear minor (1:4 to 1/10) interactions ~ 4% to 8%

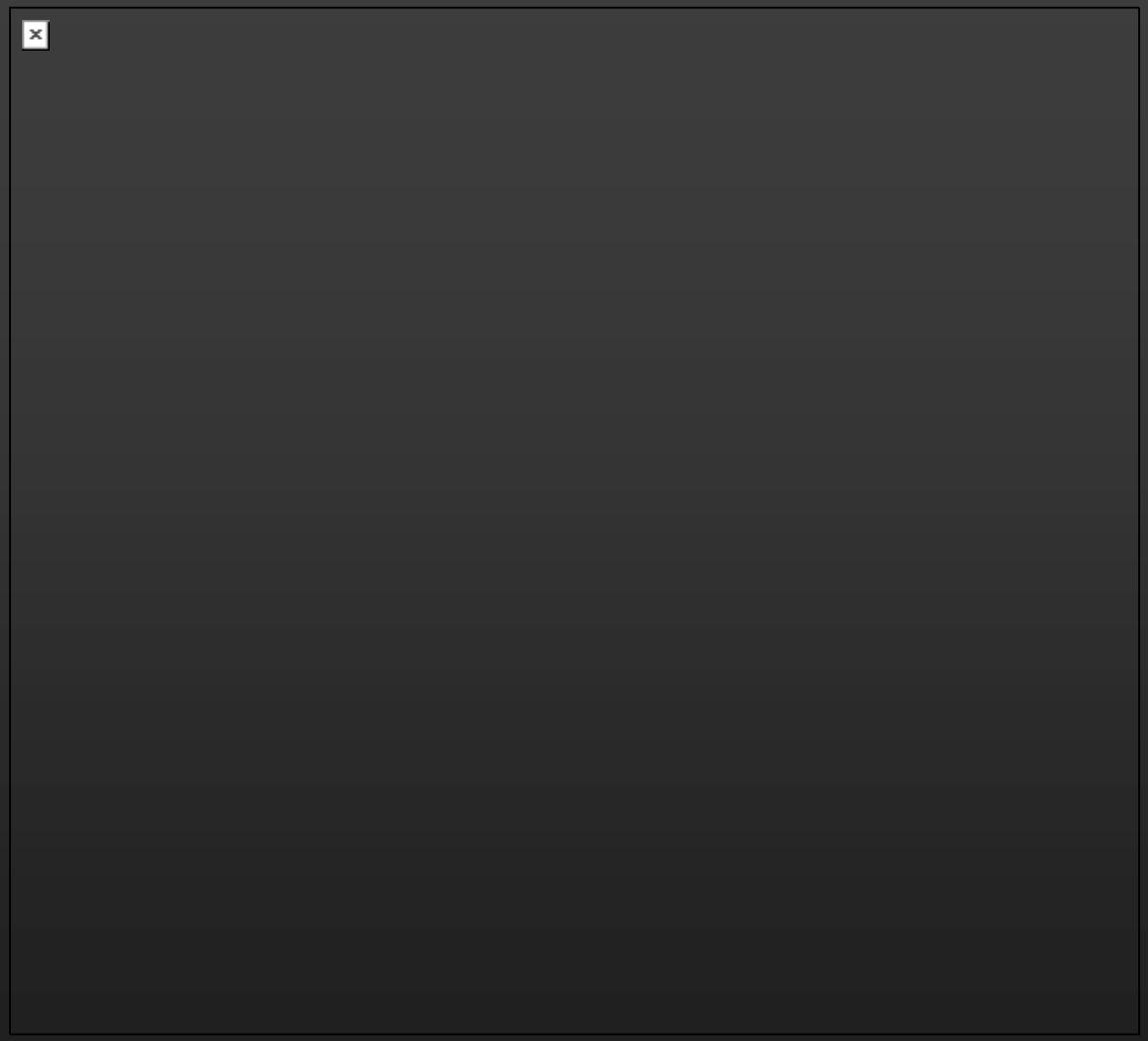
fraction of ambiguous minor or major interactions ~ 1% to 2%



Jogee et al 2008

For an assumed visibility time of 0.5 Gyr, this implies that over Tb=3-7 Gyr (z=0.2-0.8) , every massive galaxy has undergone 0.7 interactions of mass ratio >1/10, of which 1/4 are major mergers, 2/3 are minor mergers, and rest are major/minor.

Compare merger rate of galaxies with LCDM models



- Data
  Rate= n f /T_{vis} for (major+minor)

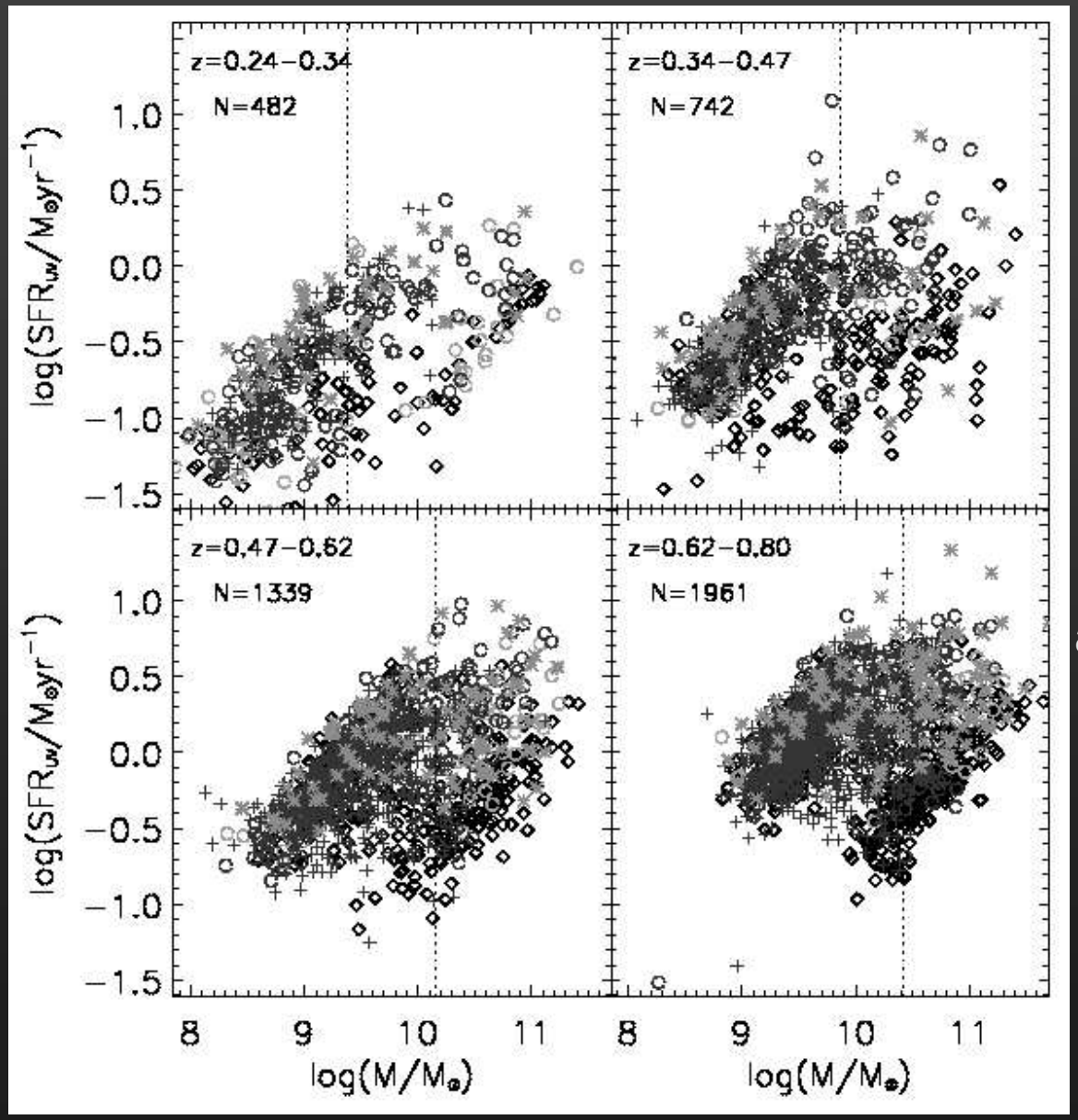
- Models
  solid line = f(major + minor)
  dotted lime = f_major

- Models
  - 3 SAMs w/ AGN feedback
  - HOD w/ AGN feedback
  - SPH cosmological

For high mass galaxies,the (major + minor) merger rate of models
- show factor of 5 dispersion
- bracket the observed rate & show qualitative agreement

Jogee et al 2008

SFR$_{UV}$ vs Mass



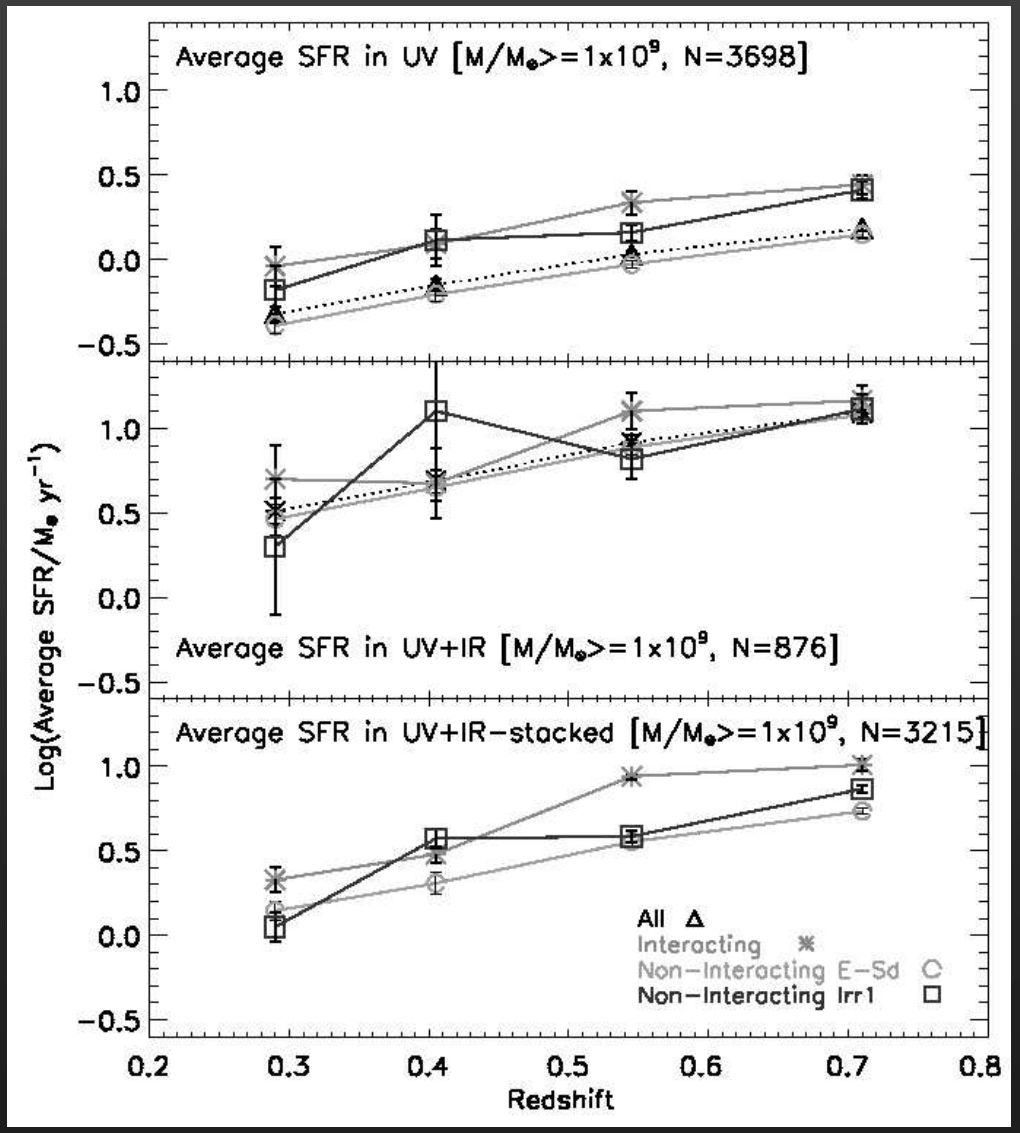
Total No of galaxies = 4524

SFR_{UV} ~ 0.1--25 M_o yr^{-1}

Median (SFR_{IR}/SFR_{UV}) ~ 4 for 900 galaxies with both Spitzer and UV data

à significant obscured SF

<SFR> in Interacting vs Non-Interacting Galaxies over last 7 Gyr



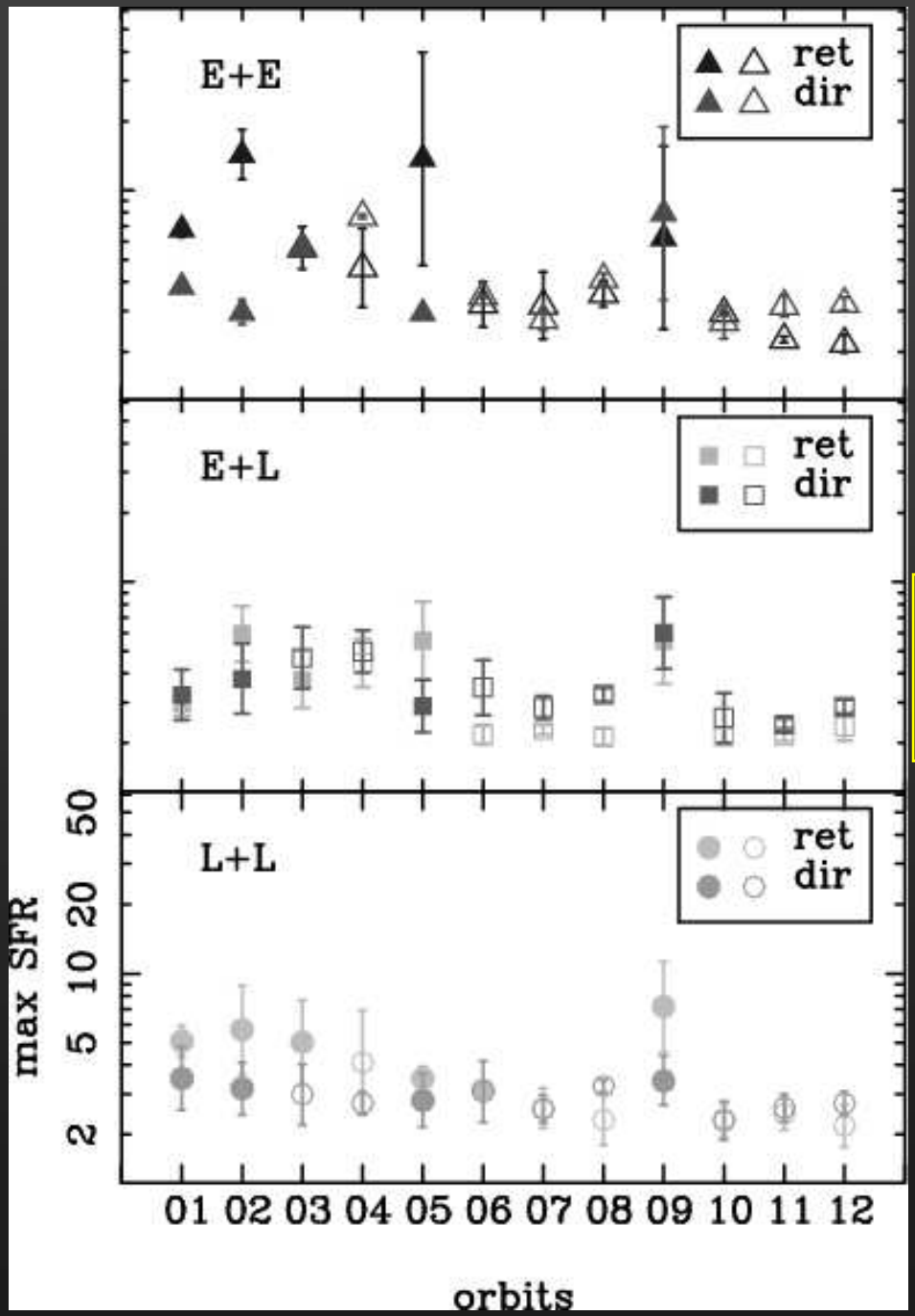
Jogee et al 2008

3 measures of SFR

1) SFR_{UV} from L_{UV} of COMBO-17 for full sample [N= 3698]
2) SFR_{UV} + SFR_{IR} from Spitzer 24 mu, detected in only 24% of sample [N=878]
3) SFR_{UV} + $SFR_{IR\text{-stacked}}$ from stacking 24 mu frame (Zheng et al 2007) for 87% of sample

Mean SFR of visibly interacting galaxies is enhanced only by a modest factor (~1.6 to 2) w.r.t that of non-interacting galaxies

Similar results by Robaina et al. in prep

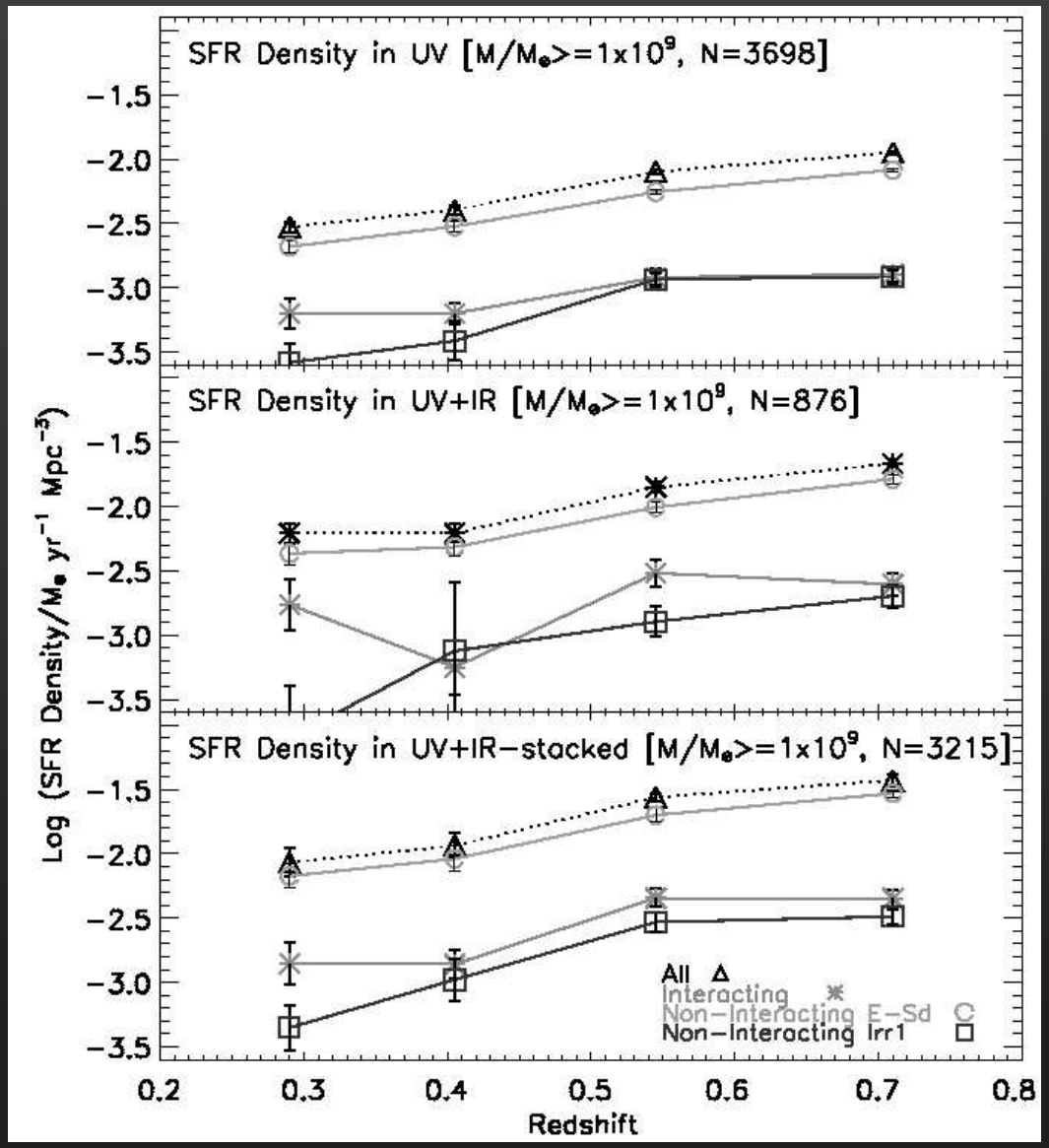


Di Matteo, P. et al. 2007

Statistical study of several hundred TREE-SPH simulations of major mergers of different B/D, gas, orbital parameters, etc

They find max SFR of most mergers is only enhanced by ~2 to3, compared to isolated case

SFR density from interacting galaxies over last 7 Gyr



For M*>=1e9 Mo systems, visibly interacting systems account for less than 30% of the SFR density over z~0.2--0.8 (T_b=3 to 7 Gyr)

• Decline in SFR density driven by shutdown in SF of normal galaxies (Gas consumption by SF ? Decline in smooth gas accretion rate ? Transition of SF to lower masses)

Jogee et al 2008

Summary: Galaxy Interactions & their Impact on SF over 7 Gyr

1. Interaction history for high mass (M>=2.5e10) galaxies

- Fraction of interacting systems (for mass ratio >1/10) ~ 8% to 9%
- For an assumed visibility time of 0.5 Gyr, this implies that over Tb=3-7 Gyr, every massive galaxy has undergone 0.7 interactions of mass ratio 1/10, of which 1/4 are major mergers, 2/3 are minor mergers, and rest are major/minor.

2. Visual vs automated CAS methods

CAS-based merger fraction

- agrees within a factor of ~2 with visual results for high mass galaxies
- overestimates f by a factor of 3 at z>0. 5 for intermediate mass galaxies

3. Comparison with LCDM-based models

For high mass galaxies, the (major + minor) merger rate of models show a factor of 5 dispersion and bracket the observed rate. Qualitative agreement

4. Impact on SF

For M*>=1e9 Mo systems, visibly interacting galaxies

- have their mean SFR enhanced by only ~1.6 to 2 wrt to non-interacting galaxies
- account for less than 30% of the SFR density over z~0.2--0.8 (Tb=3 to 7 Gyr)

Talks by Sanjuan, Balcells, Robaina, Stewart + Poster by Heiderman on f in cluster