Unveiling the low surface brightness Universe: the fundamental but unexplored role of minor mergers

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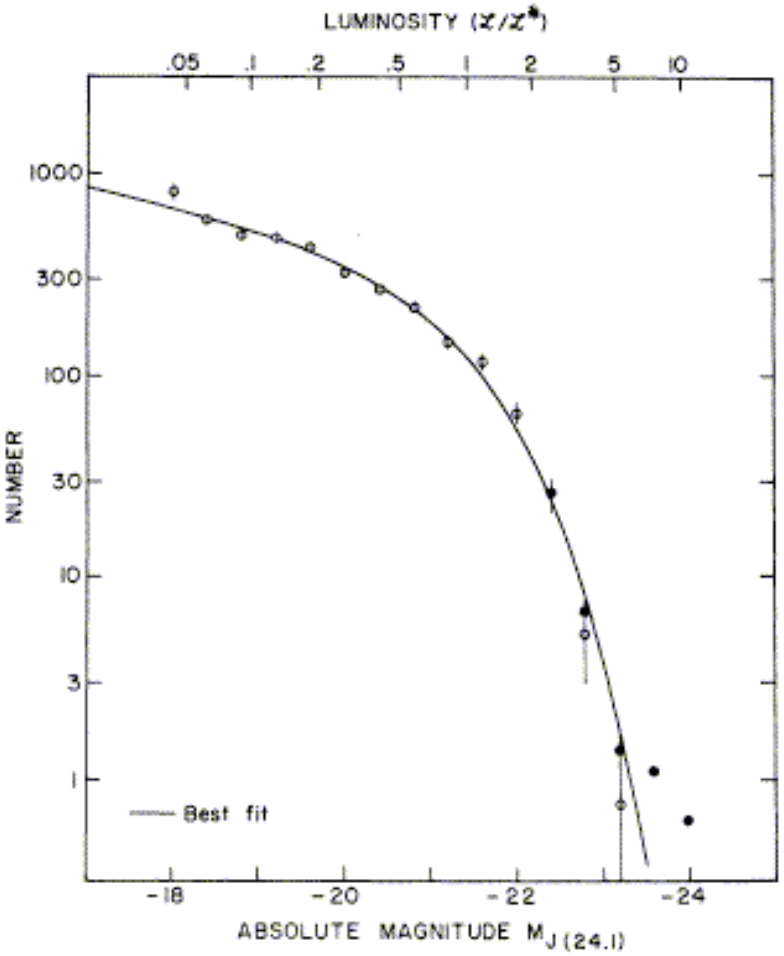
Based on:
Kaviraj 2014, MN, 440, 2944
Kaviraj 2014, MN, 437, L41

Minor mergers

Fundamental but unexplored



- Many more low-mass galaxies than high mass ones
- Most mergers are **minor mergers**
- But minor mergers produce faint tidal features, invisible in e.g. SDSS
- Potentially important process but unexplored – vast discovery space
- To understand how mergers drive galaxy evolution we need to understand **minor** mergers

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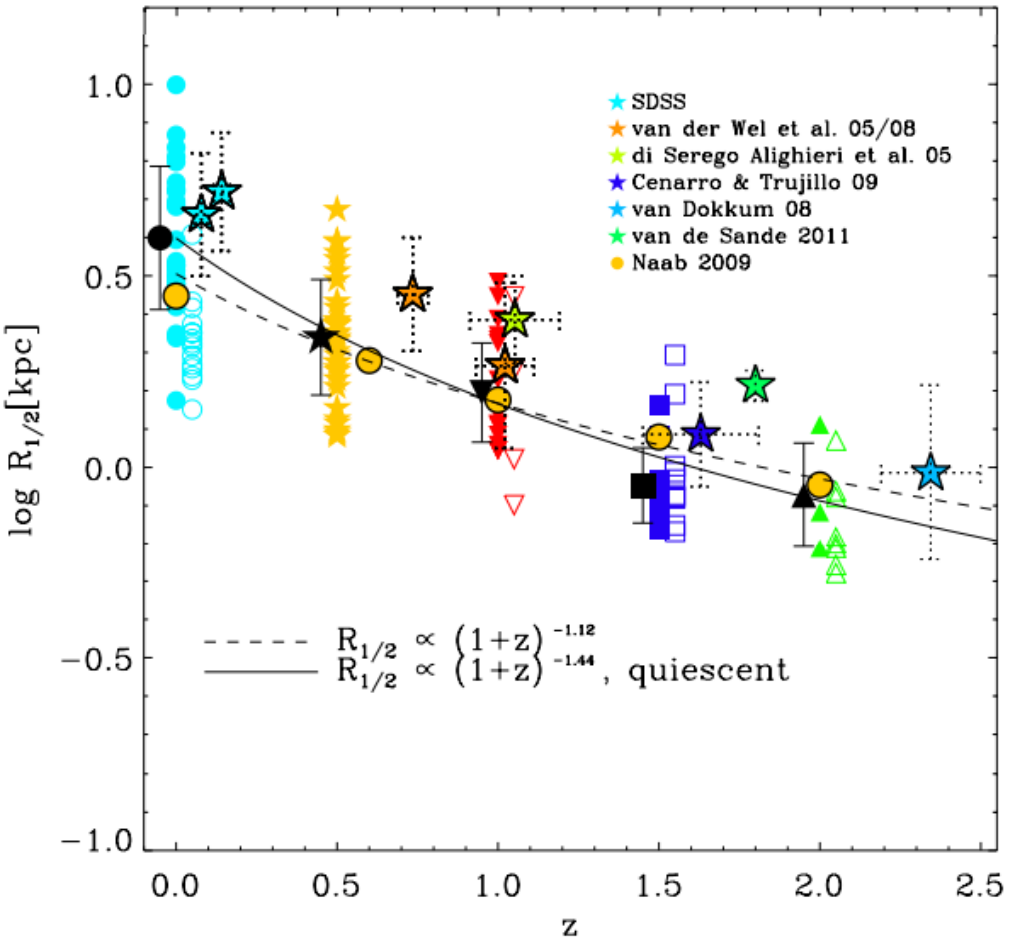
The role of minor mergers

Size growth of spheroids



Oser +12

- Spheroids show factor 3-5 growth since z~3
- Minor mergers thought to be main culprit **(e.g. Oser +12, Newman +12)**

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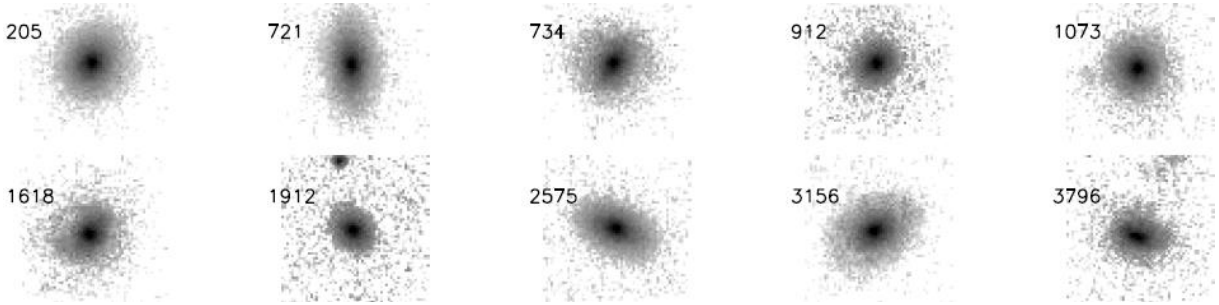
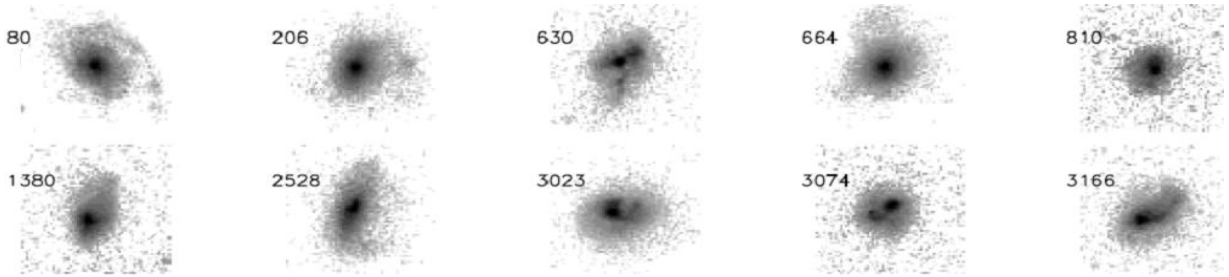
The role of minor mergers

Star formation in early-type galaxies



Relaxed ETGs



Disturbed ETGs (~35% of the ETG population)

- UV-blue ETGs morphologically disturbed
- But not enough major mergers to satisfy the number of disturbed ETGs
- **Minor mergers** drive star formation in ETGs

SK +11, MN, 411, 2148

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Minor-merger-driven galaxy evolution

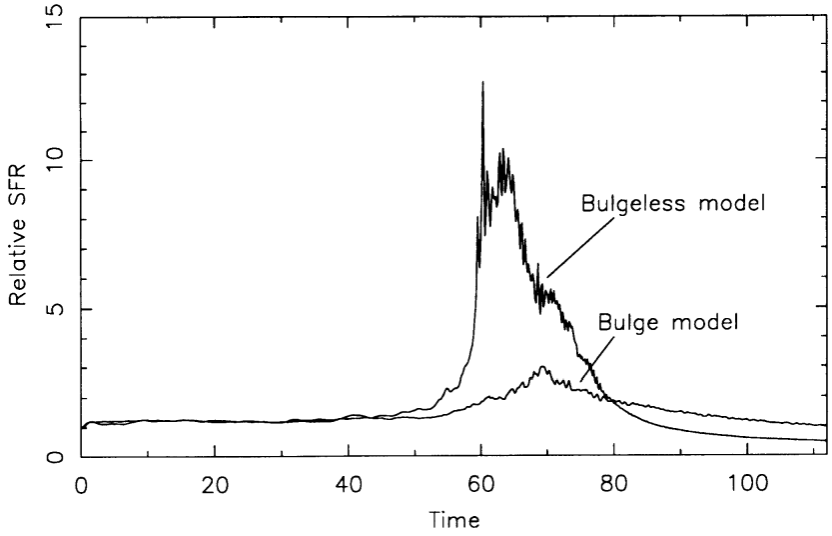
- Size growth of massive galaxies
- Star formation in early-type galaxies
- BCG growth at low redshift **(e.g. Chris Collins' talk yesterday)**
- AGN triggering **(e.g. Yjan Gordon's poster)**
- May be important for morphological transformation at high redshift

Minor-merger-driven star formation

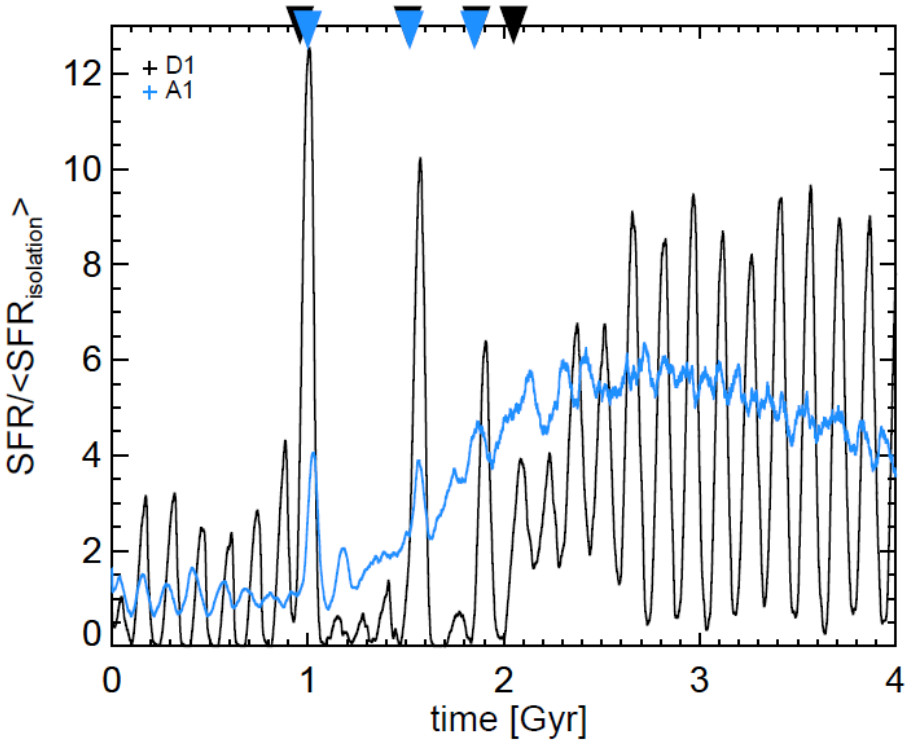
What fraction of the local star formation budget is driven directly by minor mergers?

Minor-merger-driven star formation

Theoretical expectations



Minor merger with massive gas-rich galaxy (Mihos & Hernquist 94)



Minor merger with dwarf galaxy (Starkenburg +16)

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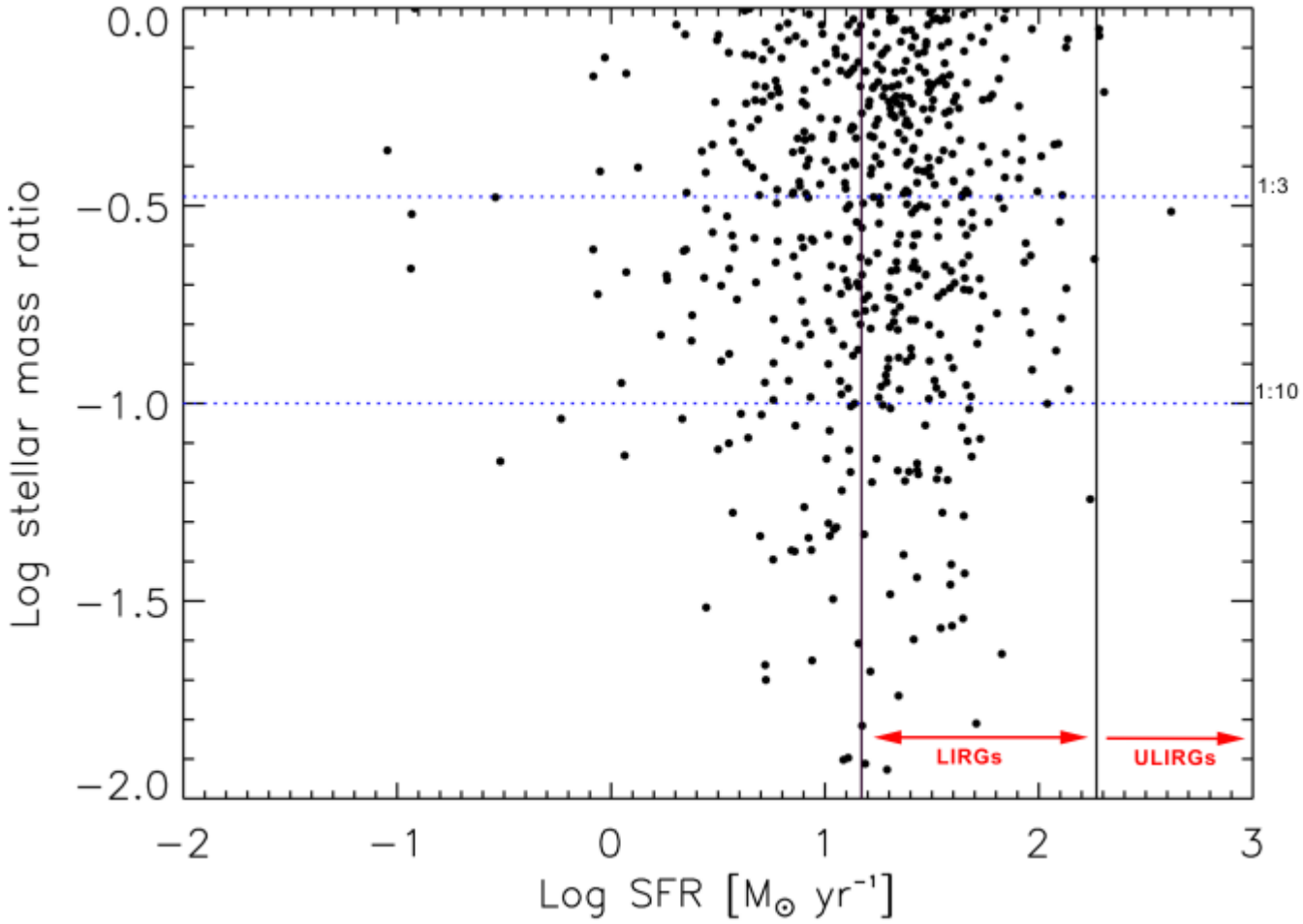
Minor-merger-driven star formation

Observations



Minor mergers

Carpineti +15

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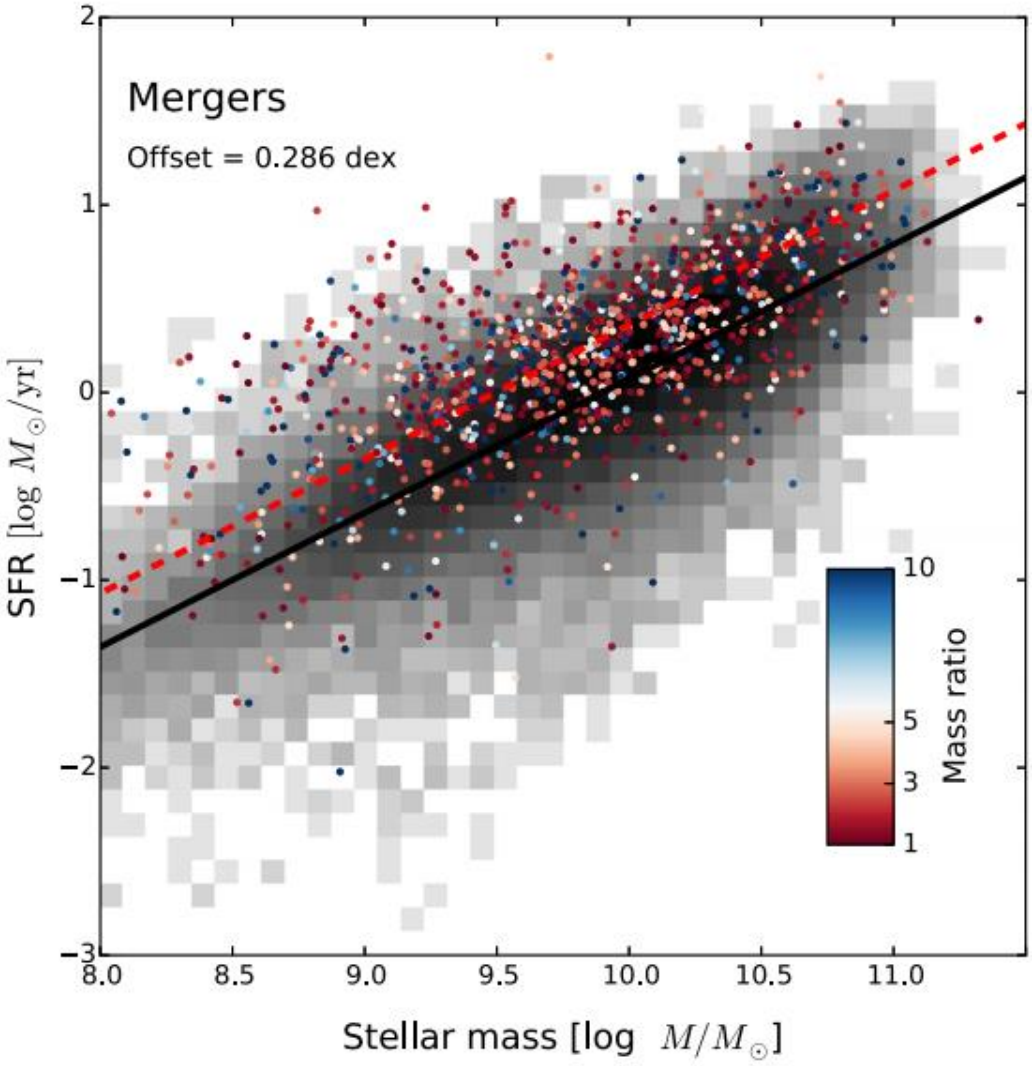
Minor-merger-driven star formation

Observations



Willett +15

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Studying minor mergers is difficult

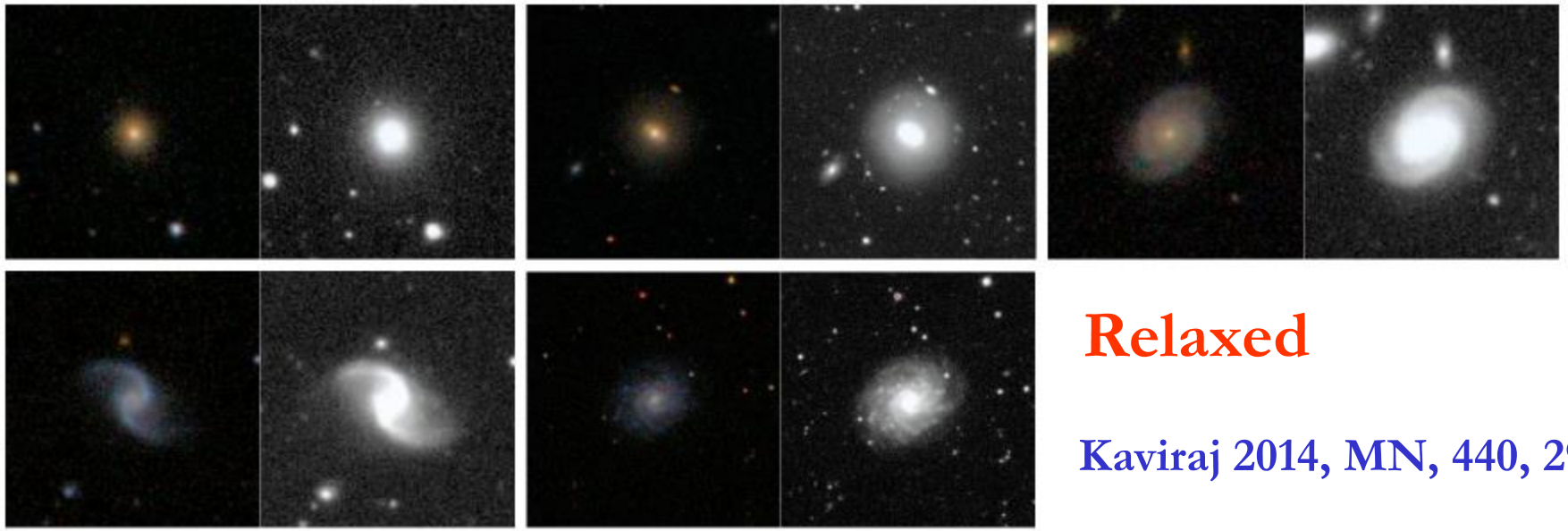
- Minor mergers poorly studied because (1) close pairs work difficult (2) tidal debris from minor mergers very faint
- Star formation most enhanced in minor merger *remnants* **(Woods+ 07, Ellison +13)**
- Need deep, wide survey → large sample of minor-merger remnants
- Use SDSS Stripe 82: 300 deg^2, two mags deeper than standard SDSS

Selecting minor mergers

- At low redshift major mergers destroy disks and create spheroids **(e.g. Barnes+ 02)**

- **Disturbed spirals** are minor merger remnants (disk still intact)

Selecting minor mergers from Stripe 82



Relaxed

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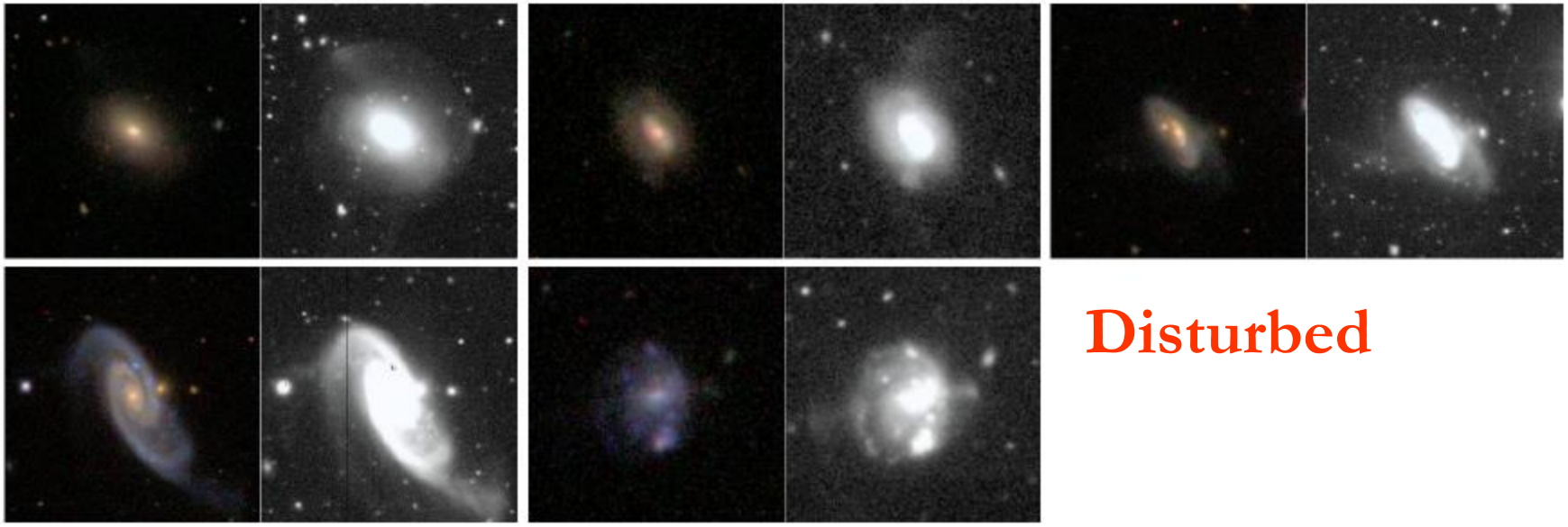

Disturbed

How much SF is driven by minor mergers?

Need to know:

(1) enhancement in star formation **η** due to minor merger

(2) fraction of time **D** galaxy spends in enhanced SF mode

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$$S = \underbrace{\phi_0.(1-D).m.\delta t}_{S_{NORM}} + \underbrace{\eta.\phi_0.D.m.\delta t}_{S_{MM}}$$

How much SF is driven by minor mergers?

Need to know:

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(2) fraction of time **D** galaxy spends in enhanced SF mode

$$S = \underbrace{\phi_0.(1-D).m.\delta t}_{S_{NORM}} + \underbrace{\eta.\phi_0.D.m.\delta t}_{S_{MM}}$$

$$F_{MM} = \frac{S_{MM}}{S} = \frac{\eta.D}{1+D.(\eta-1)}$$

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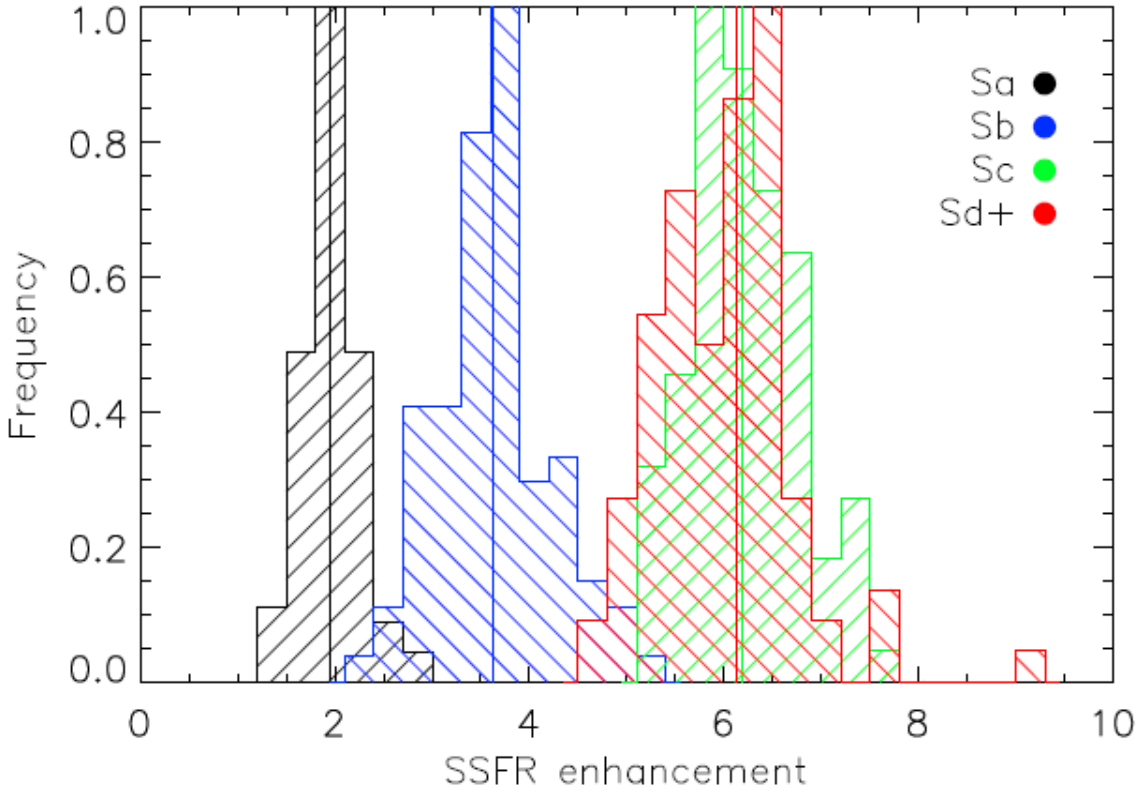
How much SF is driven by minor mergers?



Morphology	D	η	F_{mm}
Sa	0.16	1.98	0.27
Sb	0.17	3.62	0.43
Sc	0.13	6.15	0.48
Sd/Irr	0.11	6.14	0.43

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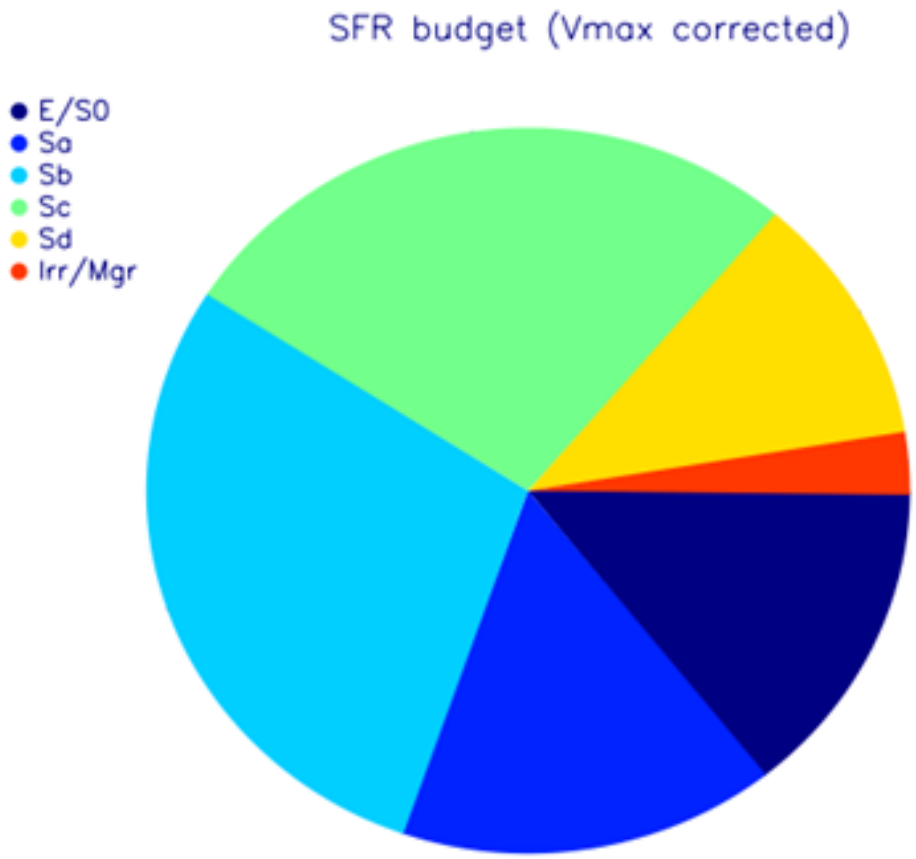
How much SF is driven by minor mergers?

F_{MM} ×



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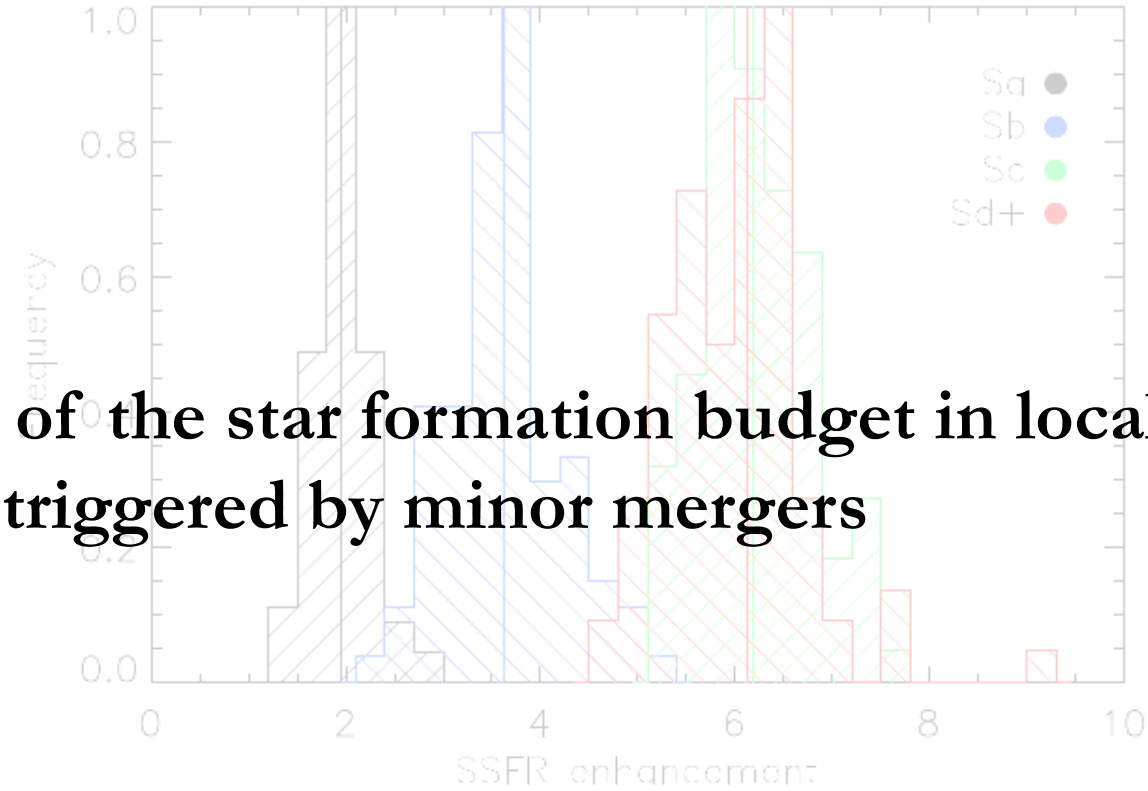
How much SF is driven by minor mergers?



~40% of the star formation budget in local spirals is likely triggered by minor mergers

Morphology	D	η	F_{mm} (via Eqn. 2)	Proportion of spiral SF budget (from K13)
Sa	0.16	1.98	0.27	0.19
Sb	0.17	3.62	0.43	0.34
Sc	0.13	6.15	0.48	0.32
Sd+	0.10	3.62	0.43	0.15

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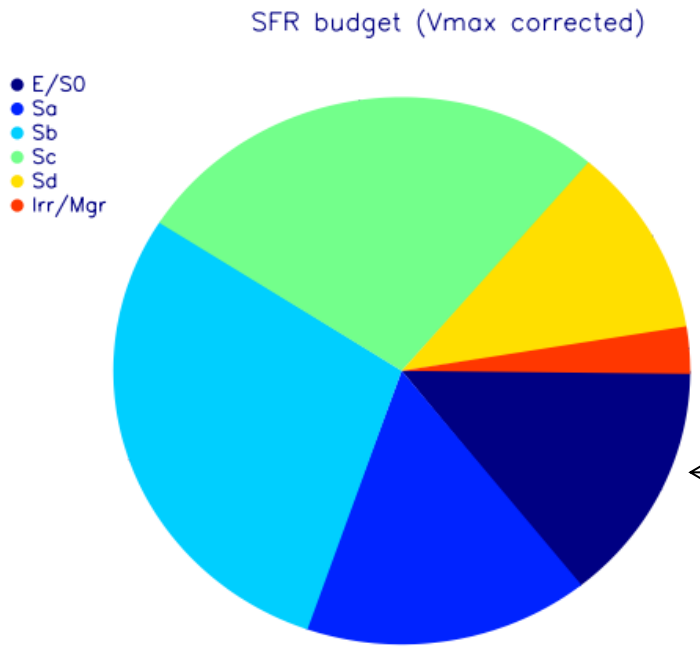
How much SF is driven by minor mergers?



E/S0 fraction ~ 14%

Morphology	Fraction of star formation budget
E/S0	$0.143^{\pm 0.056}$
Sa	$0.160^{\pm 0.063}$
Sb	$0.288^{\pm 0.090}$
Sc	$0.271^{\pm 0.100}$
Sd	$0.112^{\pm 0.041}$
Irr/Mgr	$0.026^{\pm 0.019}$

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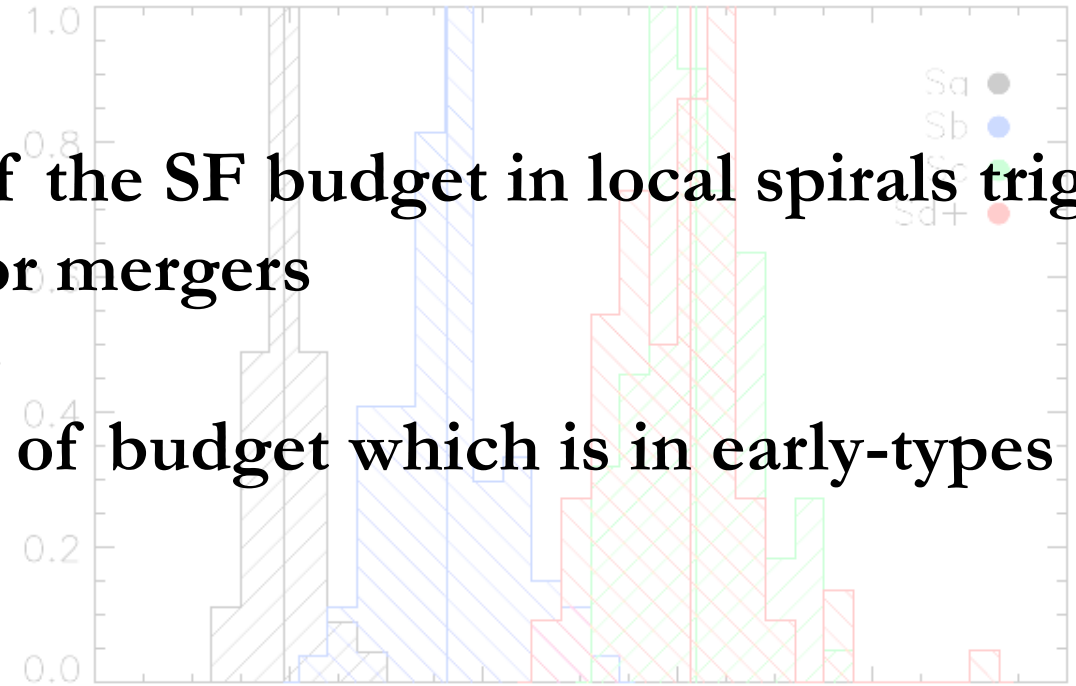
How much SF is driven by minor mergers?



~40% of the SF budget in local spirals triggered by minor mergers

+ ~14% of budget which is in early-types

= around half of the local star formation attributable to minor mergers

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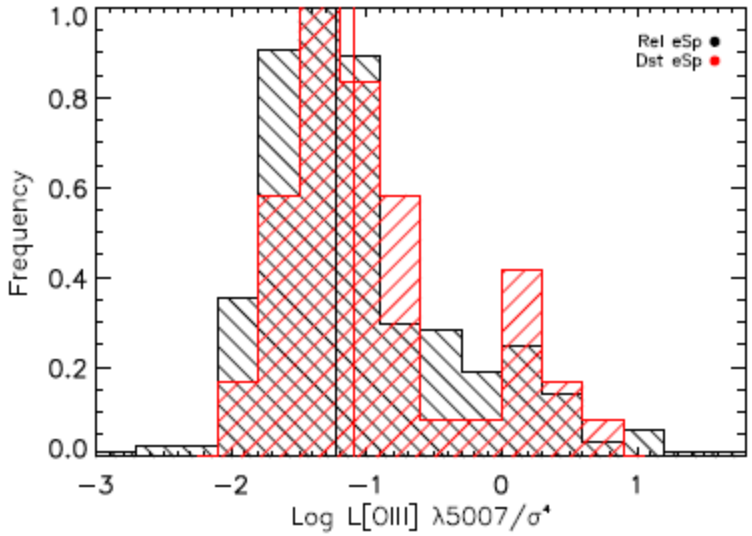
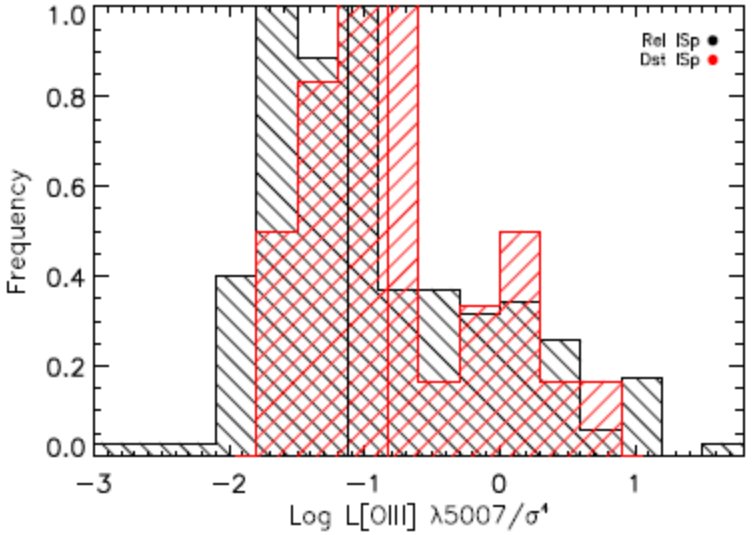
Do minor mergers affect BH growth?



Early spirals



Late spirals

- Use [OIII] line to probe nuclear accretion
- Complication: [OIII] driven by both AGN and SF
- Restrict analysis to Seyferts where [OIII] dominated by AGN
- Nuclear accretion enhanced by 40 – 200% (not as much as star formation)

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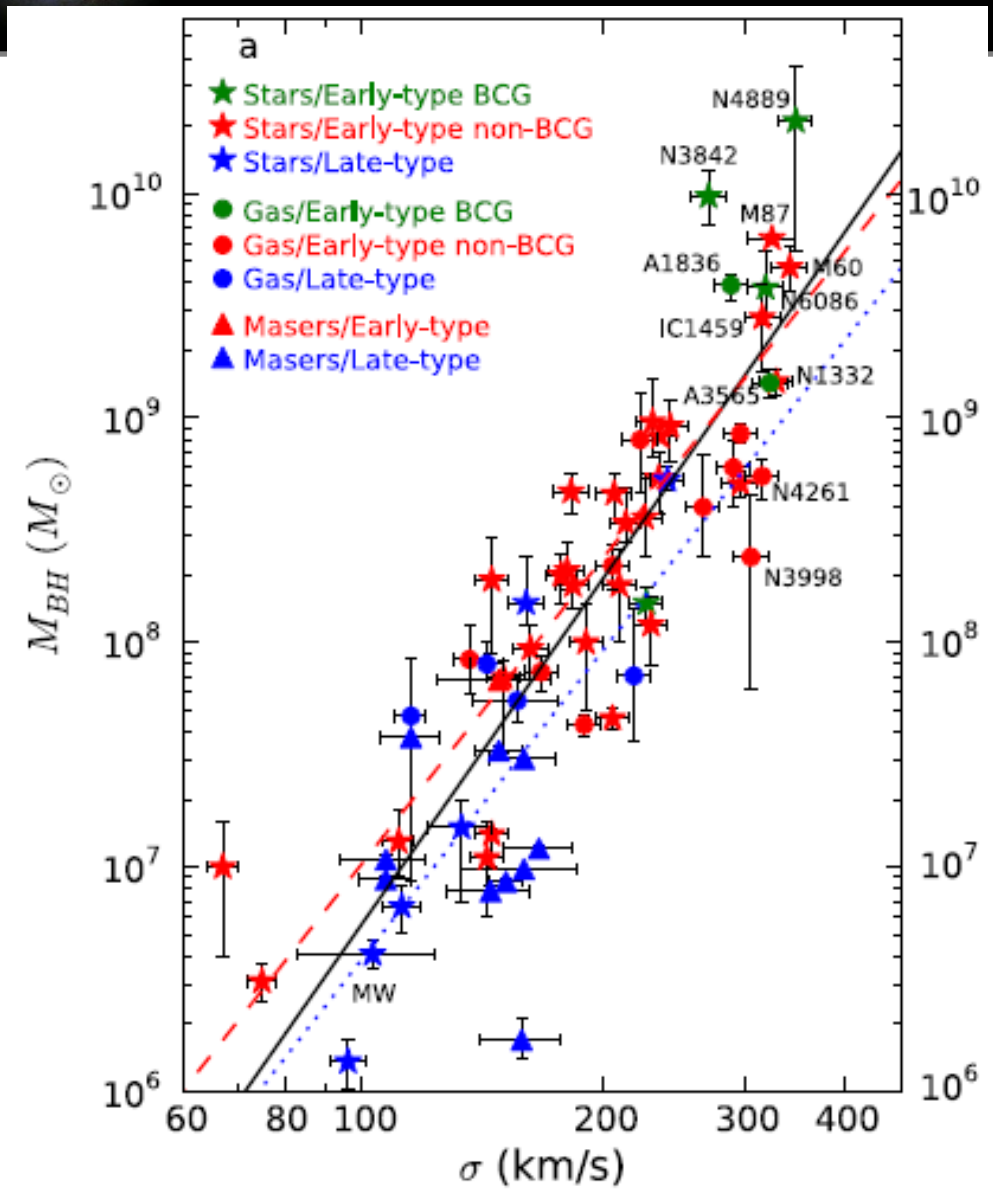
Do minor mergers affect BH growth?



- Positive correlation between galaxy and BH mass **(McConnell+ 11)** – galaxy and BH grow in lockstep
- Tight correlation in ellipticals, larger scatter in spirals implying weaker coupling between SF and BH growth
- Weak coupling (time delay c.f. Debora Sijacki's talk earlier today?) in minor mergers a possible explanation of this larger scatter

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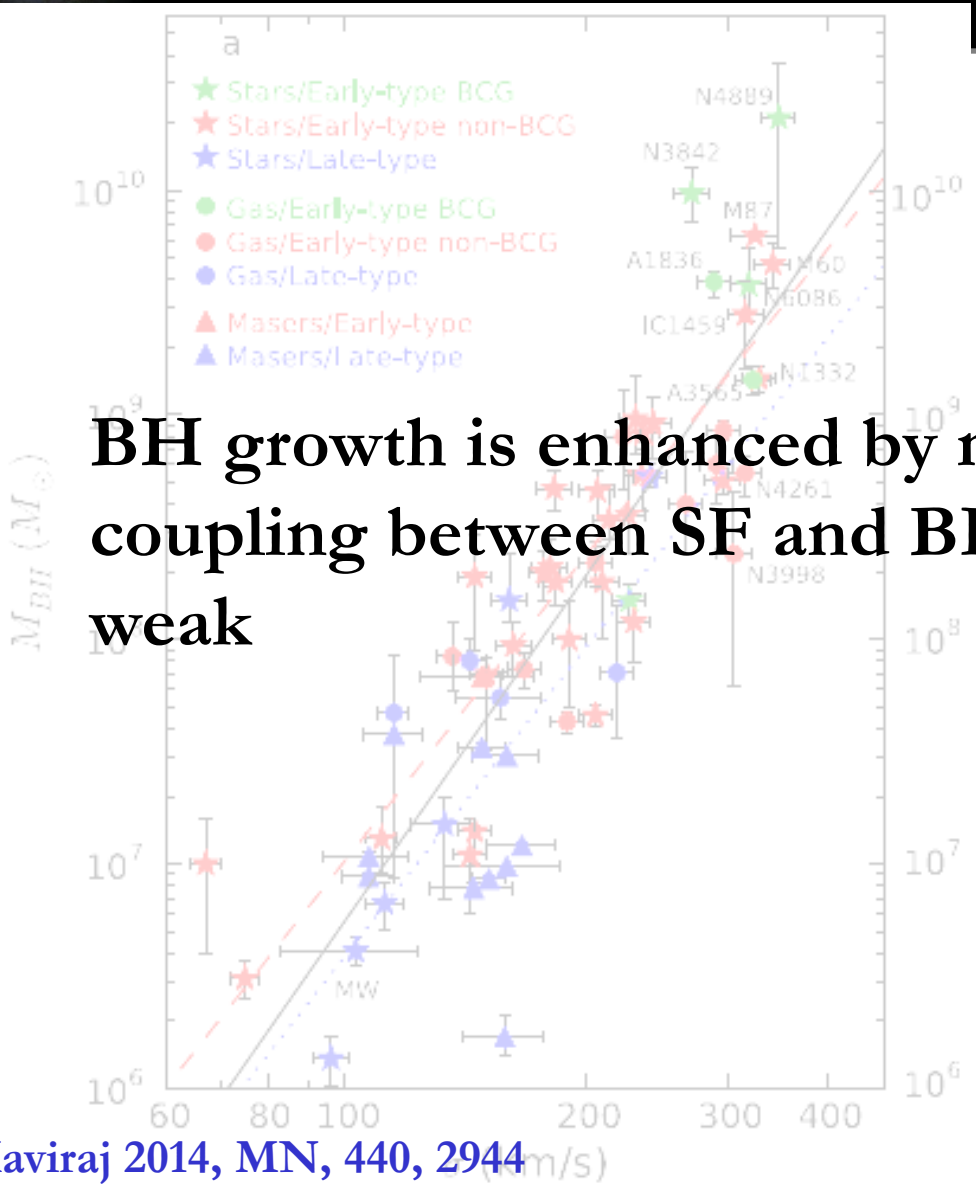
Do minor mergers affect BH growth?



BH growth is enhanced by minor mergers - but coupling between SF and BH growth relatively weak

- Positive correlation between stellar mass and BH mass **(McConnell+ 2011)** – galaxy and BH grow in lockstep
- Tight correlation in elliptical galaxies, larger scatter in spirals implying weaker coupling between SF and BH growth
- Weak coupling in minor mergers a possible explanation of this larger scatter

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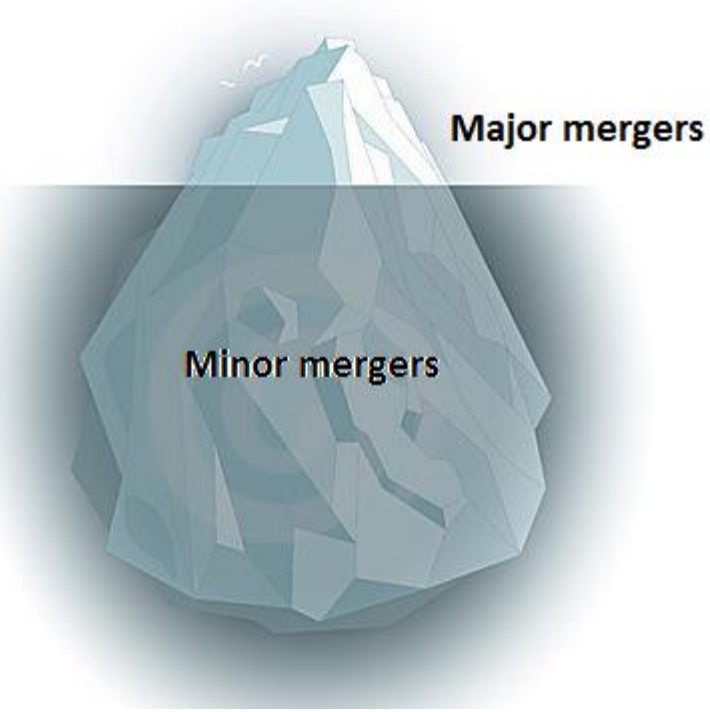
The critical role of minor mergers



- Minor mergers drive ~40% of SF in disk galaxies and around half of all local SF
- Fundamental process in galaxy evolution but poorly understood
- To understand the role of galaxy merging we need to understand **minor** mergers
- First systematic studies of minor mergers will be possible using e.g. LSST

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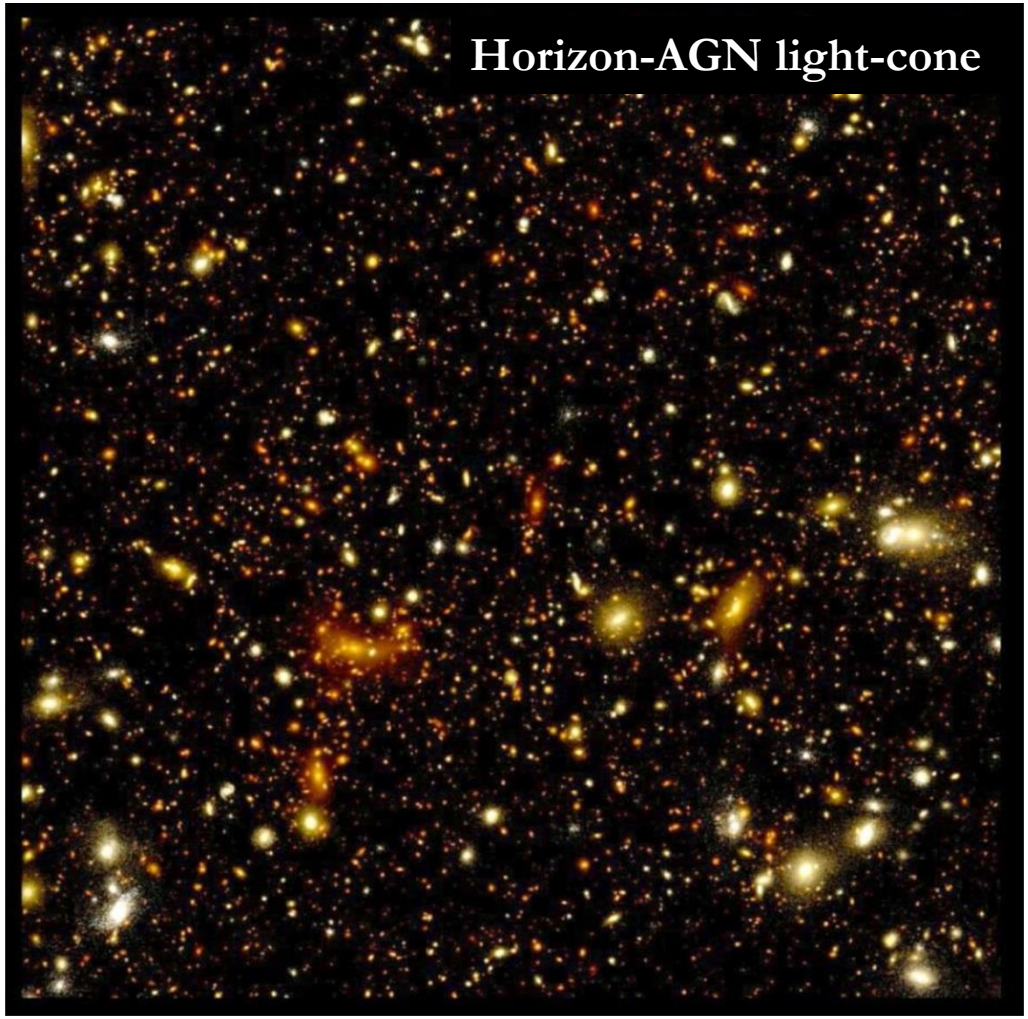
LSB science in the LSST era

Simulations: detection/characterisation of LSB tidal features



Kaviraj + 17

- Big data era will produce unprecedented amounts of data
- Need auto-detection and characterisation of merger remnants and tidal features
- Full hydro simulations in cosmological volumes, will be critical for developing such algorithms

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LSB science in the LSST era

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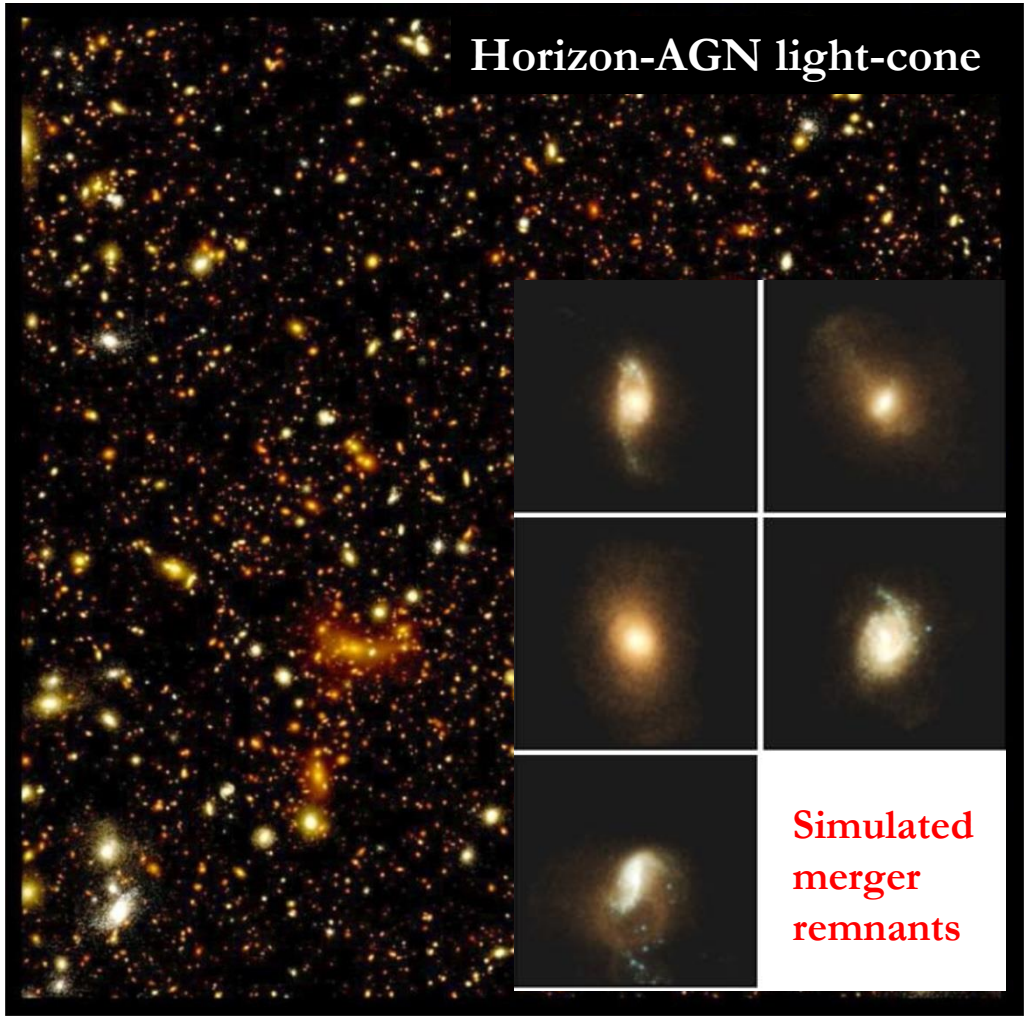

Kaviraj + 17

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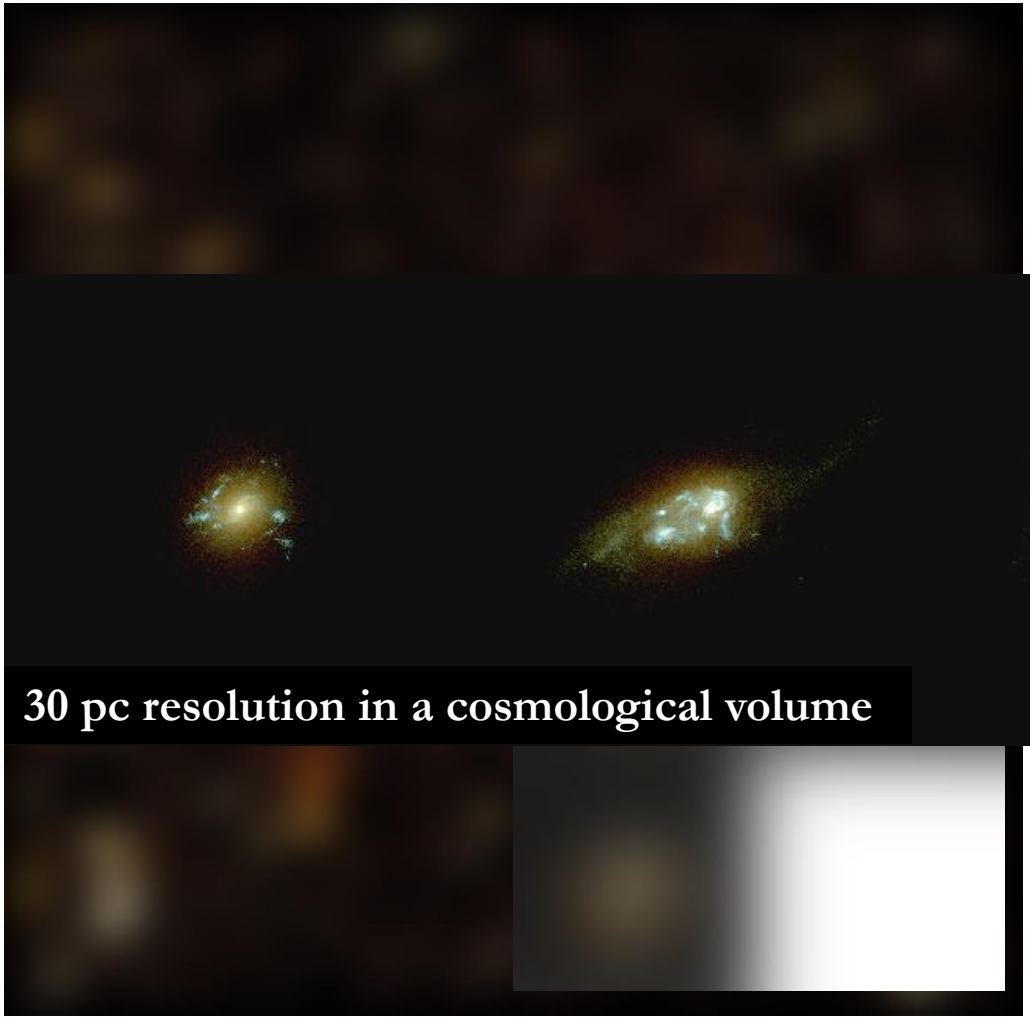

New Horizon (z>1)

30 pc resolution in a cosmological volume

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- Big data era will produce unprecedented amounts of data

algorithms

Dubois, SK in prep

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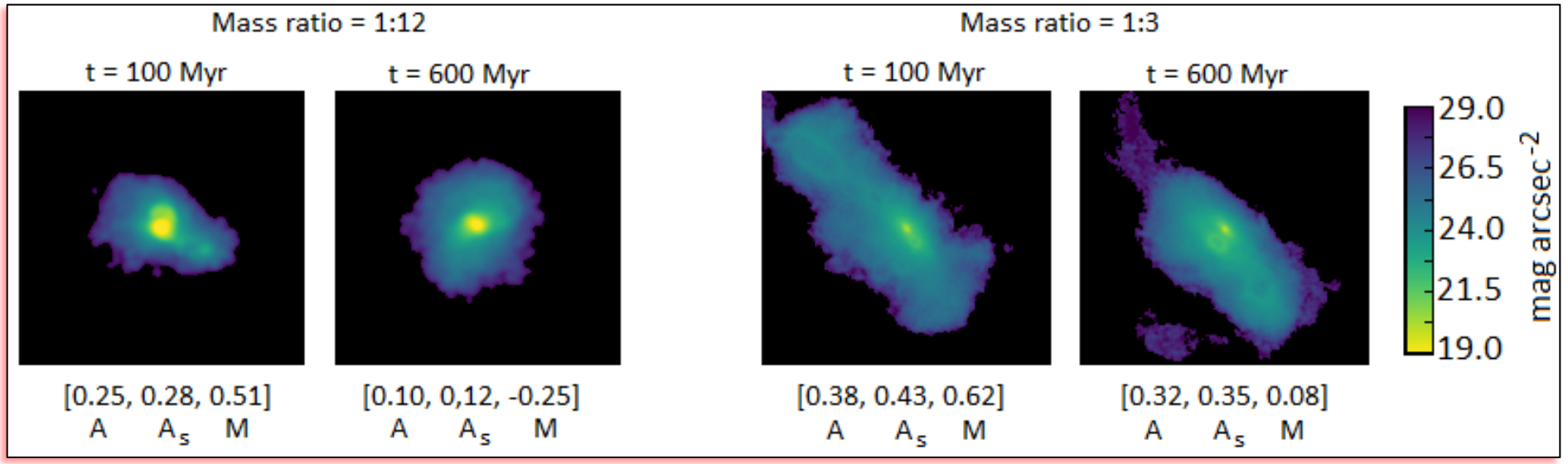
LSB science in the LSST era

Simulations: detection/characterisation of LSB tidal features



Algorithms can be built that use morphological parameters (**e.g. Pawlik +16, Conselice +03**) and/or machine learning **(e.g. Hocking +17)** to:

- Detect merger remnants
- Separate remnants based on their properties → characterise mergers

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LSB science in the LSST era

Galaxy morphology: machine learning methods

Supervised or Unsupervised?

Supervised

Training data set consists of known galaxies + classifications

Spiral

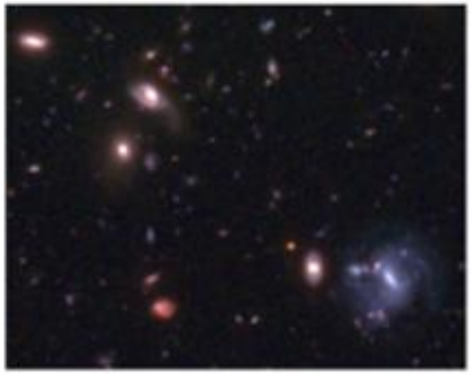
Elliptical

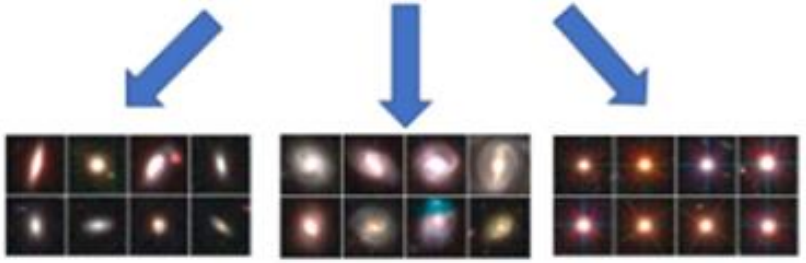
In use – predict the classification:

Elliptical or spiral?

Unsupervised

Training data set consists of FITS survey images. No classifications are used.





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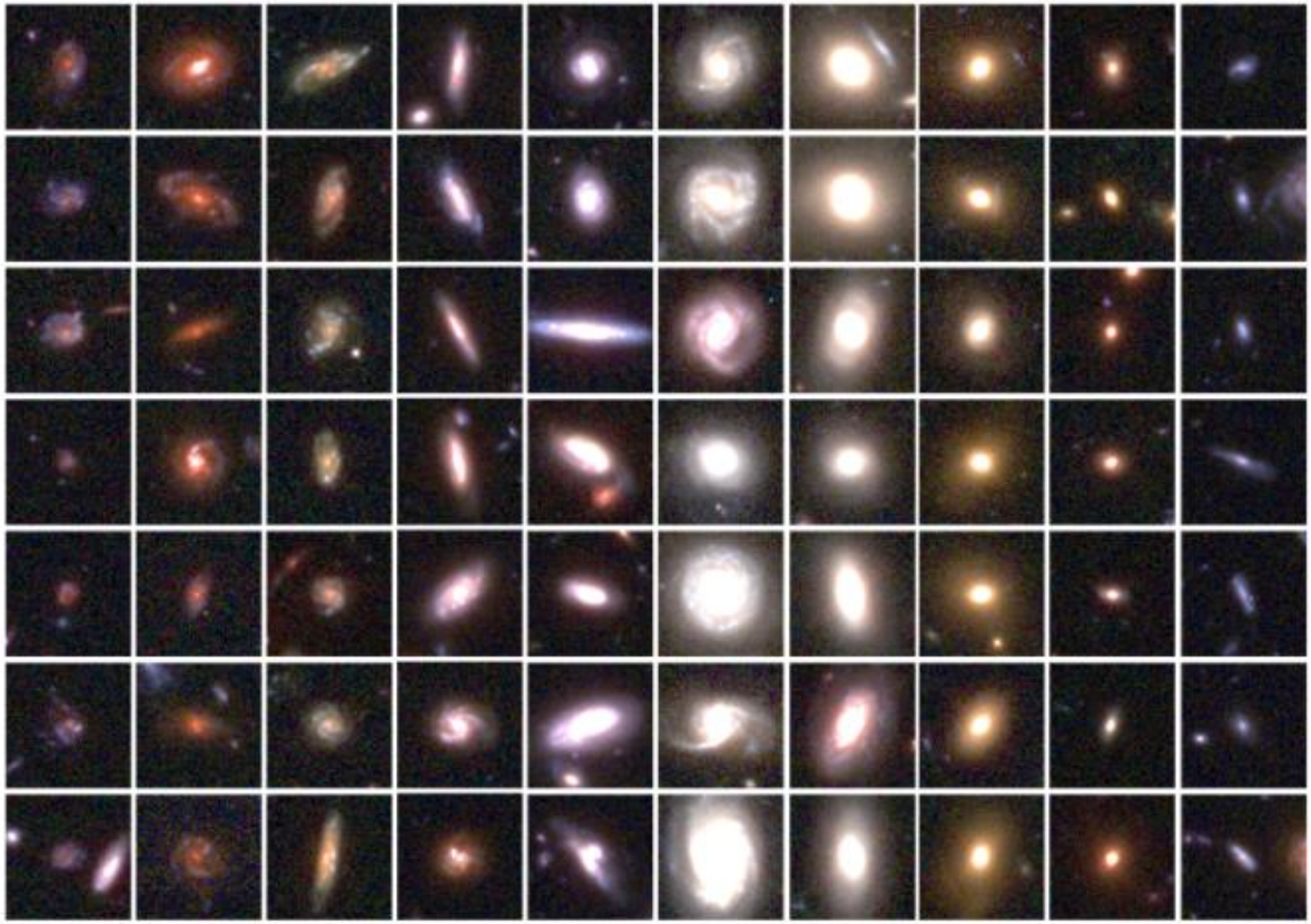
Galaxy morphology: machine learning methods



Hocking et al. arXiv:1709.05834

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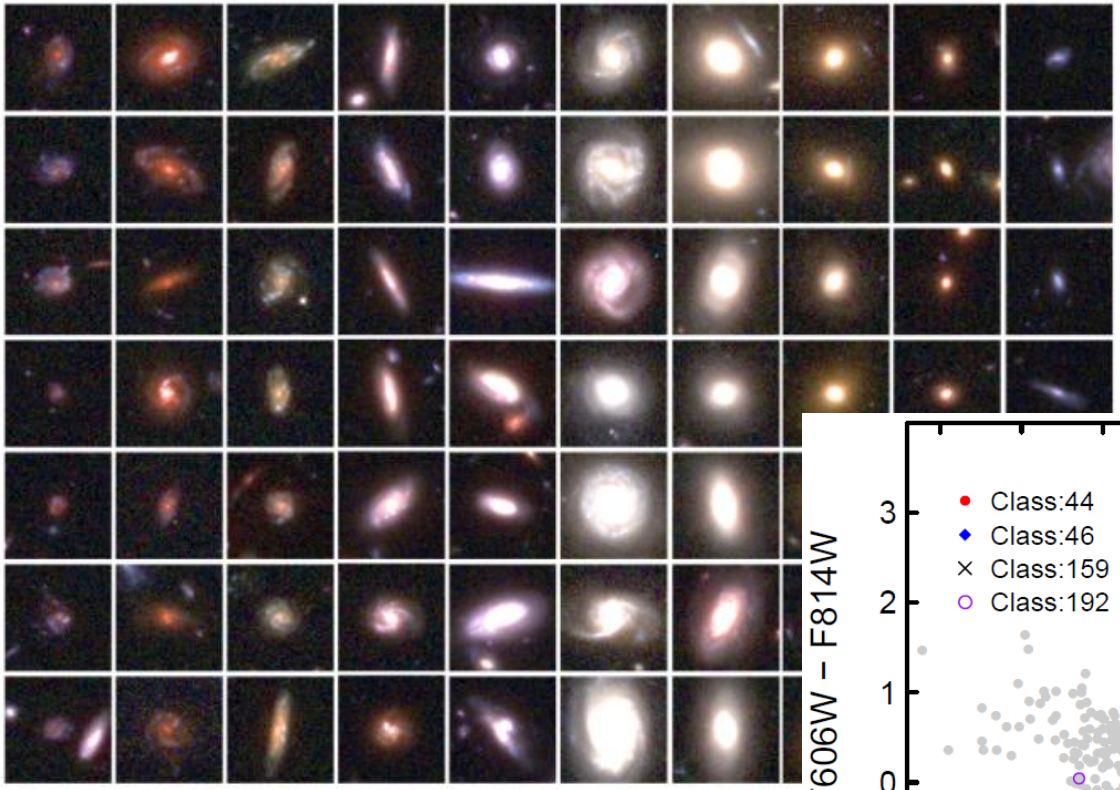
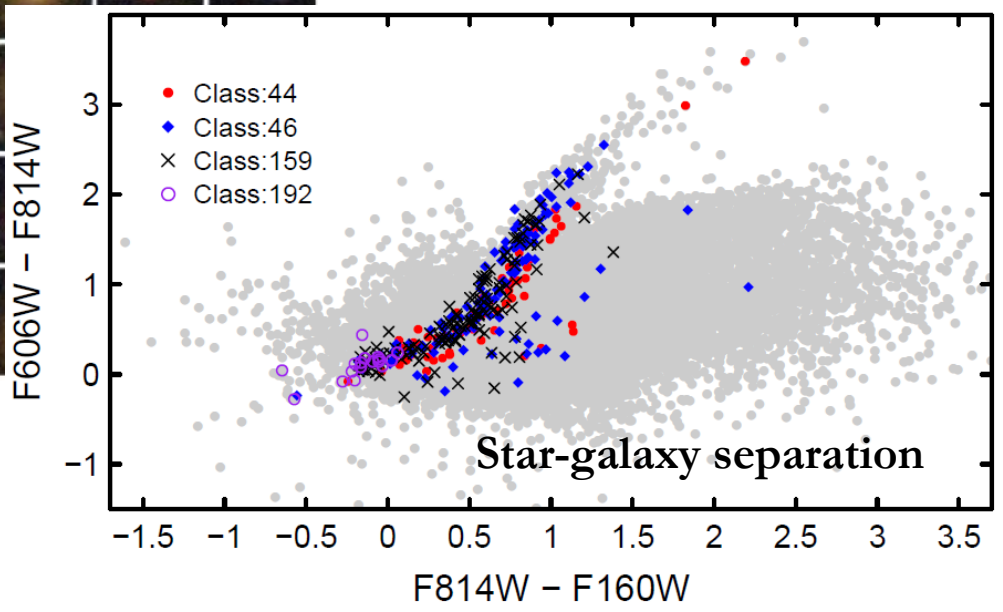
LSB science in the LSST era

Galaxy morphology: machine learning methods



- Prototype has been built on CANDELS
- Will be implemented on LSST and precursors



Hocking et al. arXiv:1709.05834

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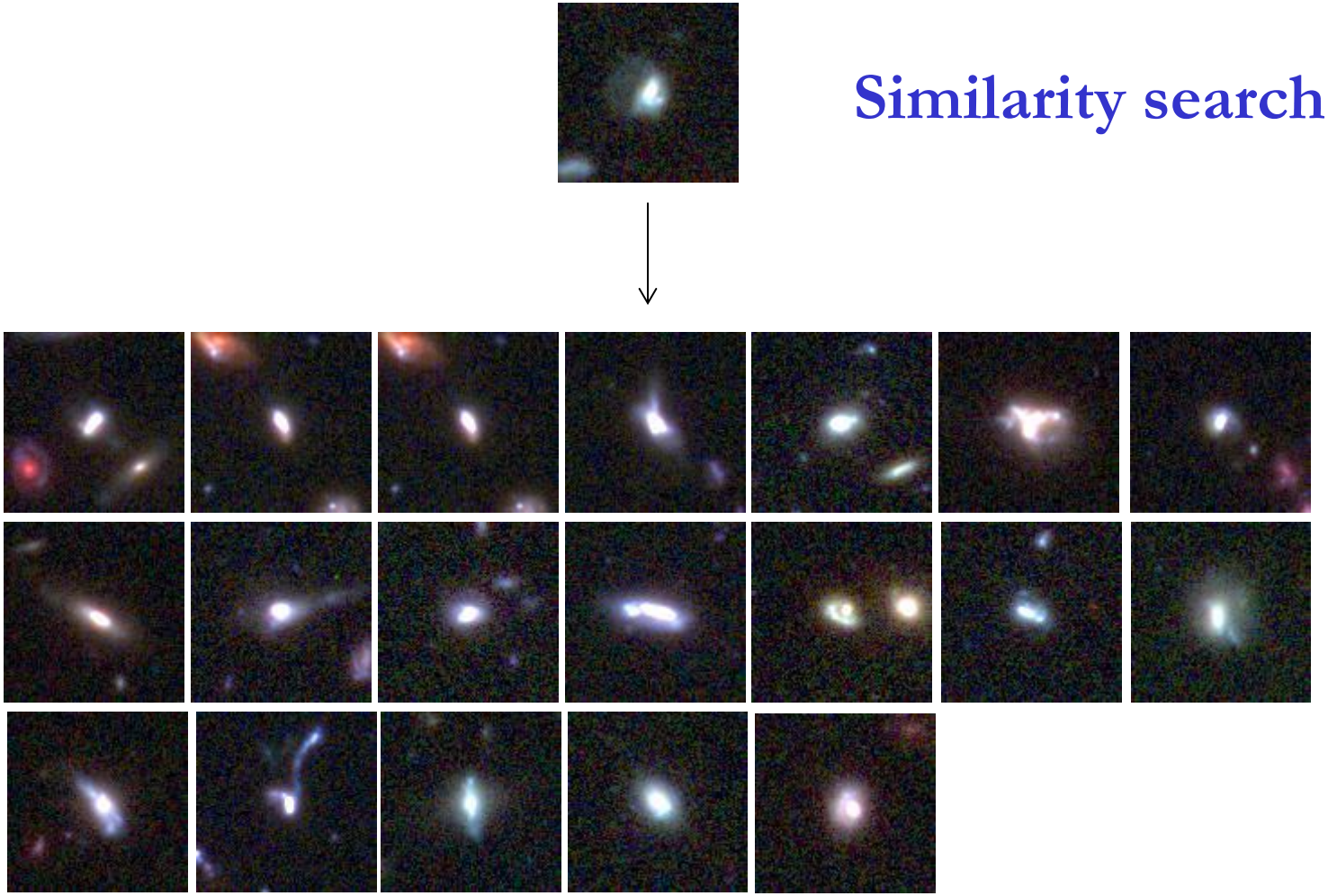
LSB science in the LSST era

LSB feature detection: machine learning methods



Similarity search

Hocking et al. arXiv:1709.05834

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Summary

- Minor mergers are fundamental to our understanding of galaxy evolution
- But almost completely unexplored – vast discovery space!
- Exciting new era of LSB astronomy with e.g. LSST promises unprecedented insights into role of mergers
- Simulations essential for developing tools for LSB science

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