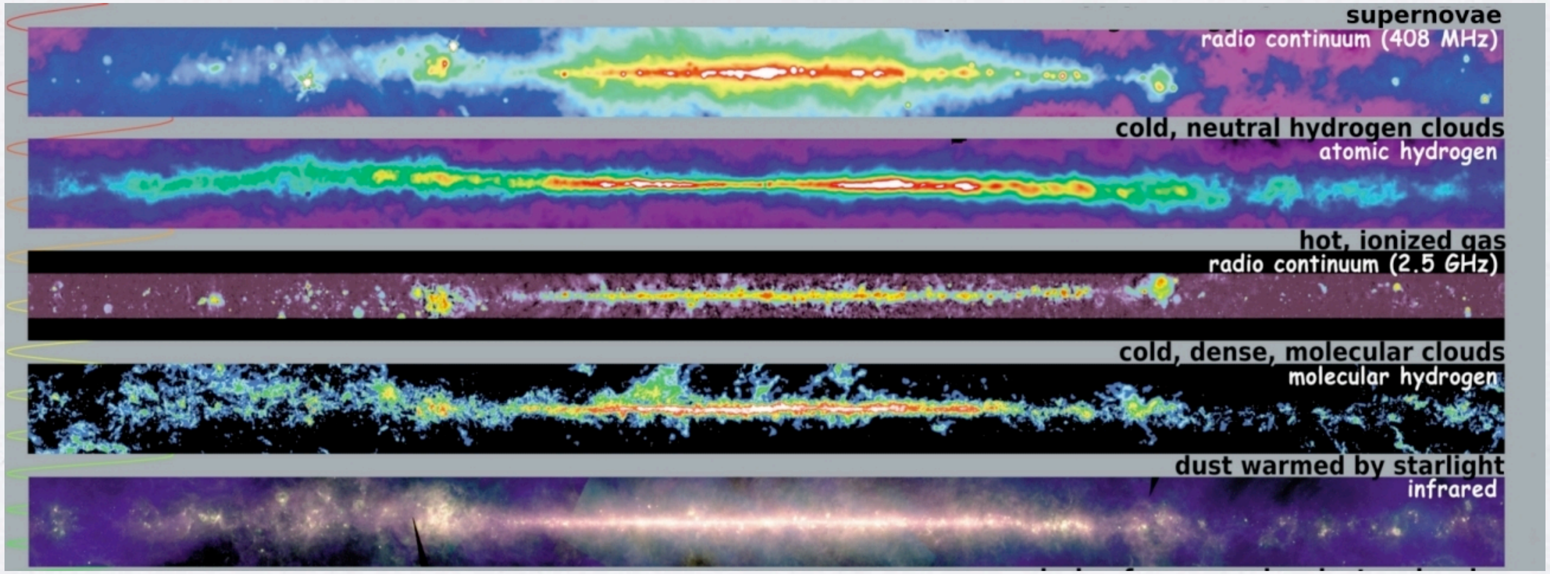
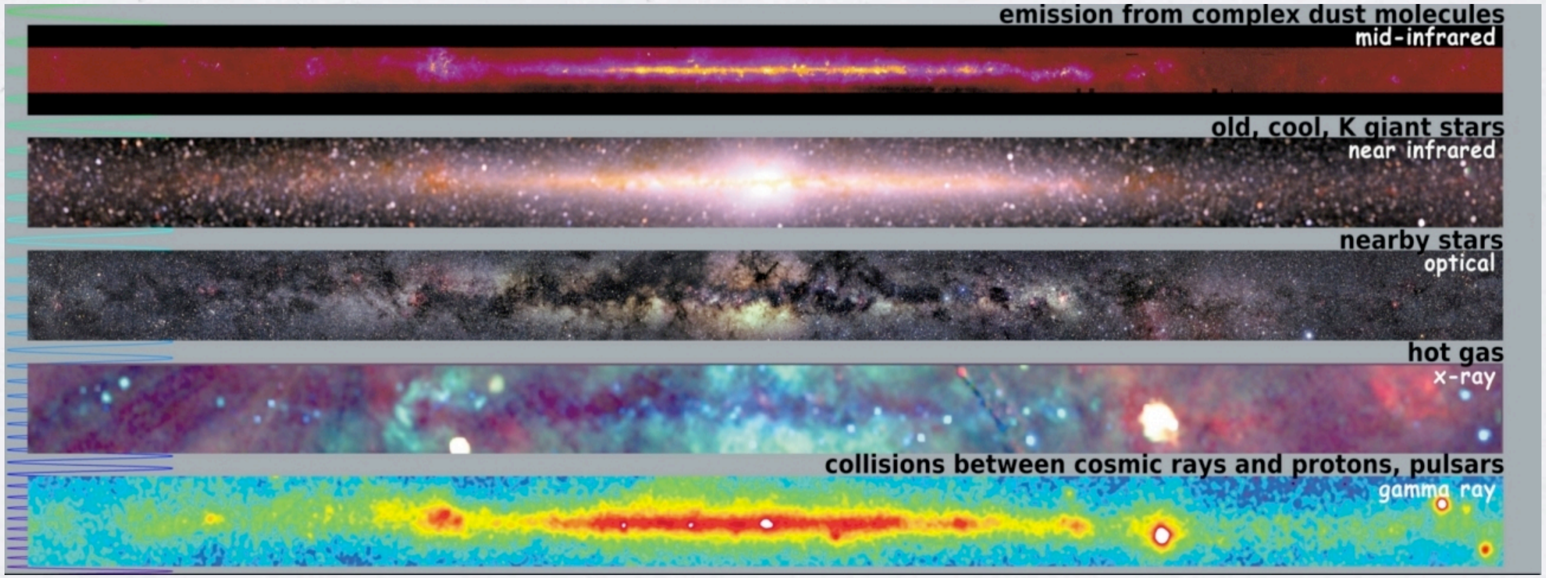
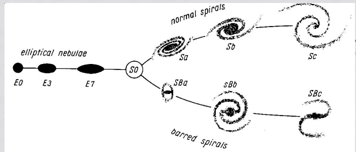


MULTIWAVELENGTH MORPHOLOGY

Andrew Hopkins
Australian Astronomical Observatory

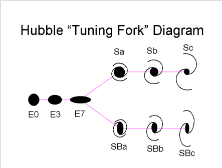


Australian Government
Department of Industry



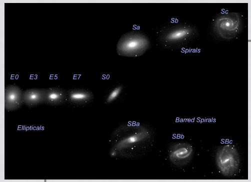
Overview

- What this talk is:
  - Arguing that the Hubble Sequence has outlived its usefulness
  - Worse, it may now in fact be holding us back
  - A plea for precision
- What this talk is not:
  - Science
  - New results
  - Anything you don't know already



What do we mean by morphology?

- The shape formed by the distribution of stars within a galaxy?
- The shape formed by the distribution of **old** stars?
- The shape formed by the distribution of gas?
- The shape formed by the distribution of **ionised** gas?
- The shape formed by the distribution of dust?
- Ambiguities here can lead to very real errors when trying to compare results between authors/surveys, or data/simulations



STATISTICAL SCIENCE

previous :: next

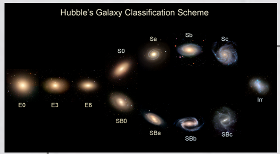
Classifier Technology and the Illusion of Progress

David J. Hand

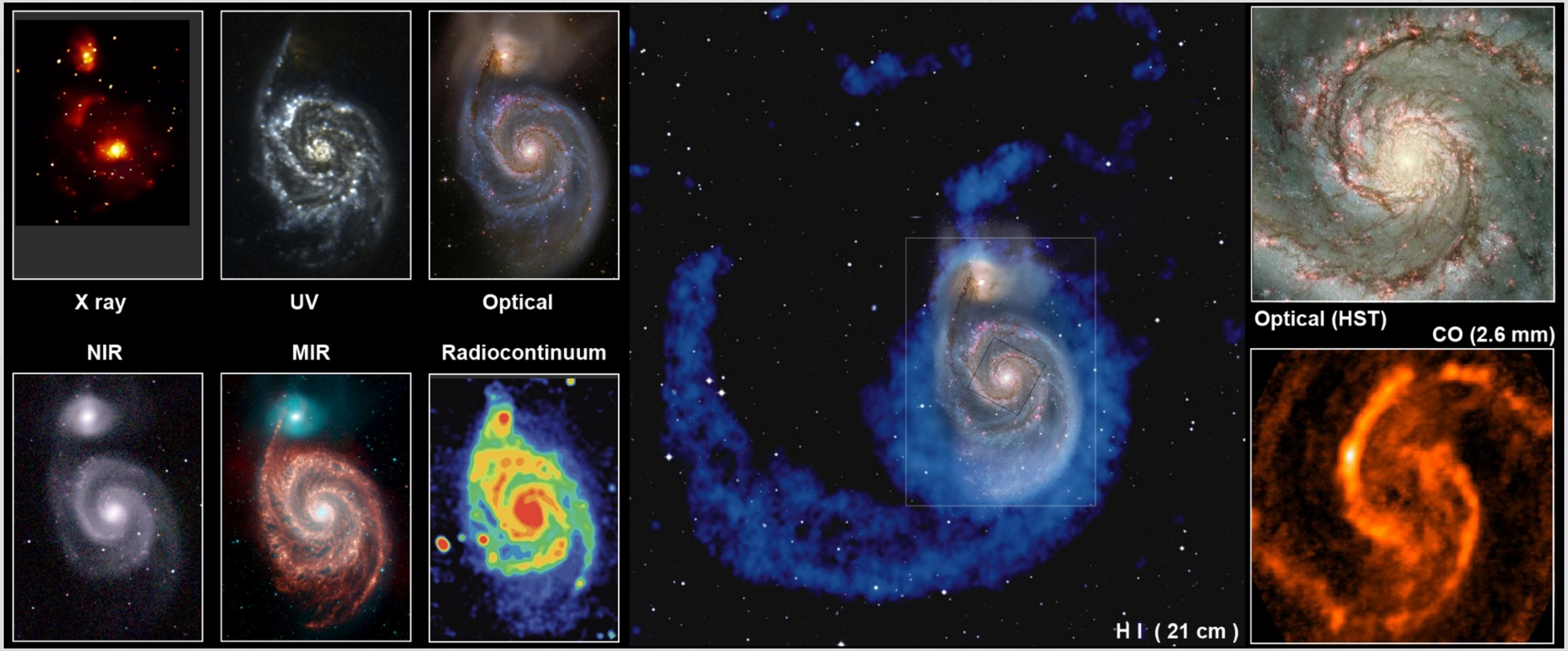
Source: Statist. Sci. Volume 21, Number 1 (2006), 1-14.

Abstract

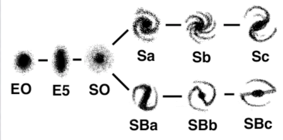
A great many tools have been developed for supervised classification, ranging from early methods such as linear discriminant analysis through to modern developments such as neural networks and support vector machines. A large number of comparative studies have been conducted in attempts to establish the relative superiority of these methods. This paper argues that these comparisons often fail to take into account important aspects of real problems, so that the apparent superiority of more sophisticated methods may be something of an illusion. In particular, simple methods typically yield performance almost as good as more sophisticated methods, to the extent that the difference in performance may be swamped by other sources of uncertainty that generally are not considered in the classical supervised classification paradigm.



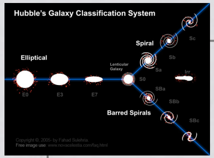
M51 and NGC 5195



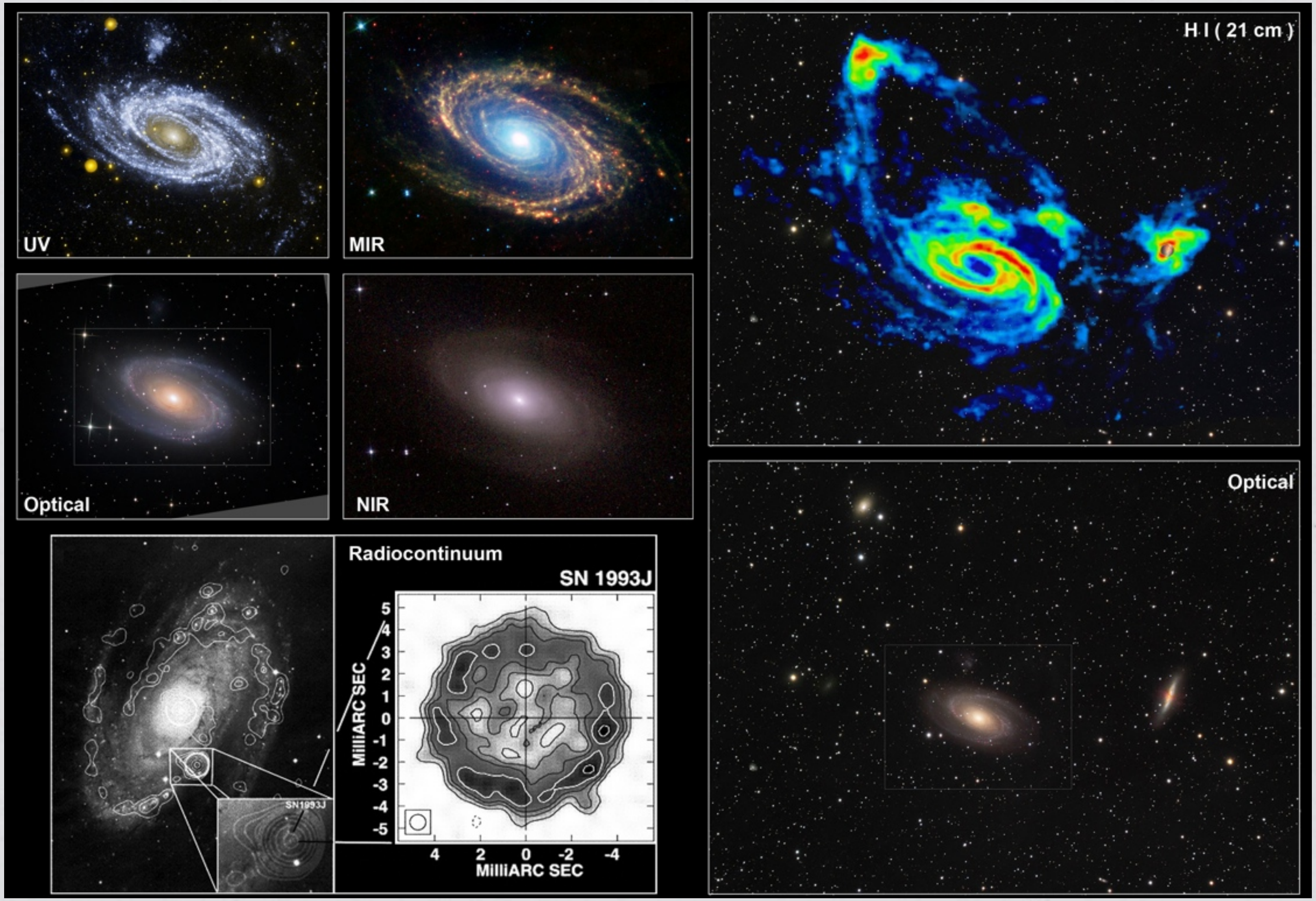
Credit: Ángel López-Sánchez



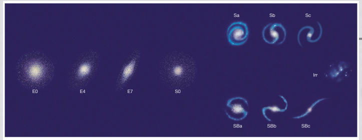
M51 and NGC 5195



M81

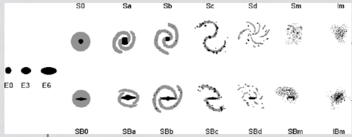


Credit: Ángel López-Sánchez



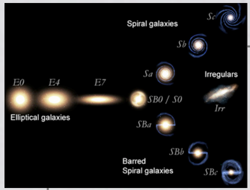
M106


Spiral Galaxy M 106
Hubble Heritage
NASA and ESA • ACS/WFC HST WFC3/UVIS WFPC2 • STScI-PRC13-06



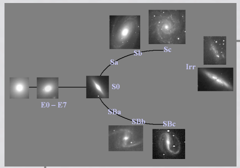
What use is morphology?

- We use it as a convenient mental or verbal shorthand.
- It is convenient to label things in two (sometimes three) categories, as our brains have not evolved to be comfortable thinking in many dimensions.
- We seem to like bimodalities. We find them all over the place:
  - Red/blue
  - Star-forming/quiescent or active/passive
  - high-n/low-n
- But real physical distributions span a continuum.
- As Darren reminded us, morphology is a consequence of physics.

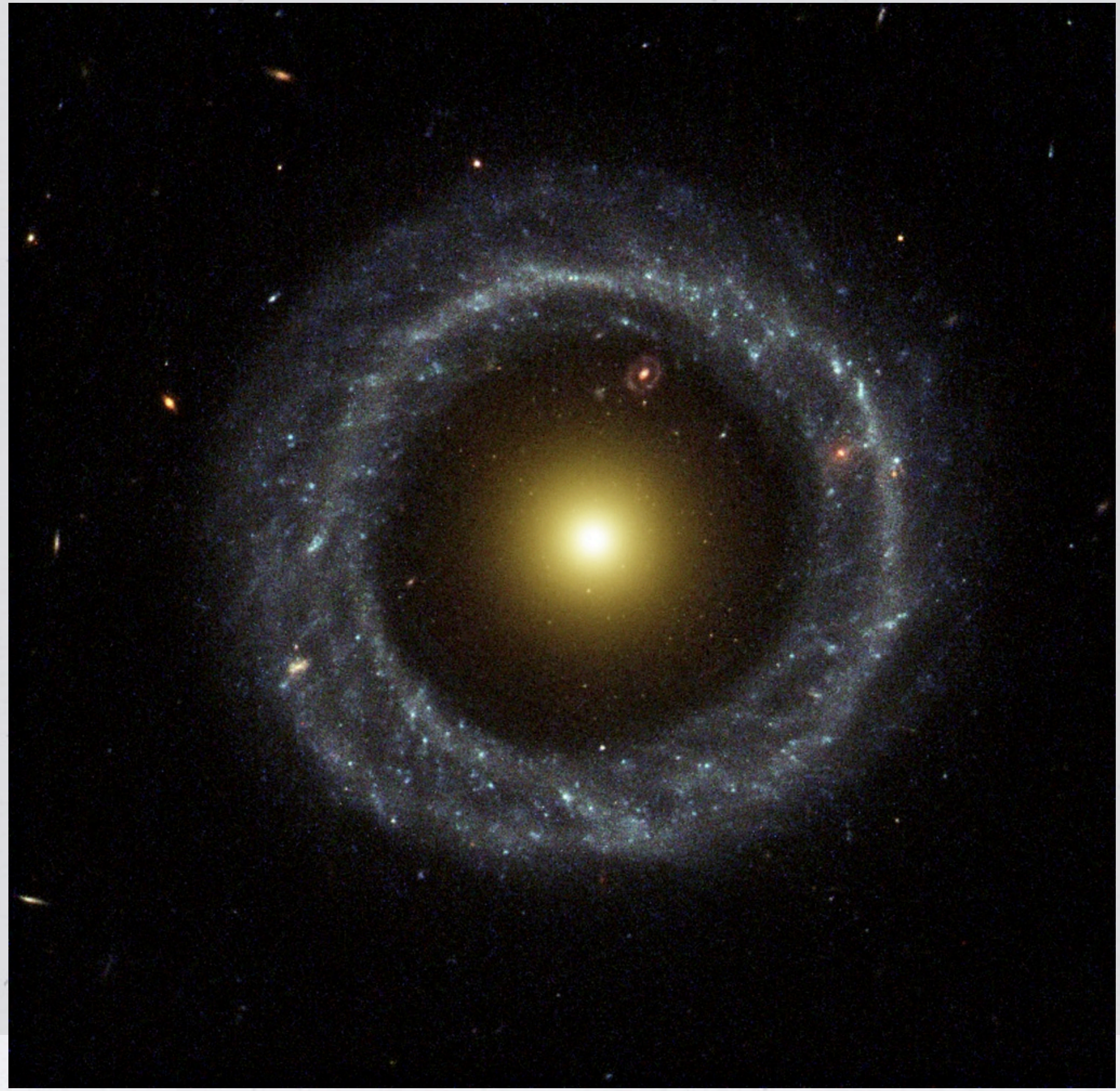


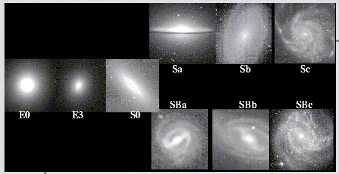
How reliable is morphology?

- Brooke's tidal tails masquerading as spiral arms.
- Jennifer's high-z clumpy disks masquerading as mergers.
- Bulge fraction: discriminating David's (or Roger's) pseudo-bulges (pseudo-disks?) from classical bulges



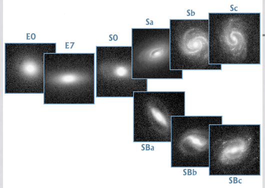
Hoag's object



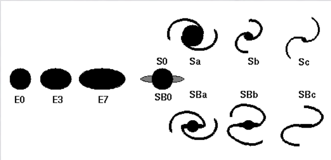


Limitations with morphology

- Galaxies look different depending on wavelength, resolution, mass, environment, redshift, sensitivity.
- Our convenient terminology shorthand can lead to confusion and imprecision. Worse, it can lead to erroneous conclusions. (E.g., "quenched"; are Kevin's zombie galaxies "quenched" yet or not?)
- Every galaxy is unique: The closer you look the weirder it becomes. (E.g., Sukyoung's deep images.)
- It is important to be clear about what question you are trying to answer. The metrics used should be derived (or chosen) to answer a well-posed scientific question.

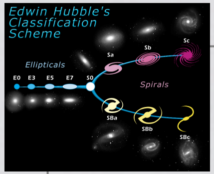


The Hidden Tiger



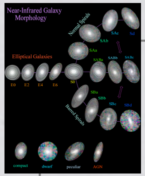
Just butterfly collecting?

- Clearly classification for its own sake is not the goal.
- Taxonomy is useful, as it provides a form of data compression. But it is only a step along the way.
- What we want to achieve is an understanding of the underlying astrophysics.



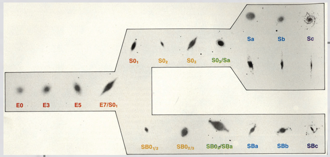
Quantitative morphology

- Jennifer Lotz gave an excellent overview yesterday of quantitative morphology measures; CAS, Gini-M20, light profile or structure fits, etc.
- It is clear that any metric, to be useful, must be quantitative and objective.
- Existing implementations have been applied primarily to monochromatic data. They can be limited by resolution (redshift), and choice of photometric band, for example.
- In principle, we can use more information, mutiple wavelength imaging, to move such metrics to a point where they can measure something more representative of the underlying astrophysics.



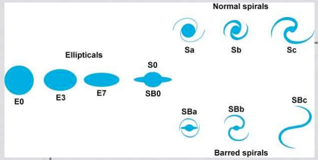
Quantitative morphology

- Distance information is also known for many 10^6 galaxies, and adds an important constraint in quantifying structure.



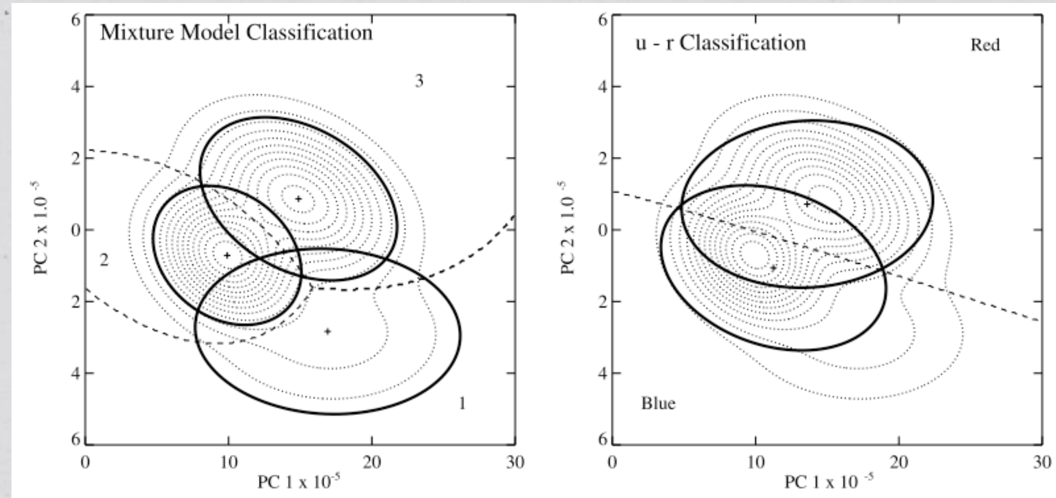
A brief diversion: bimodality

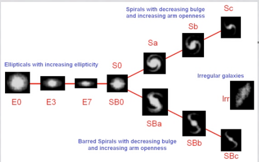
- It is clear that the bimodalities we see in colour (red/blue), shape (e.g., Sersic high-n/low-n), star formation rate (active/passive), are not interchangeable. Yet we often use the terms “early” and “late” to abbreviate any or all of these. (See Taylor et al., MNRAS, submitted.)
- Stop it.
- No really. Stop it.



Multiwavelength morphology

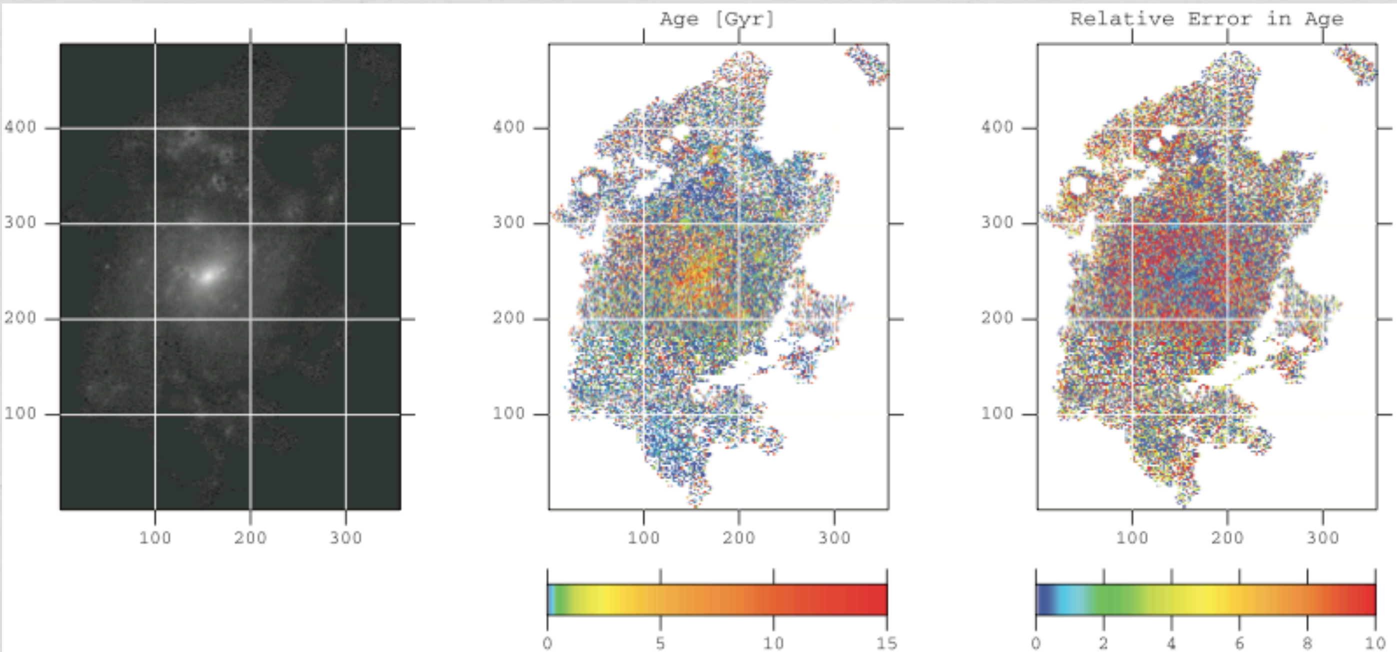
- Kelly & McKay (2005, AJ, 129, 1287) implemented a linear decomposition of galaxy images, **simultaneously** using u,g,r,i,z SDSS images.
- This approach demonstrated that galaxy populations can be classified objectively in a way that mimics colour cuts.

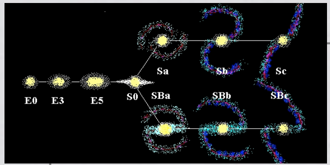




Multiwavelength morphology

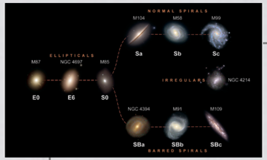
- Conti et al (2003, AJ, 126, 2330) and Welikala et al (2008, ApJ, 677, 970) implemented population synthesis fits to the colours of individual pixels in HDF and SDSS data, called "pixel-z".





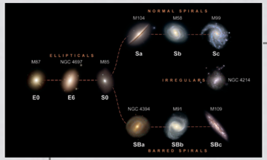
Multiwavelength morphology

- Wijesinghe et al (2010, MNRAS, 404, 2077) combined both approaches. Used "pixel-z" maps, quantified using the CAS metrics of Chris Conselice, and the linear decompositions of Brandon Kelly.
- The aim was to compare the spatial distribution of the underlying physical properties, quantified by CAS, with the quantitative morphology measure from the decomposition.
- No clear or strong connections were established.
- Likely a consequence of limitations in each of the three measurement tools.

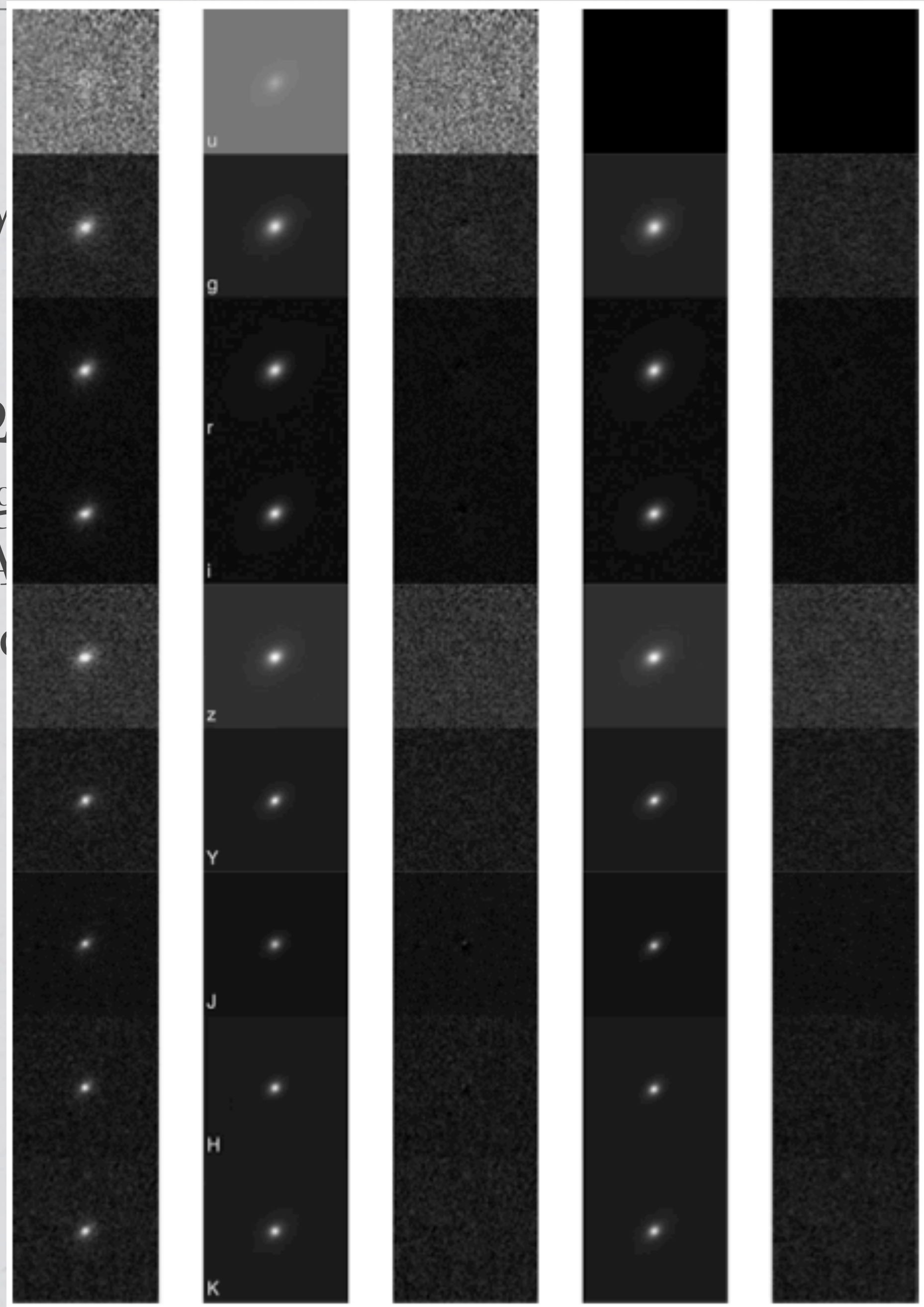


Multiwavelength morphology

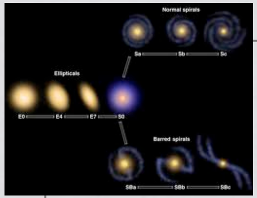
- Häußler et al (2013, MNRAS, 430, 330) implemented a different approach, using 9-band ugrizYJHK photometry from GAMA, also informed by GAMA redshifts. The "megamorph" approach simultaneously fits single Sersic profiles to 9 photometric bands.



Multiv nology

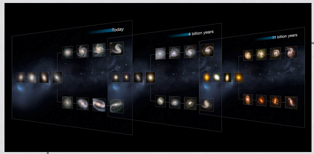


* Häußler et al (2 different approach, using MA, also informed by GA ch simultaneously fits single Sersi

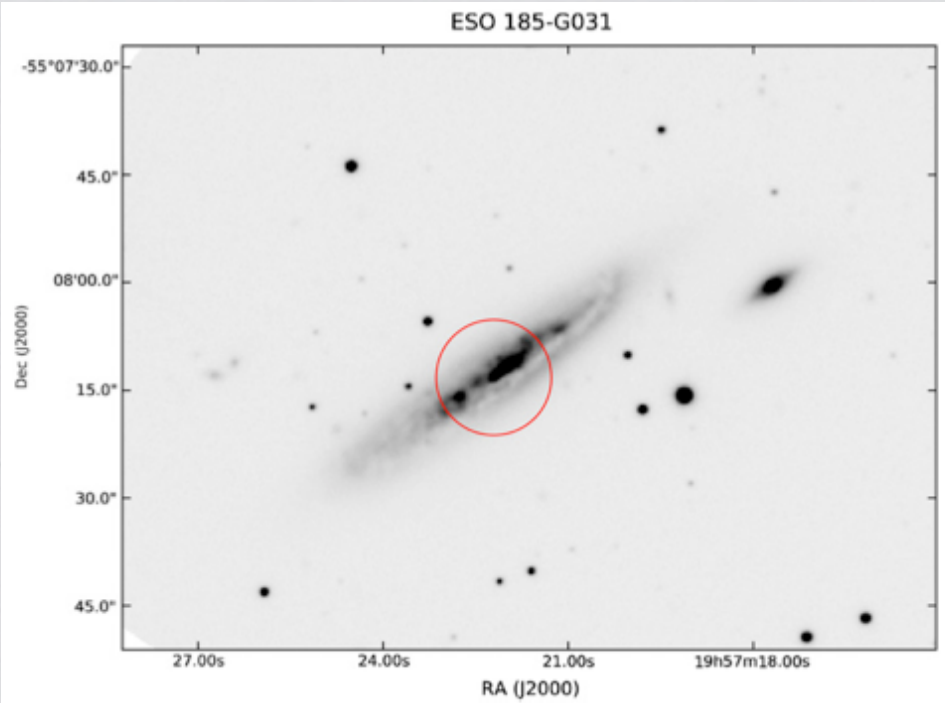


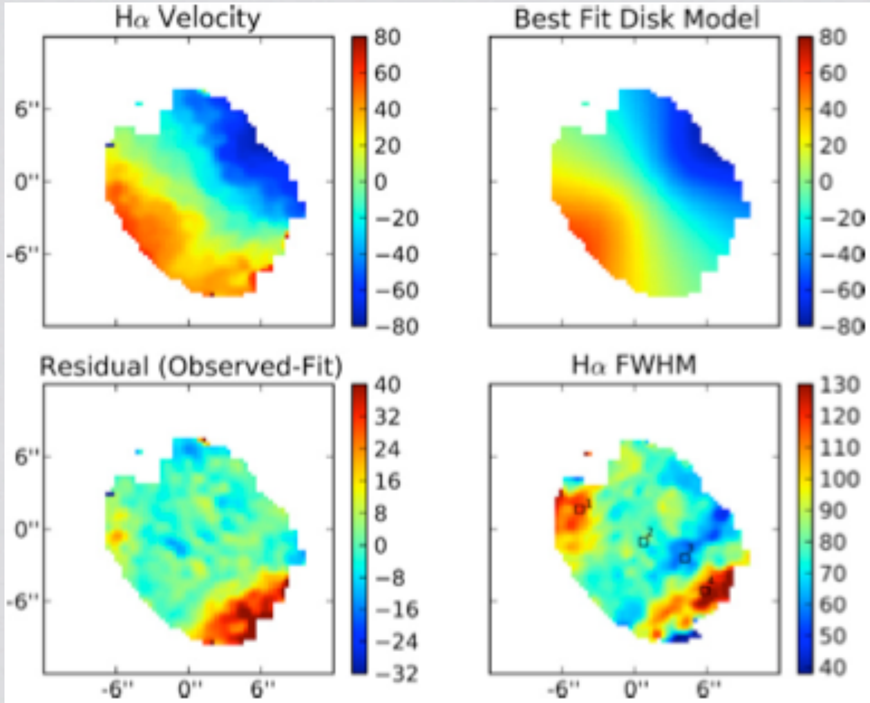
We are data rich

- With modern large-scale multiwavelength surveys we can do better.
- Using colours and population synthesis codes, for example, we can infer physical properties. Clearly much better if spectra are also available.
- IFS data is the logical next step, providing detailed physical measurements from spectra, not just colours, in a spatially resolved fashion.
- The goal should now move away from butterfly collecting to quantifying spatially distributed galaxy properties in a more fundamental way, that reflects their internal astrophysics.

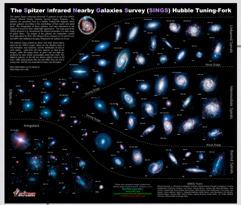


SAMI example



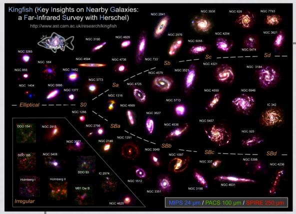


Fogarty et al., (2012, ApJ, 761, 169)



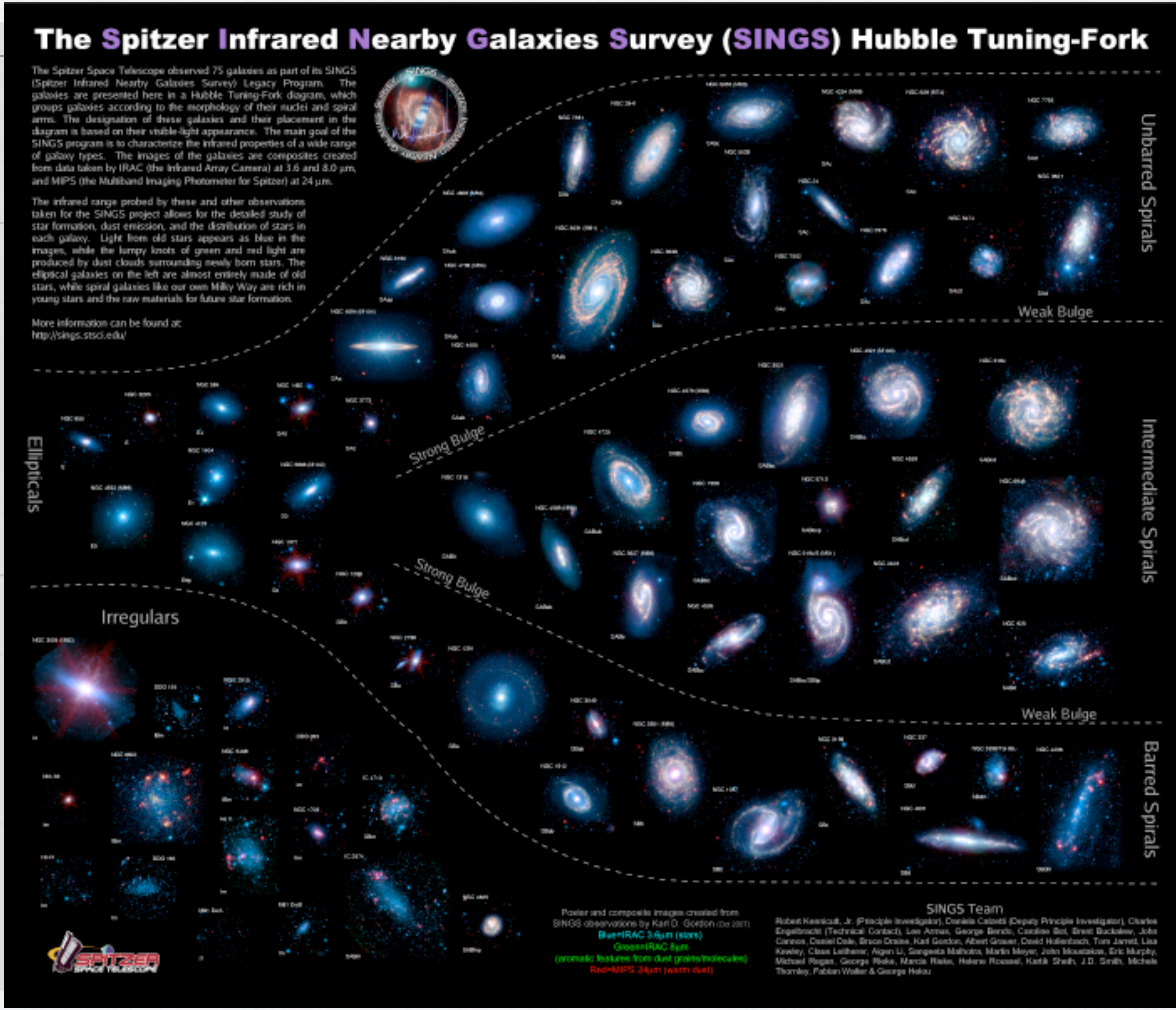
Move beyond the optical

- But we can do better still.
- We have data spanning UV-radio now, including spectra and redshifts, for many 10^5 galaxies, probably more.
- GAMA, for example, has 22-band photometry, plus spectra, for perhaps 250000 galaxies.
- SAMI already has IFS data, plus GAMA photometry, for about 650 galaxies, and will do for 3000 by mid-2016.
- We need to be able to sensibly combine information including kinematics, SED, SFR, stellar mass, dust mass, and more to maximise our understanding of the astrophysics in galaxies.
- I offer this as a challenge for the next generation of Zooniverse interfaces. TheSkyNet seems to be on the right track!



Summary

- The Hubble Tuning Fork has been a useful tool for almost a century. We now have the data to allow us to move past that, to more quantitative measures of stellar distribution and kinematics, gas distribution and kinematics, and how these are related.
- We need to define quantitative metrics that encompass the full suite of available information in order to provide more physical insight.
- Use IFS data, multiwavelength imaging, redshifts, go beyond the optical. Each butterfly is beautiful and deserves to be treated with special care.
- Bimodality is clearly a real phenomenon, but artificially classifying galaxies into two populations is limiting, and at worst erroneous.
- Early-type and late-type. Stop it.


The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork
The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0 µm, and MIPS (the Multiband Imaging Photometer for Spitzer) at 24 µm.
The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.
More information can be found at: http://sings.stsci.edu/
Unbarred Spirals
Weak Bulge
Strong Bulge
Intermediate Spirals
Strong Bulge
Weak Bulge
Barred Spirals
Ellipticals
Irregulars
Poster and composite images created from SINGS observations by Karl D. Gordon (Oct 2007)
Blue=IRAC 3.6µm (stars)
Green=IRAC 8µm
(aromatic features from dust grains/molecules)
Red=MIPS 24µm (warm dust)
SINGS Team
Robert Kennicutt, Jr. (Principle Investigator), Daniela Calzetti (Deputy Principle Investigator), Charles Engelbracht (Technical Contact), Lee Armus, George Bendo, Caroline Bot, Brent Buckalew, John Cannon, Daniel Dale, Bruce Draine, Karl Gordon, Albert Grauer, David Hollenbach, Tom Jarrett, Lisa Kewley, Claus Leitherer, Aigen Li, Sangeeta Malhotra, Martin Meyer, John Moustakas, Eric Murphy, Michael Regan, George Rieke, Marcia Rieke, Helene Roussel, Kartik Sheth, J.D. Smith, Michele Thornley, Fabian Walter & George Helou
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