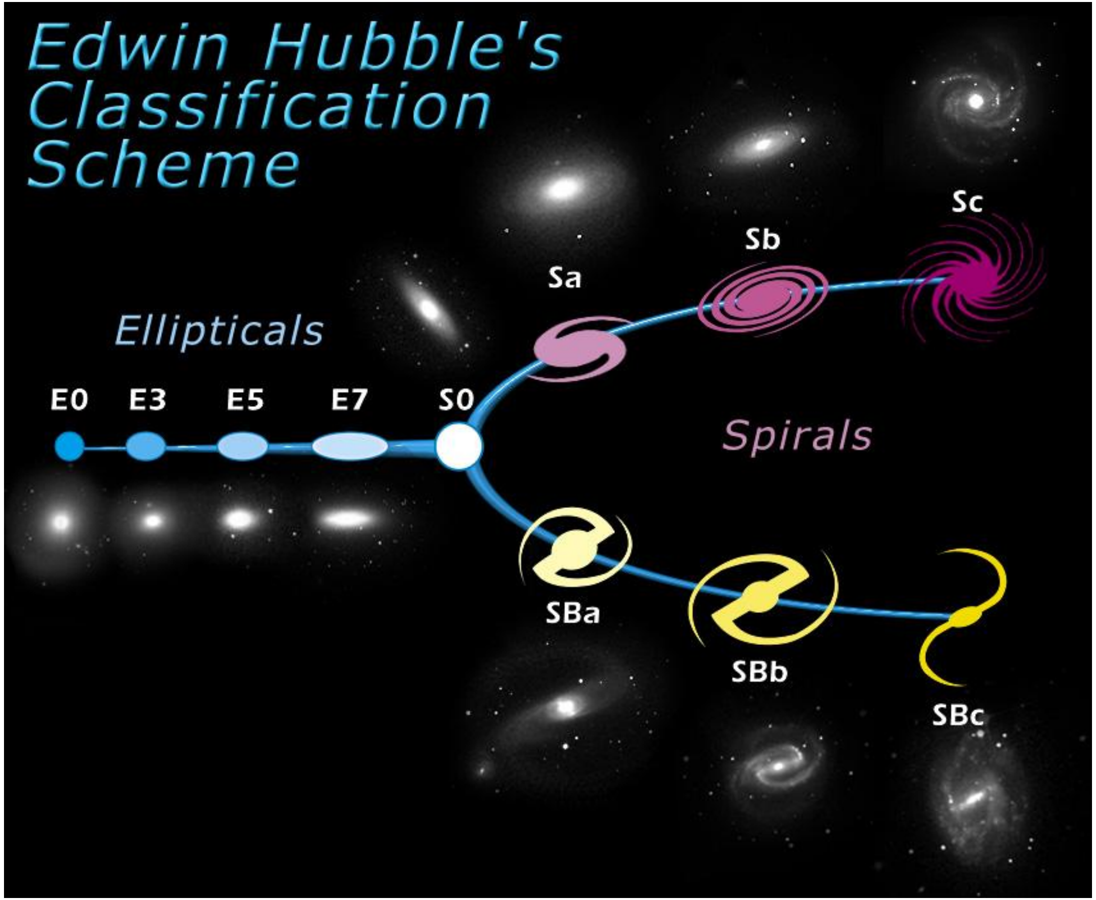
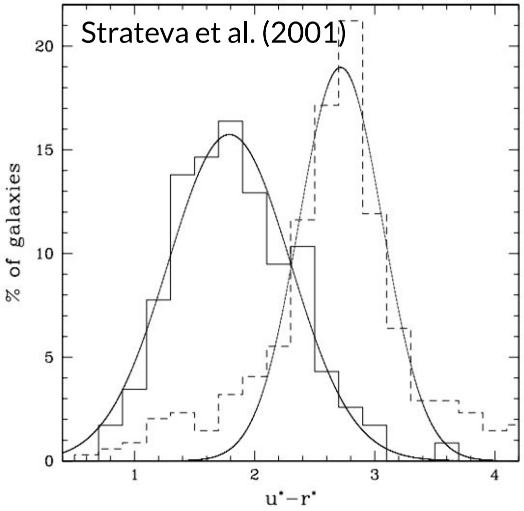
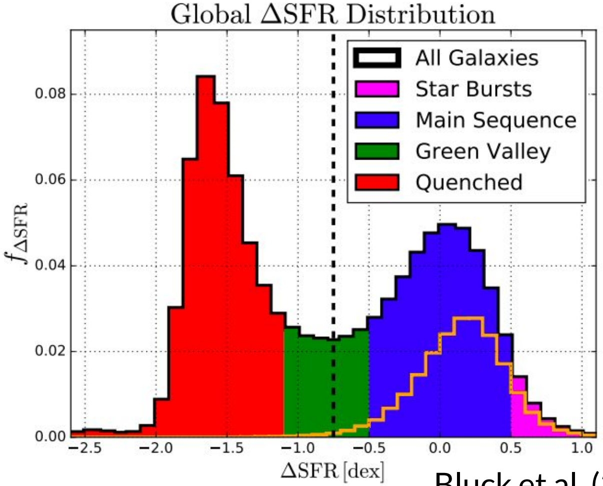
Non-Parametric Morphology Statistics as Galaxy Classifiers

The Evolution of Galaxy Structure Over Cosmic Time, Conselice 2014
Presented by Scott Wilkinson

Morphology Classes



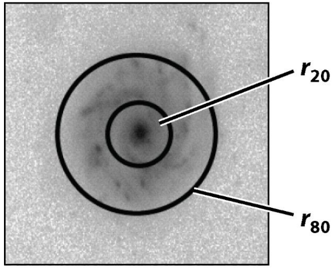




Bluck et al. (2020)

CAS - Concentration

$$C = 5\log_{10}\left(\frac{r_{80}}{r_{20}}\right)$$



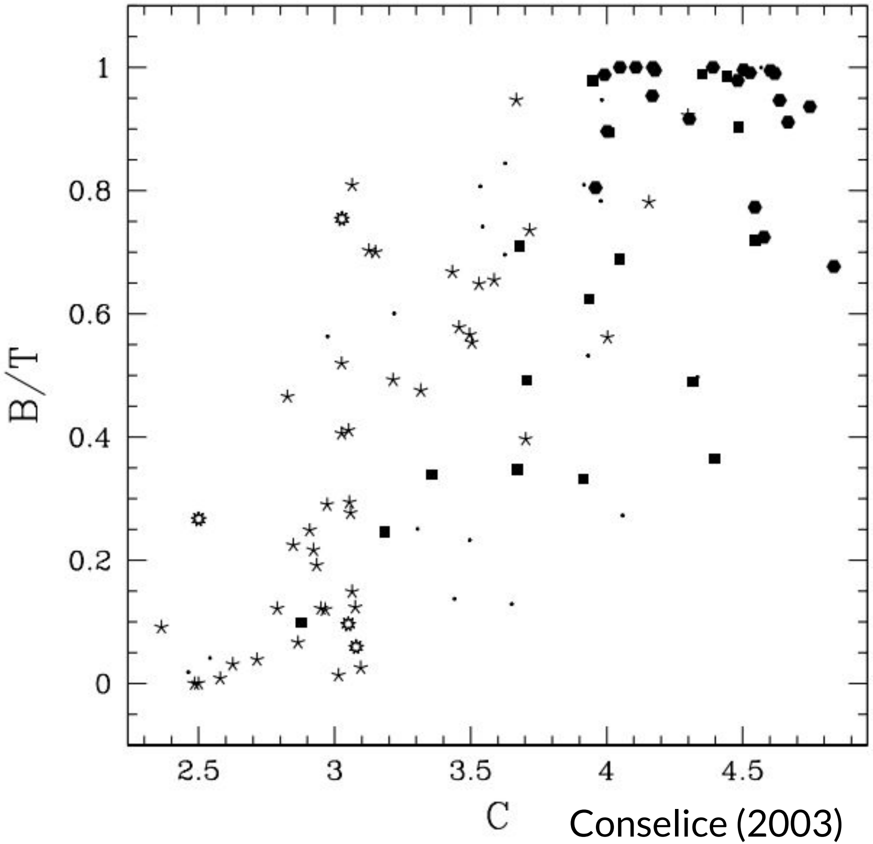
Kent 1985; Conselice 2003

Sometimes calculated as:

- C = r(75) / r(25) (de Vaucouleurs 1977)
- C = r(90) / r(50) (Strateva et al. 2001)
- C = 5 log (r(70) / r(30))

“Total flux” can either be flux within,

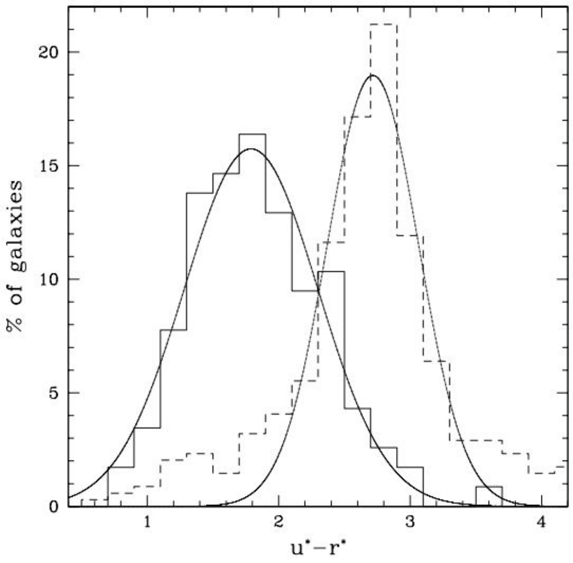
- 1.5 Rpetro (Conselice 2003)
- 2 Rpetro (Bershady 2000)



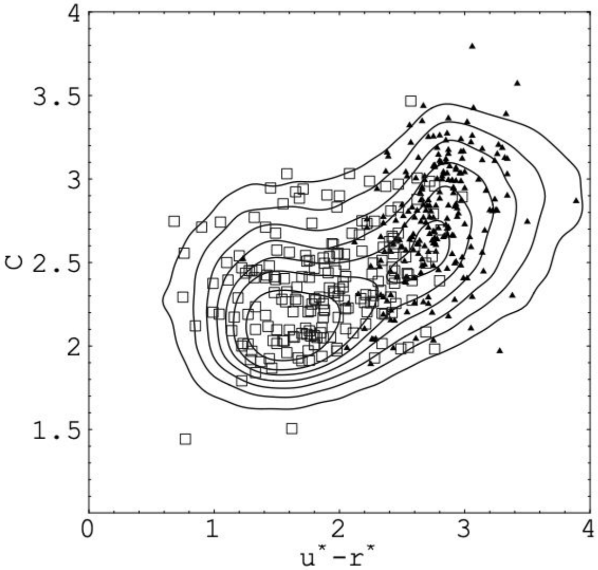
Conselice (2003)

CAS - Concentration

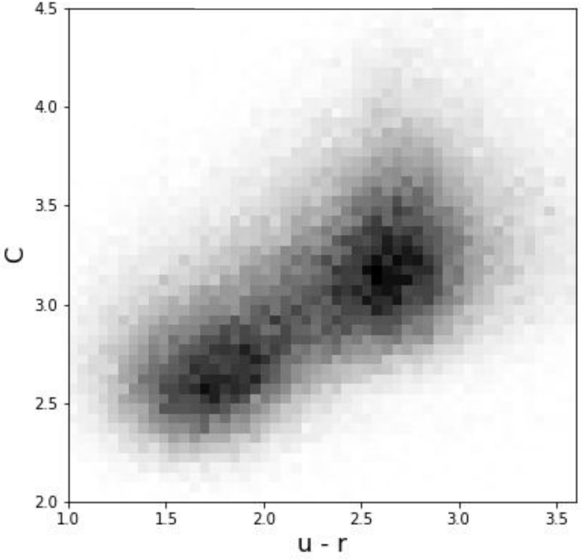
Concentration can be used as a simple single-metric classifier of galaxy morphology.



C = r(90) / r(50)



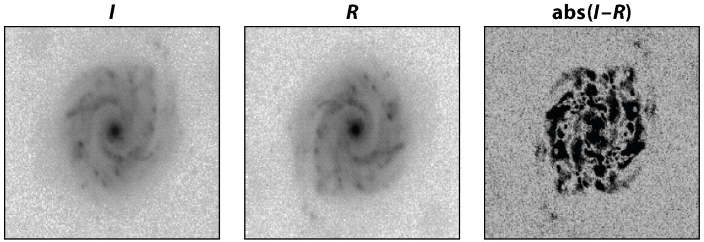
$$C = 5\log_{10}\left(\frac{r_{80}}{r_{20}}\right)$$



Strateva et al. 2001

CAS - Asymmetry

$$A = \min\left(\frac{\Sigma|I_0 - I_{180}|}{\Sigma|I_0|}\right) - \min\left(\frac{\Sigma|B_0 - B_{180}|}{\Sigma|I_0|}\right)$$



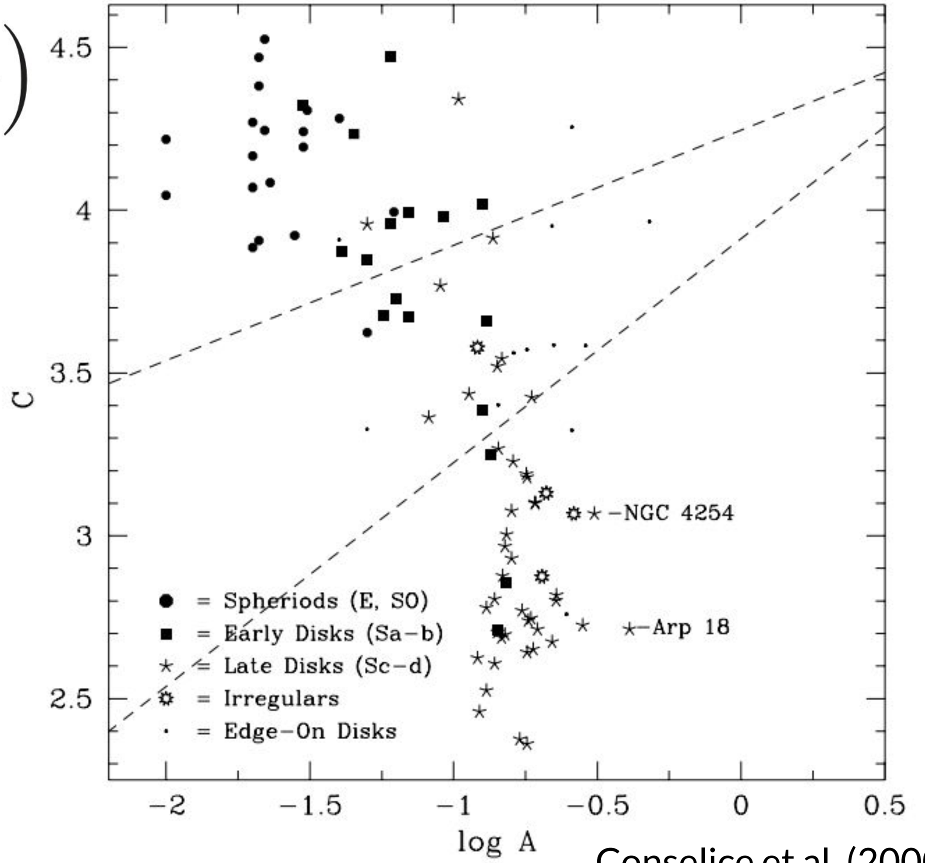
$$A = \frac{\mathrm{abs}(I-R)}{I}$$

WARNING:

Asymmetry, A: we followed the standard definition of rotational asymmetry (Shade et al. 1995; Abraham et al. 1996; Conselice et al. 2000; Conselice 2003; Hernández-Toledo 2008):

$$A = \frac{\Sigma \mid I_0 - I_\theta \mid}{2\Sigma \mid I_0 \mid} - A_{\mathrm{bgr}}, \qquad (3)$$

Pawlik et al. (2016, 2018)

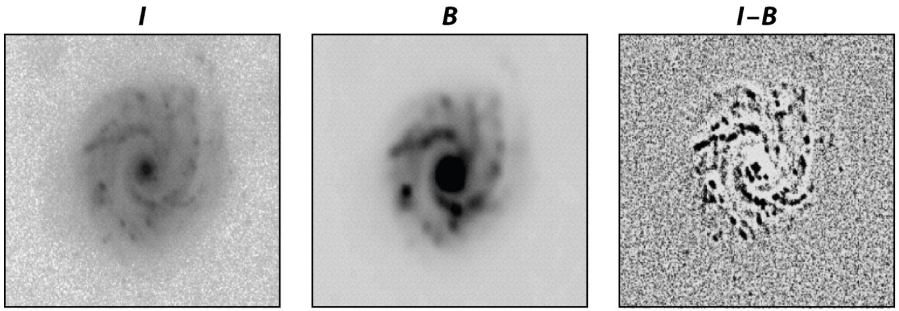


Conselice et al. (2000)

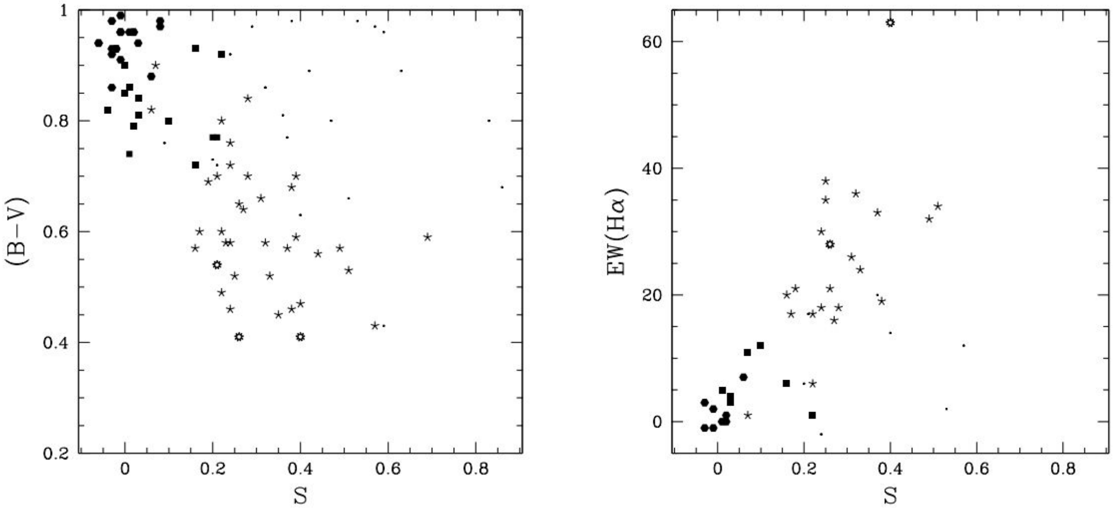
CAS - Smoothness (Clumpiness)

$$S = 10 \times \left[\left(\frac{\Sigma(I_{x,y} - I^{\sigma}_{x,y})}{\Sigma I_{x,y}} \right) - \left(\frac{\Sigma(B_{x,y} - B^{\sigma}_{x,y})}{\Sigma I_{x,y}} \right) \right]$$

Warning: sometimes no x10 (Lotz et al. 2004, 2008)



$$S = \frac{I-B}{I}$$



Conselice (2003)

$$\sigma = 0.3 \cdot 1.5 \times r(\eta = 0.2)$$

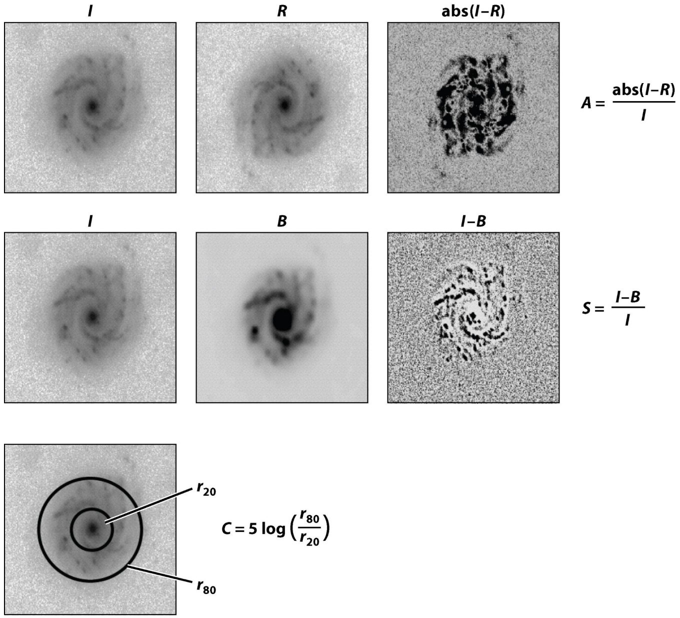
Sometimes 0.2 (Conselice 2009) or 0.25 (Lotz et al. 2004)

$$\eta(R) = \frac{I(R)}{<I(<R)>}$$

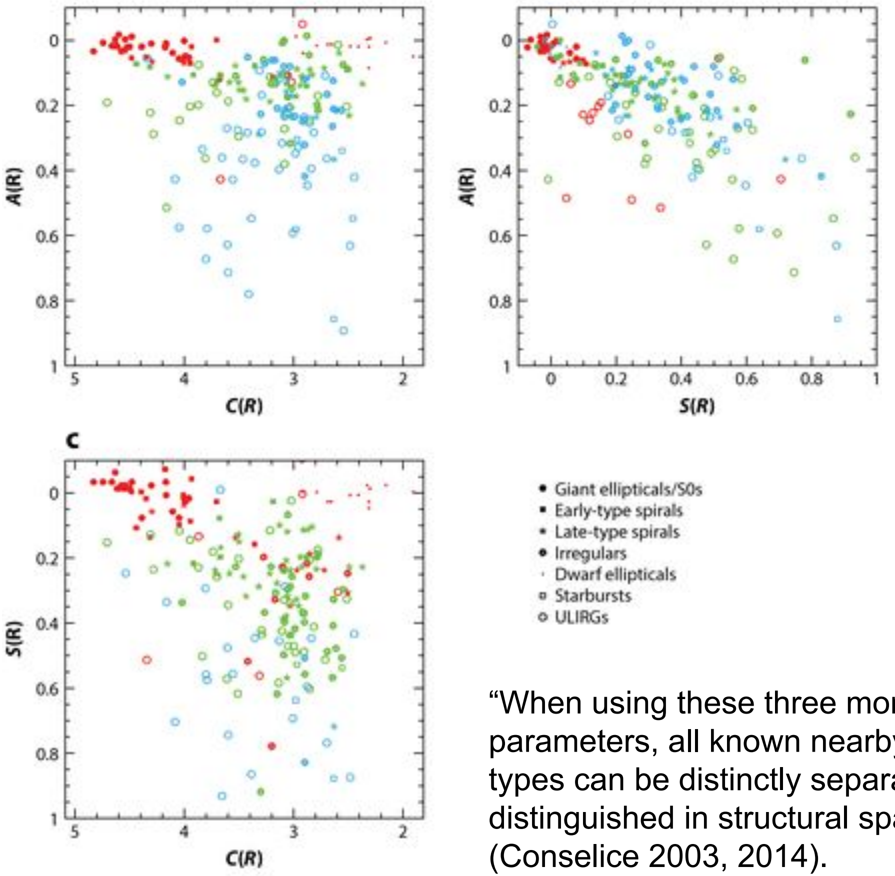
“[T]he clumpiness parameter (S) is incalculable due to limitations in the resolution of our images (PSF ~ 0. 3”)”(Bluck et al. 2012).

CAS - Summary

Galaxy type	Concentration (R)	Asymmetry (R)	Clumpiness (R)
Ellipticals	4.4 ± 0.3	0.02 ± 0.02	0.00 ± 0.04
Early-type disks (Sa-Sb)	3.9 ± 0.5	0.07 ± 0.04	0.08 ± 0.08
Late-type disks (Sc-Sd)	3.1 ± 0.4	0.15 ± 0.06	0.29 ± 0.13
Irregulars	2.9 ± 0.3	0.17 ± 0.10	0.40 ± 0.20
Edge-on disks	3.7 ± 0.6	0.17 ± 0.11	0.45 ± 0.20
ULIRGs	3.5 ± 0.7	0.32 ± 0.19	0.50 ± 0.40
Starbursts	2.7 ± 0.2	0.53 ± 0.22	0.74 ± 0.25
Dwarf ellipticals	2.5 ± 0.3	0.02 ± 0.03	0.00 ± 0.06



Conselice CJ. 2014.
Annu. Rev. Astron. Astrophys. 52:291–337

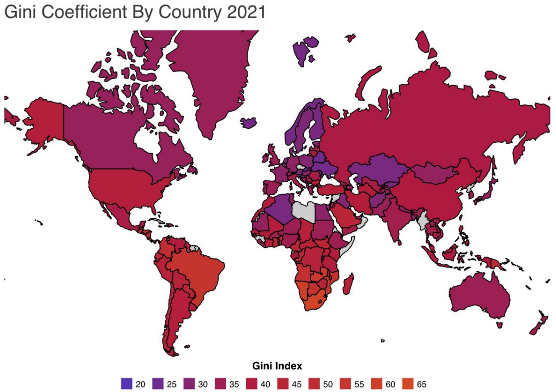


Conselice CJ. 2014.
Annu. Rev. Astron. Astrophys. 52:291–337

"When using these three morphological parameters, all known nearby galaxy types can be distinctly separated and distinguished in structural space" (Conselice 2003, 2014).

G-M20: Gini

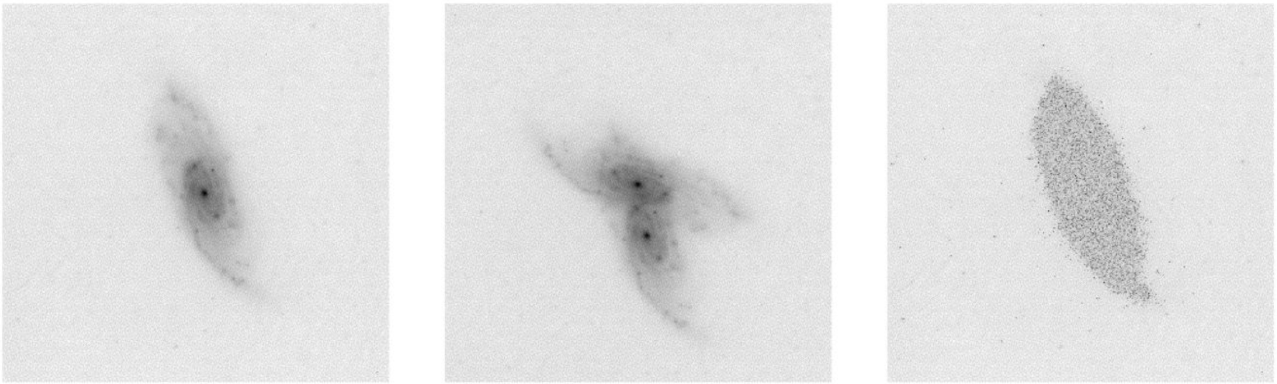
Canada: G~0.3
South Africa: G~0.6

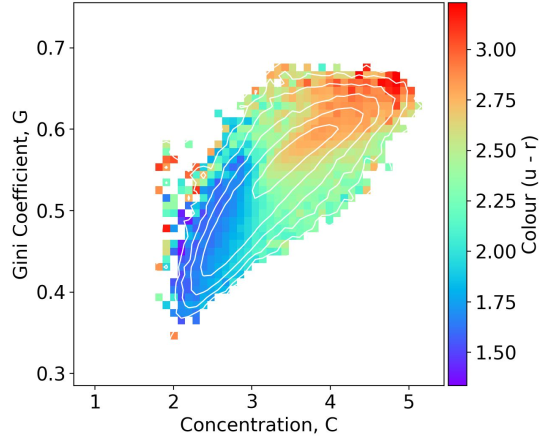


$$G = \frac{1}{\bar{X}n(n-1)} \sum_{i=1}^{n} (2i - n - 1) X_i$$

G=1, if all the light is concentrated in a single pixel
G=0, if all the light is equally distributed across the galaxy

All three images have the same value of G...





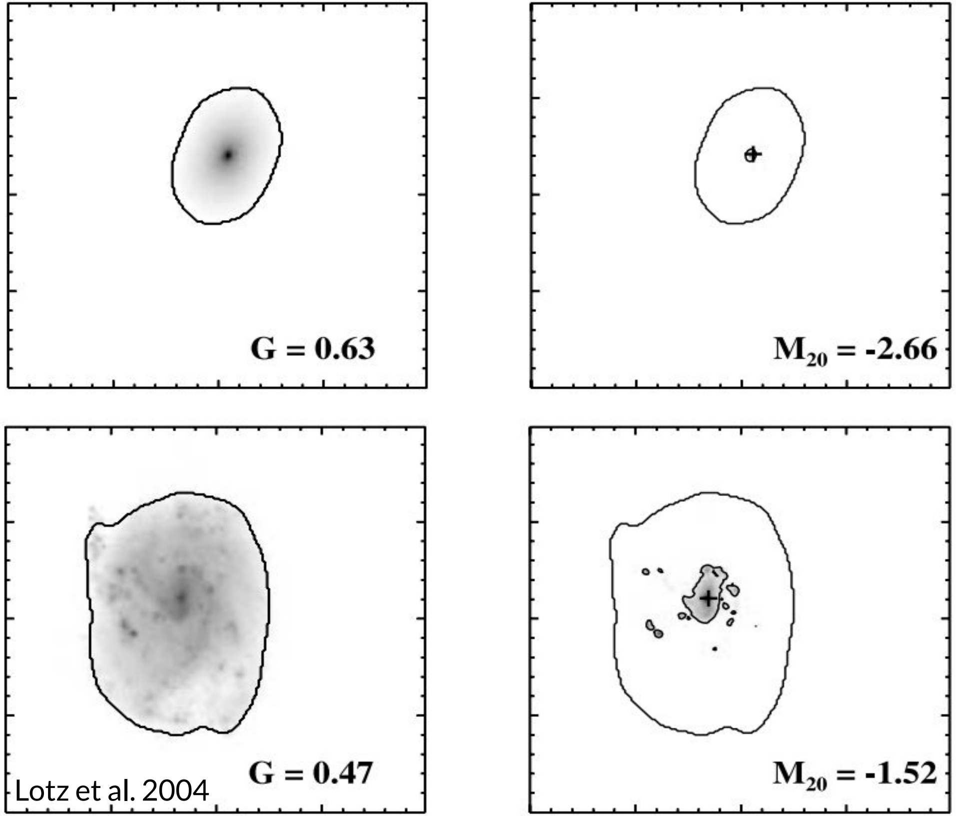
Abraham et al. 2002

Gini-M20: M20

$$M_{\mathrm{tot}} = \sum_i^n M_i = \sum_i^n f_i \left[(x_i - x_c)^2 + (y_i - y_c)^2\right]$$

$$M_{20} \equiv \log 10\left(\frac{\sum_i M_i}{M_{\mathrm{tot}}}\right), \text{ while} \sum_i f_i < 0.2 f_{\mathrm{tot}}$$

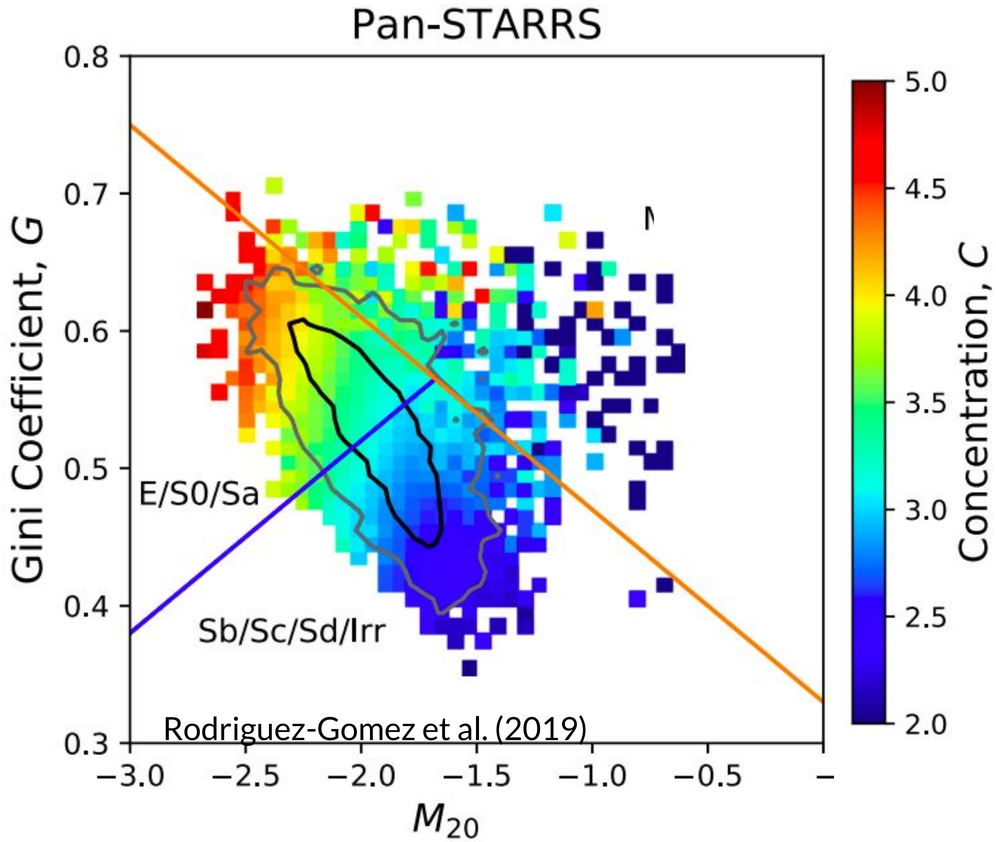
M20 measures the spatial variance of the brightest 20% of pixels (relative to the whole galaxy)



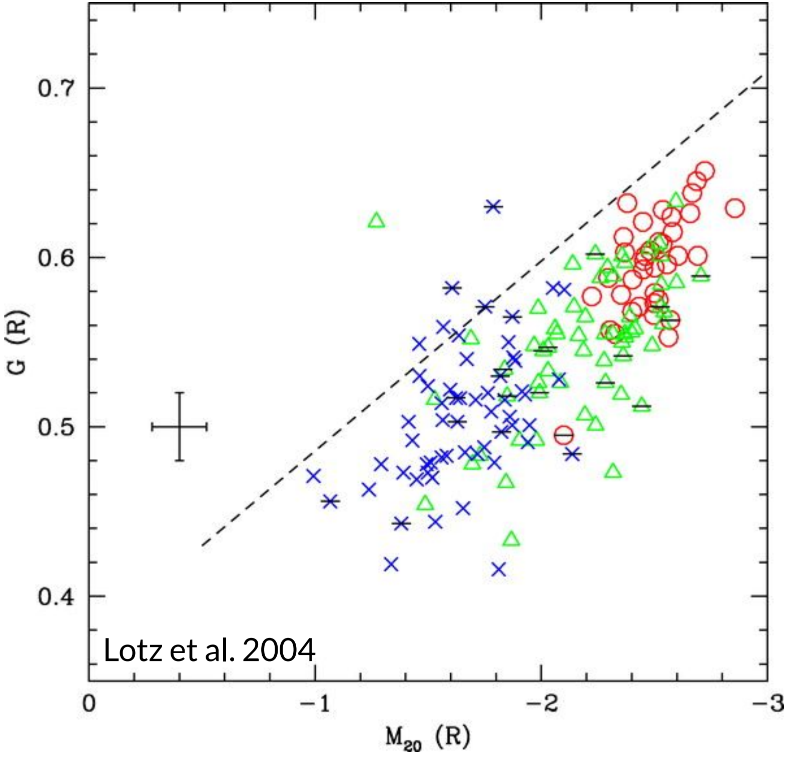
Lotz et al. 2004

Gini-M20

In tandem, Gini and M20 can be used to classify galaxies, too.

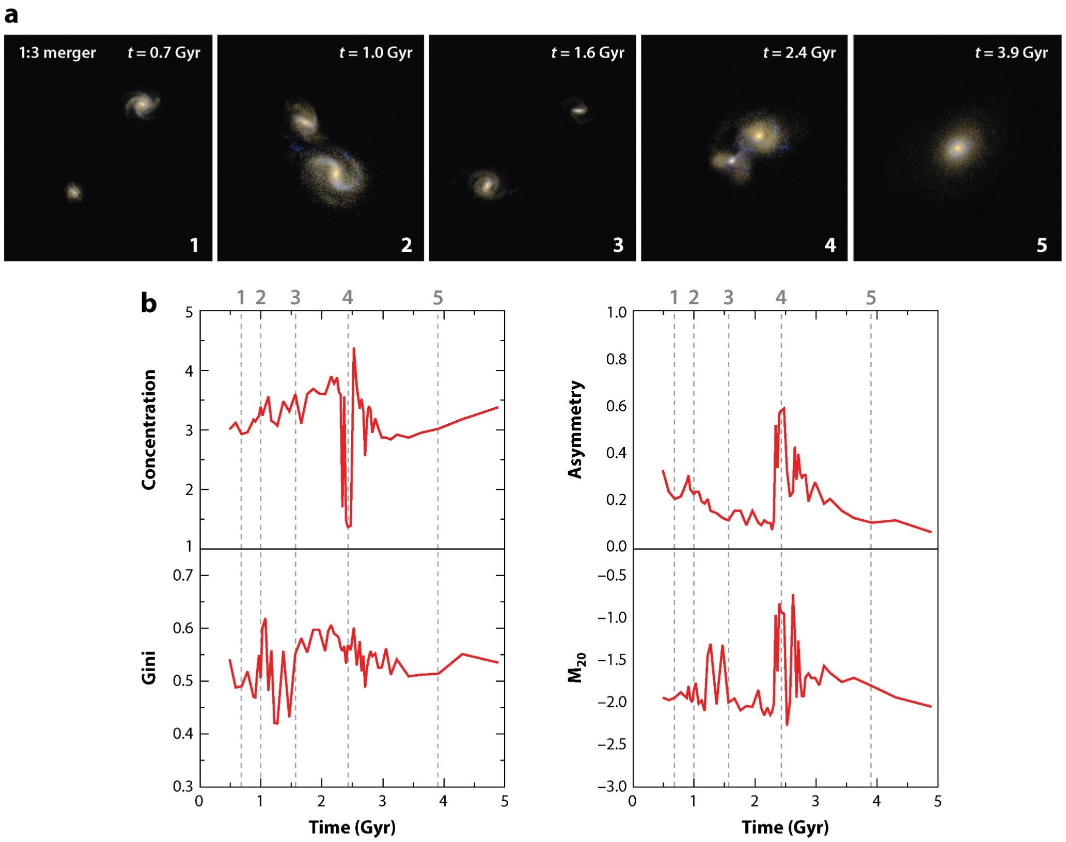


Rodriguez-Gomez et al. (2019)



Lotz et al. 2004

Non-parametric Morphology of Mergers

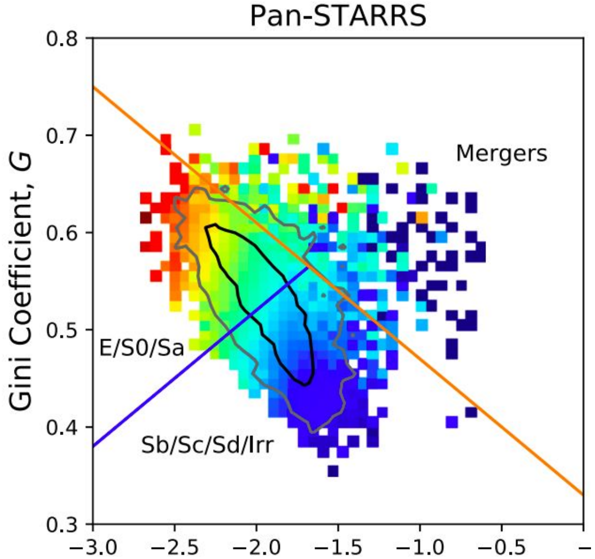


Conselice CJ. 2014.
Annu. Rev. Astron. Astrophys. 52:291–337

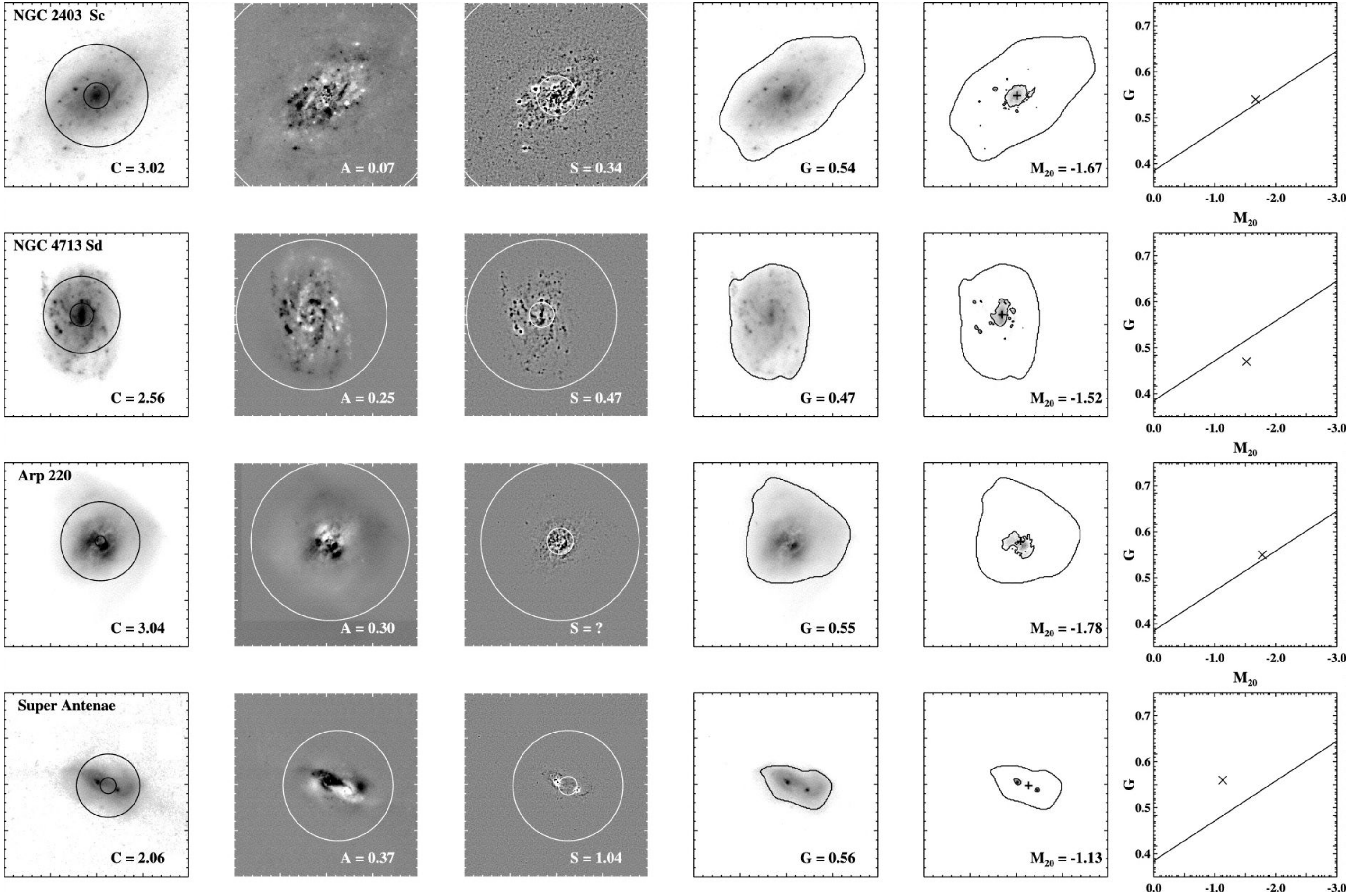
Merger Definitions:

CAS: **A > 0.35 & A > S**

G-M20: $G > -0.14M_{20} + 0.33$



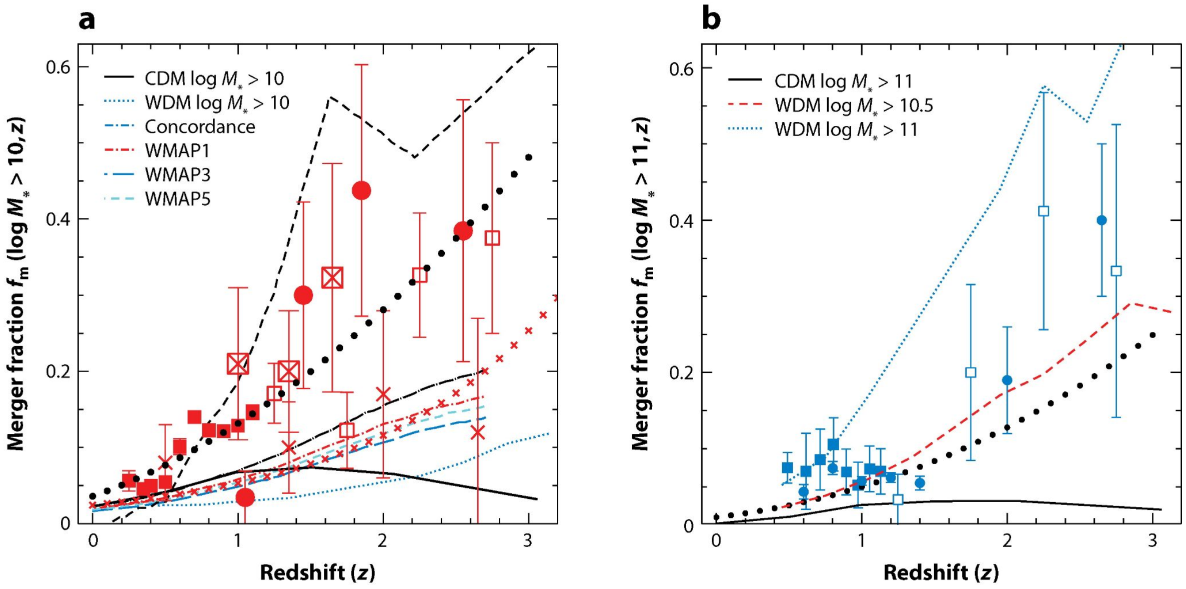
Visual Assessment



Lotz et al. 2004

Merger Fraction through Cosmic Time

$$f_{\mathrm{m}}(M_*, z) = \frac{N_{\mathrm{m}}}{N_{\mathrm{T}}} \qquad f_{\mathrm{m}} = f_0 \times (1+z)^m$$



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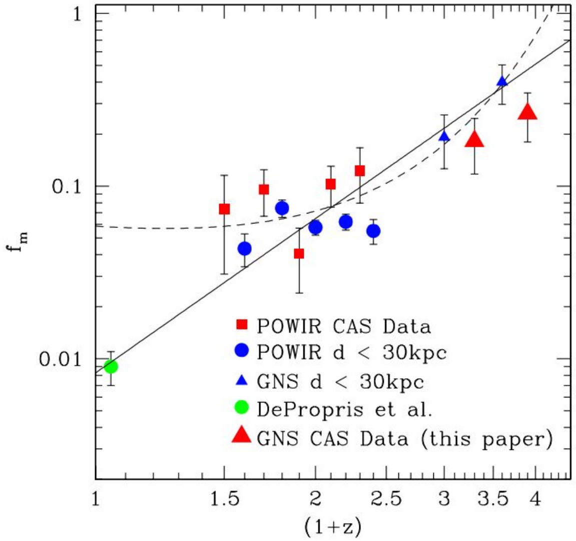
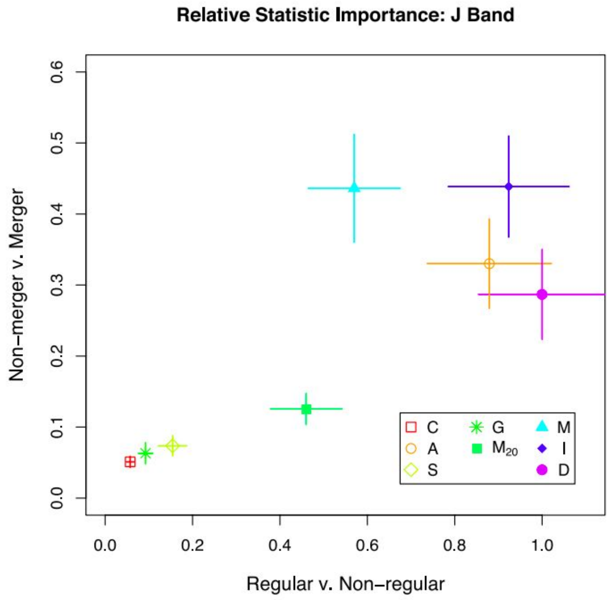


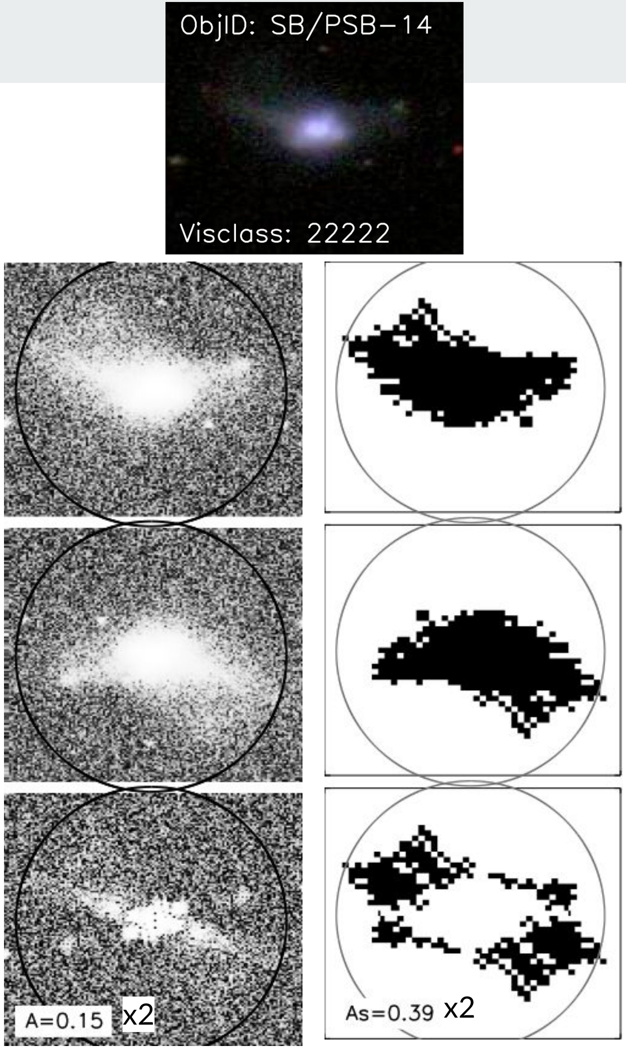
Bluck et al. (2012)

Since Conselice 2014...

Some new non-parametric morphology statistics:

- MID statistics (Freeman et al. 2013)
- Shape Asymmetry(Pawlik et al. 2016)
- Outer Asymmetry (Pawlik et al. 2016)

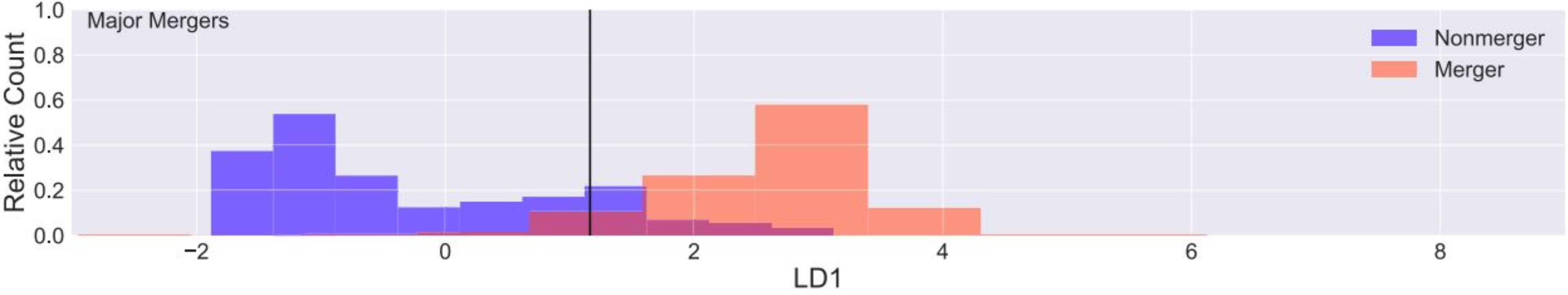




An attempt to combine the metrics...

Trained on a suite of hydrodynamical simulations with SDSS imaging realism applied, Nevin et al. (2019) uses Linear Discriminant Analysis to combine metrics and identify mergers...

$$\begin{aligned}\mathrm{LD1_{major}} &= 0.69\,\mathrm{Gini} + 3.84\,C + 5.78\,A + 13.14\,A_S \\ &- 3.68\,\mathrm{Gini} * A_S - 6.5\,C * A_S - 6.12\,A * A_S \\ &- 0.81,\end{aligned}$$



The LDA can’t be applied to other surveys without retraining...

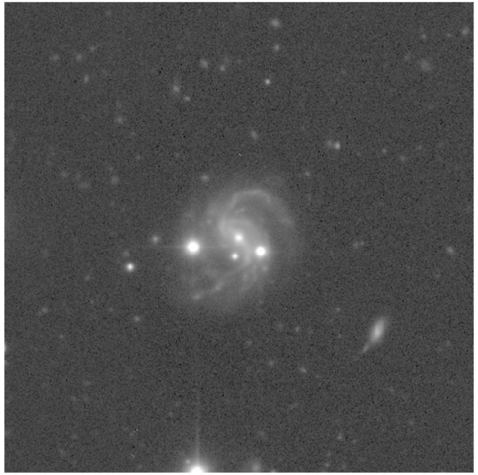
Problems not Addressed

Foreground star contamination can increase G, M20, A, and S and decrease C.

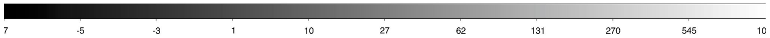
Effects of PSF FWHM, pixel scale, depth, wavelength

Observability timescale

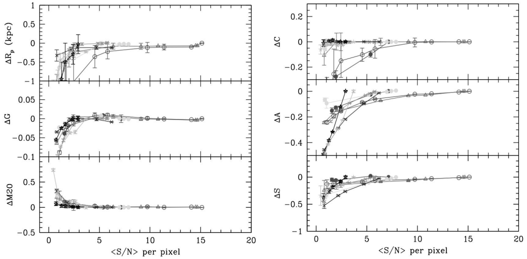
Can you reliably compare these statistics over cosmic time and in different imaging?



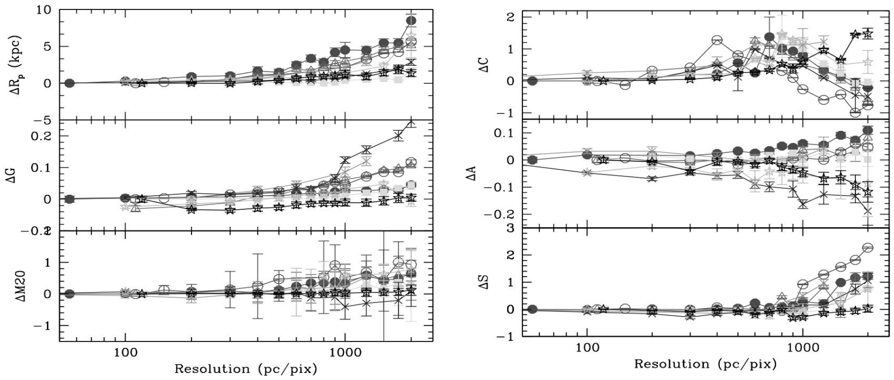
C = 1.68
A = 0.88
S = 0.18
G = 0.64
M20 = -0.944



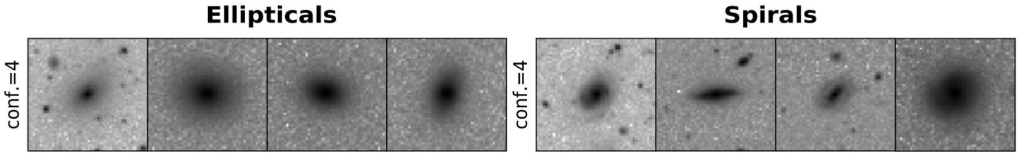
Conselice 2014 does not mention “PSF,” “FWHM,” “seeing,” “foreground,” or “contamination.”

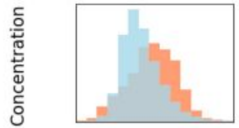


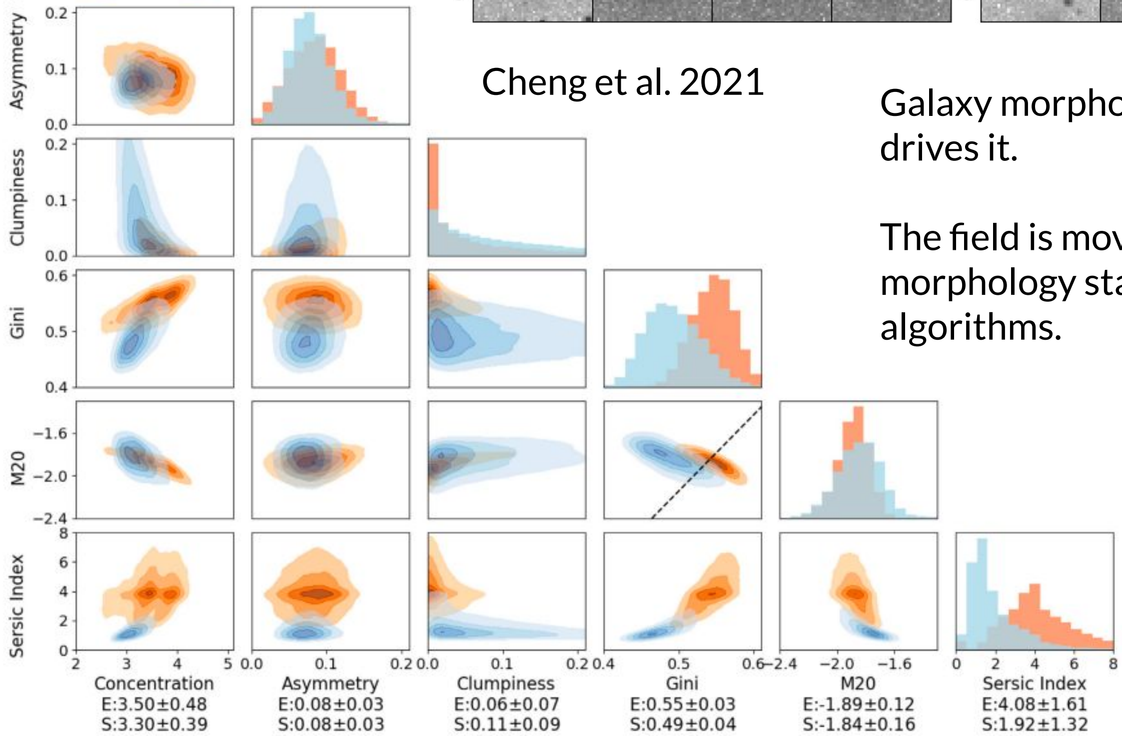
Lotz et al. (2004)



Machine Learning







superior confidence ($16 \leq i < 18$ and $z < 0.25$)

Cheng et al. 2021

Galaxy morphology is as nuanced as the physics that drives it.

The field is moving away from non-parametric morphology statistics and towards machine learning algorithms.

Questions?

Additional Figures