Galaxies: Introduction

ASTR 505

Astronomy 505: Galaxies
Section A01, Fall 2020

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Website for lecture notes and assignments: http://www.astro.uvic.ca/~jwillis/teaching/astr505/astr505.html

Lectures: Tuesday 2.30-4.30pm. Lectures are provided online via Blackboard Collaborate.

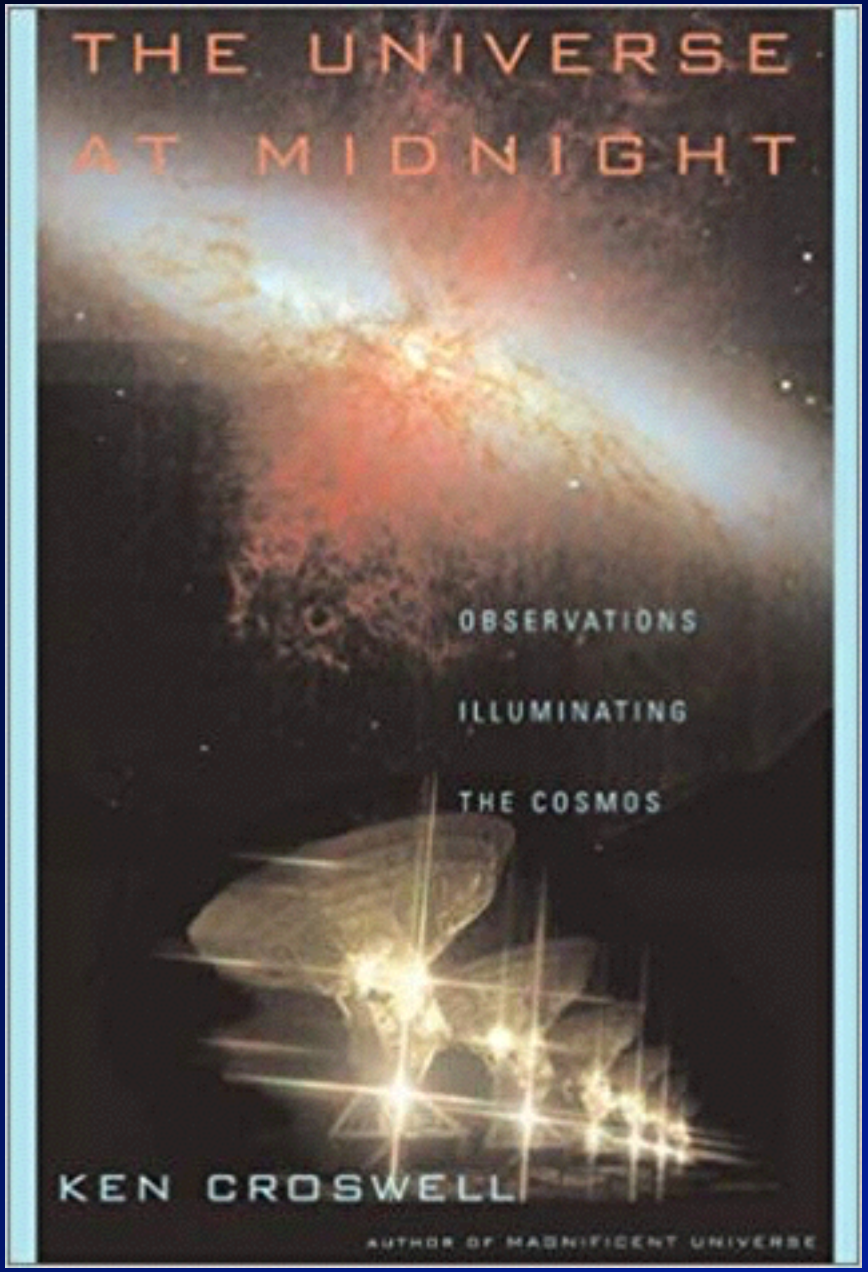
Office hours: Upon request via skype or similar.

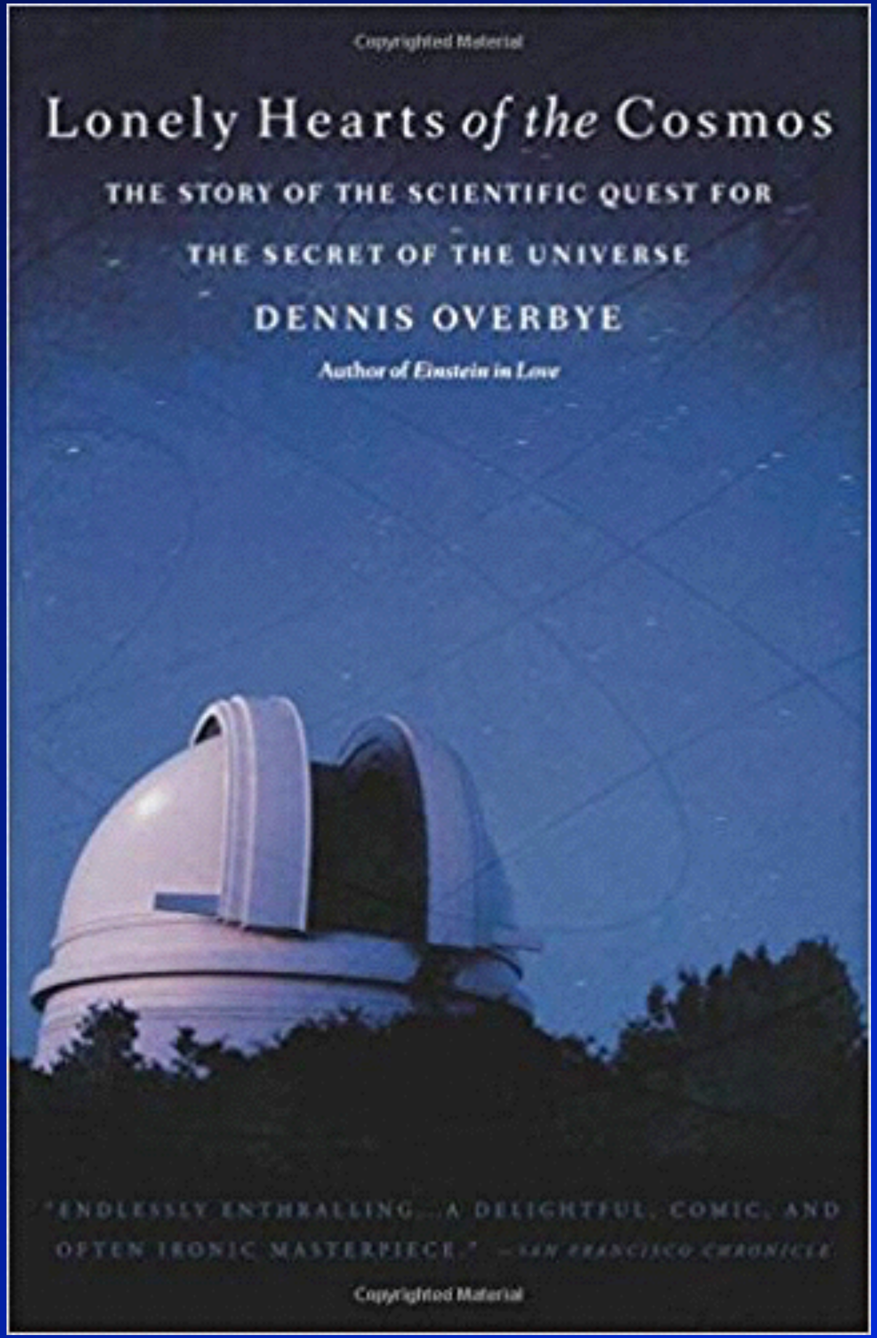
Course text: The structure and evolution of galaxies by Steven Phillipps. Galaxies in the Universe by Sparke and Gallagher is a good alternative.

Course outline: The formation and evolution of galaxies from a modern research perspective. Topics may include the observed properties of galaxies, the growth of galaxies from initial conditions, the development of galactic scaling relations, the relationship between galaxies and large-scale structure and the physical evolution of galaxies.

Course assessment:
Assignments: 100%.

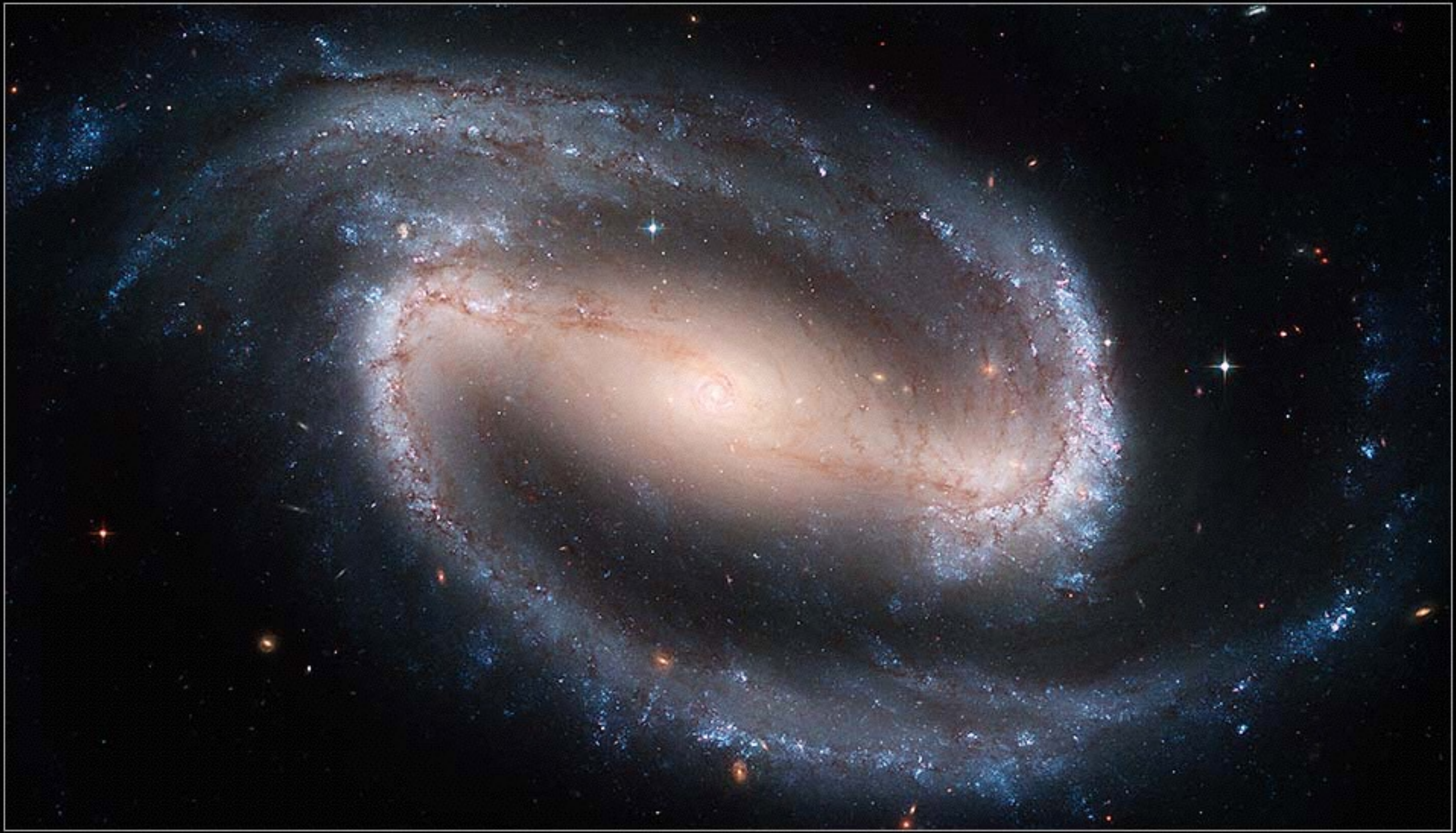
Approximately four assignments will be issued through the semester. Late assignments will not be accepted.





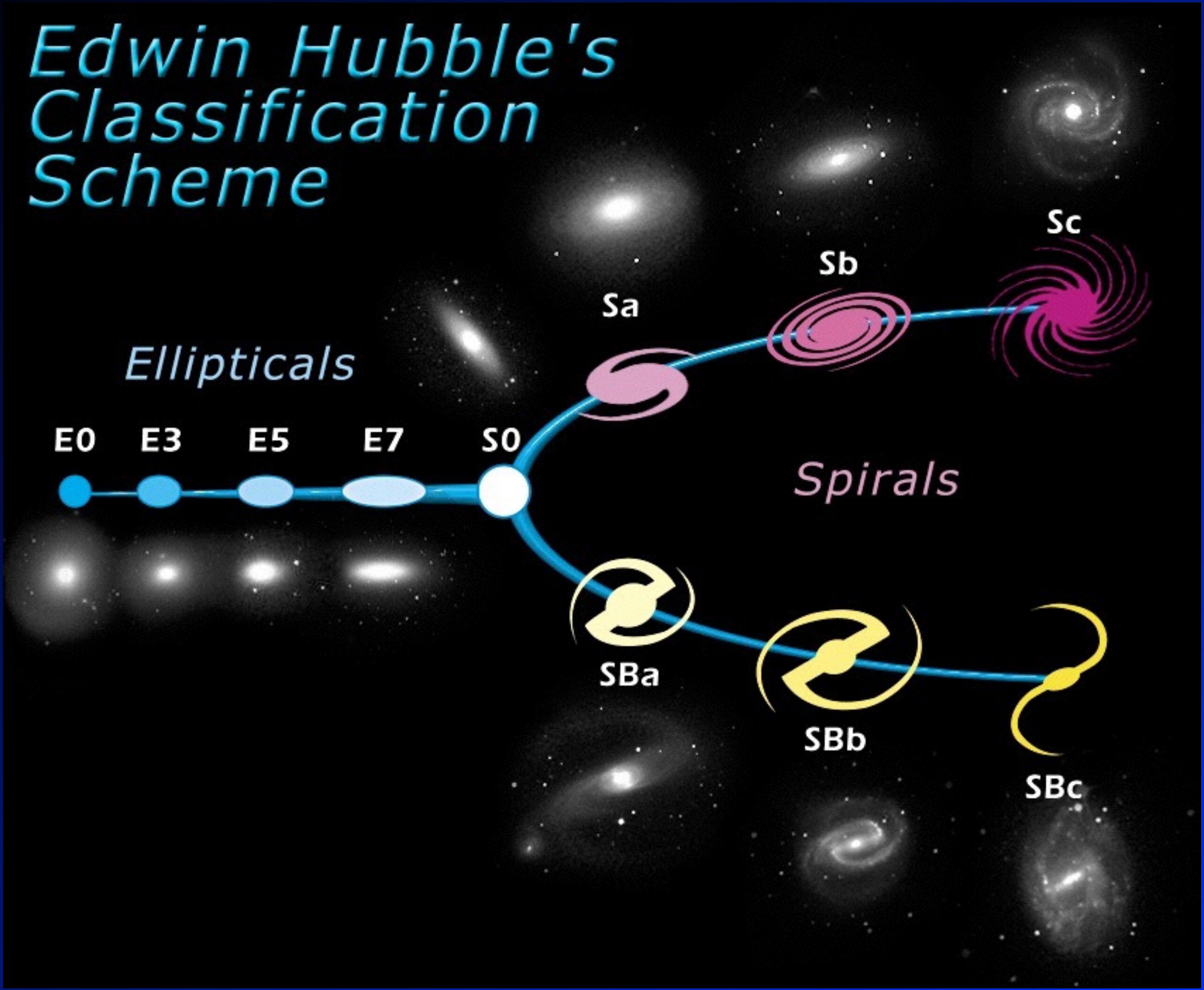
abebooks.com

Barred Spiral Galaxy NGC 1300



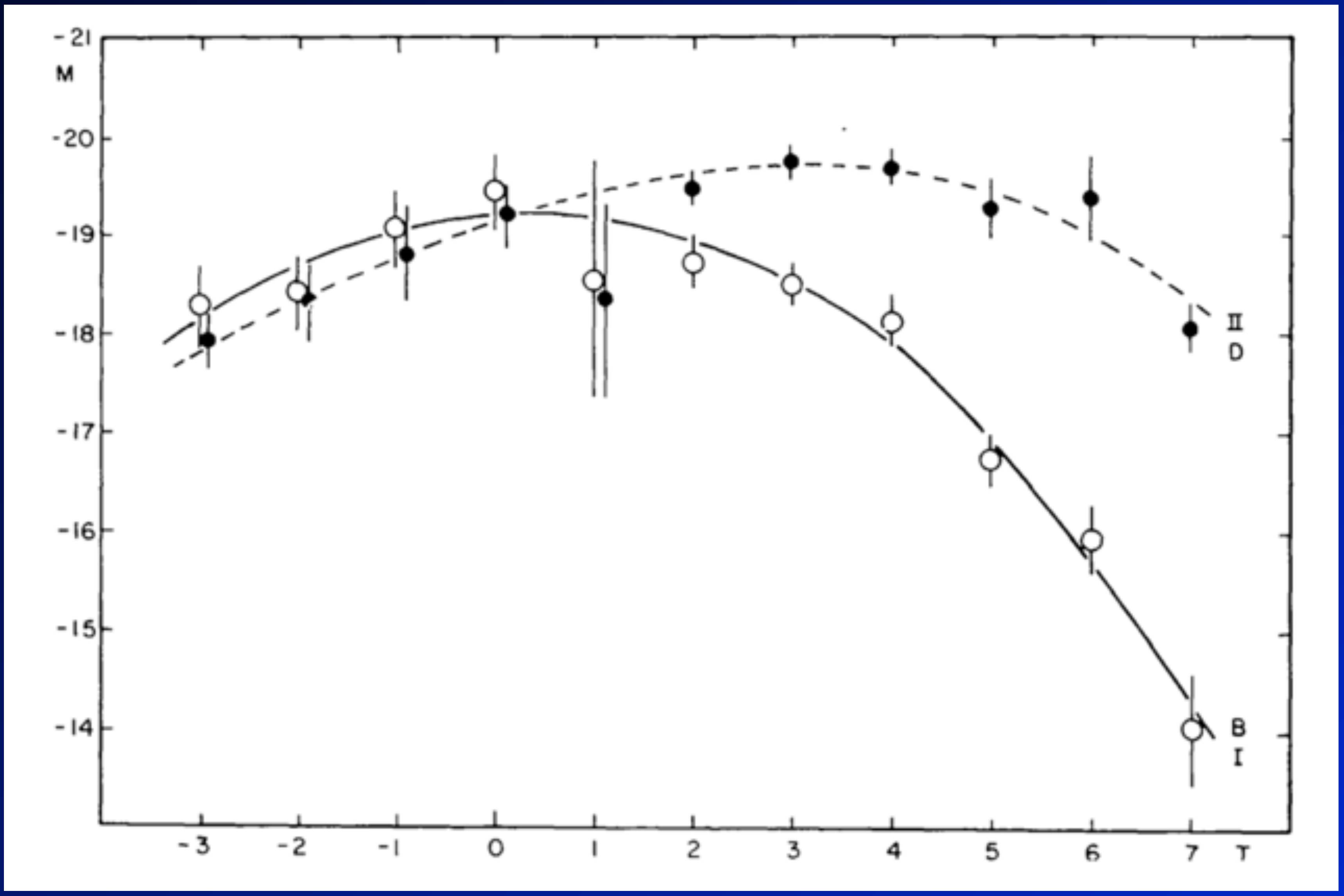
Hubble Heritage

NASA, ESA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC05-01


Edwin Hubble's Classification Scheme
Ellipticals
E0
E3
E5
E7
S0
Sa
Sb
Sc
Spirals
SBa
SBb
SBc

T-types: quantitative morphology?

Magnitude



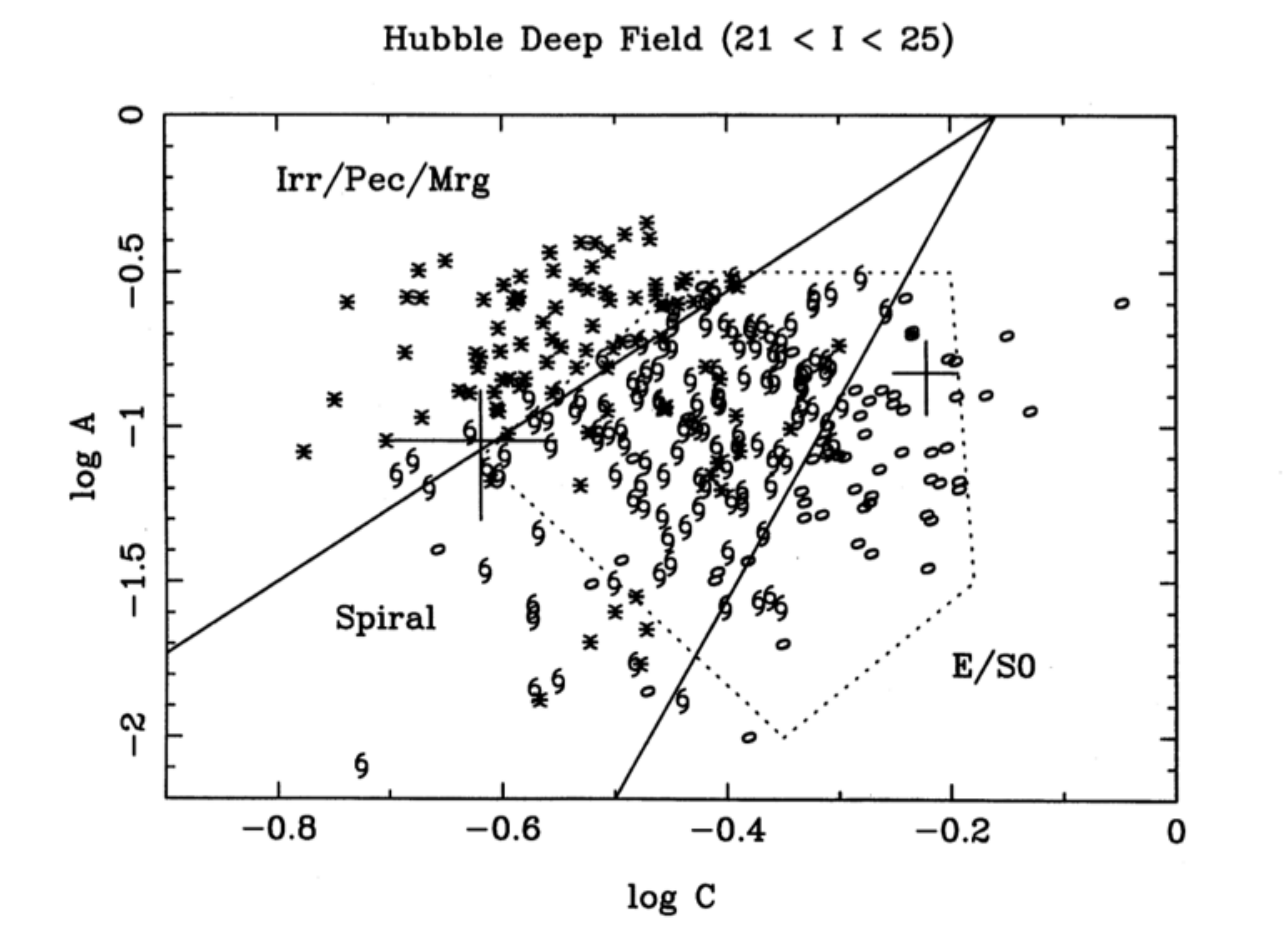
Disk

Bulge

Numerical Hubble stage

Hubble stage T	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10
de Vaucouleurs class[4]	cE	E	E^+	$S0^-$	$S0^0$	$S0^+$	S0/a	Sa	Sab	Sb	Sbc	Sc	Scd	Sd	Sdm	Sm	Im
approximate Hubble class[5]	E			S0			S0/a	Sa	Sa-b	Sb	Sb-c	Sc			Sc-Irr	Irr I	

Asymmetry and concentration



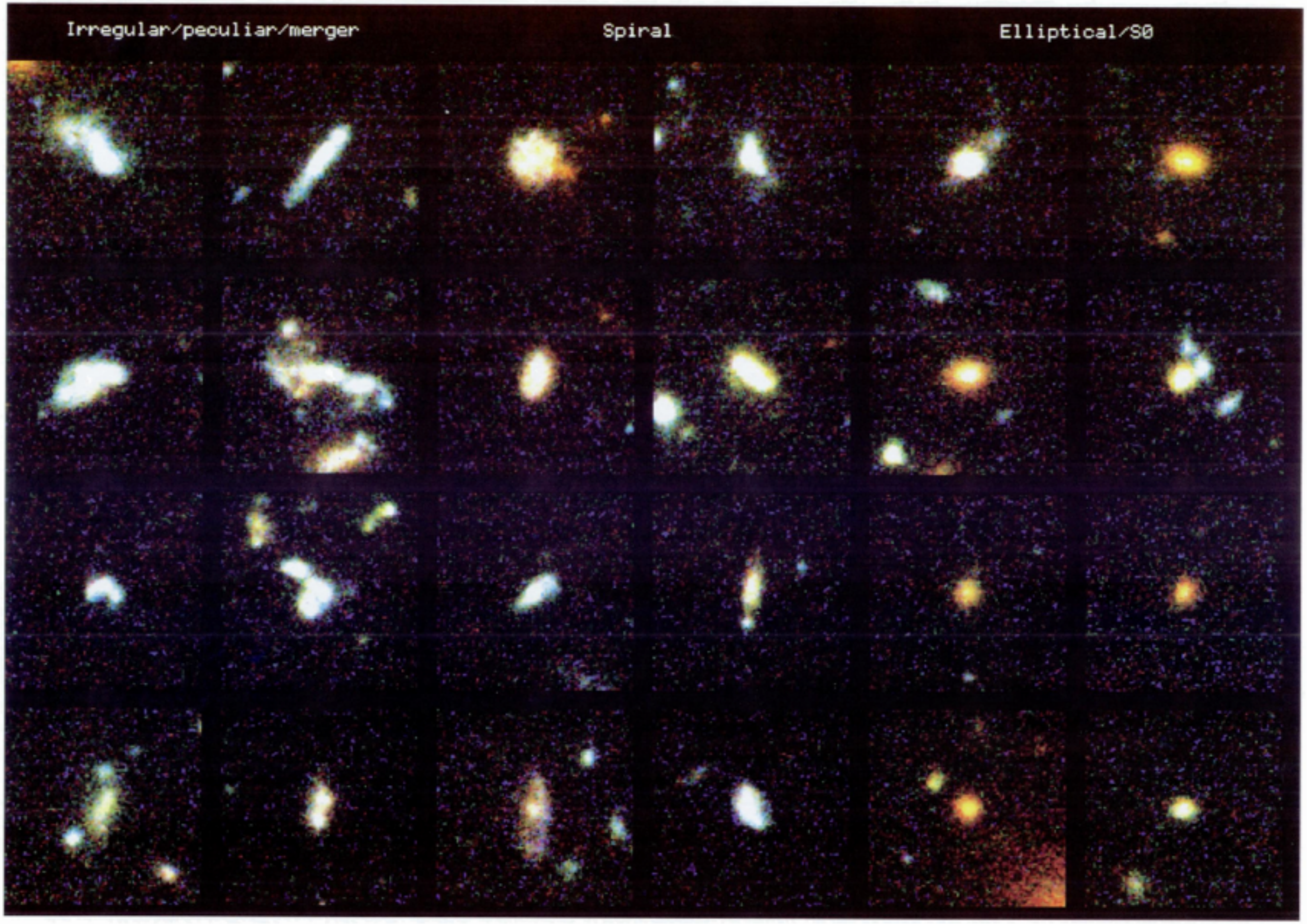
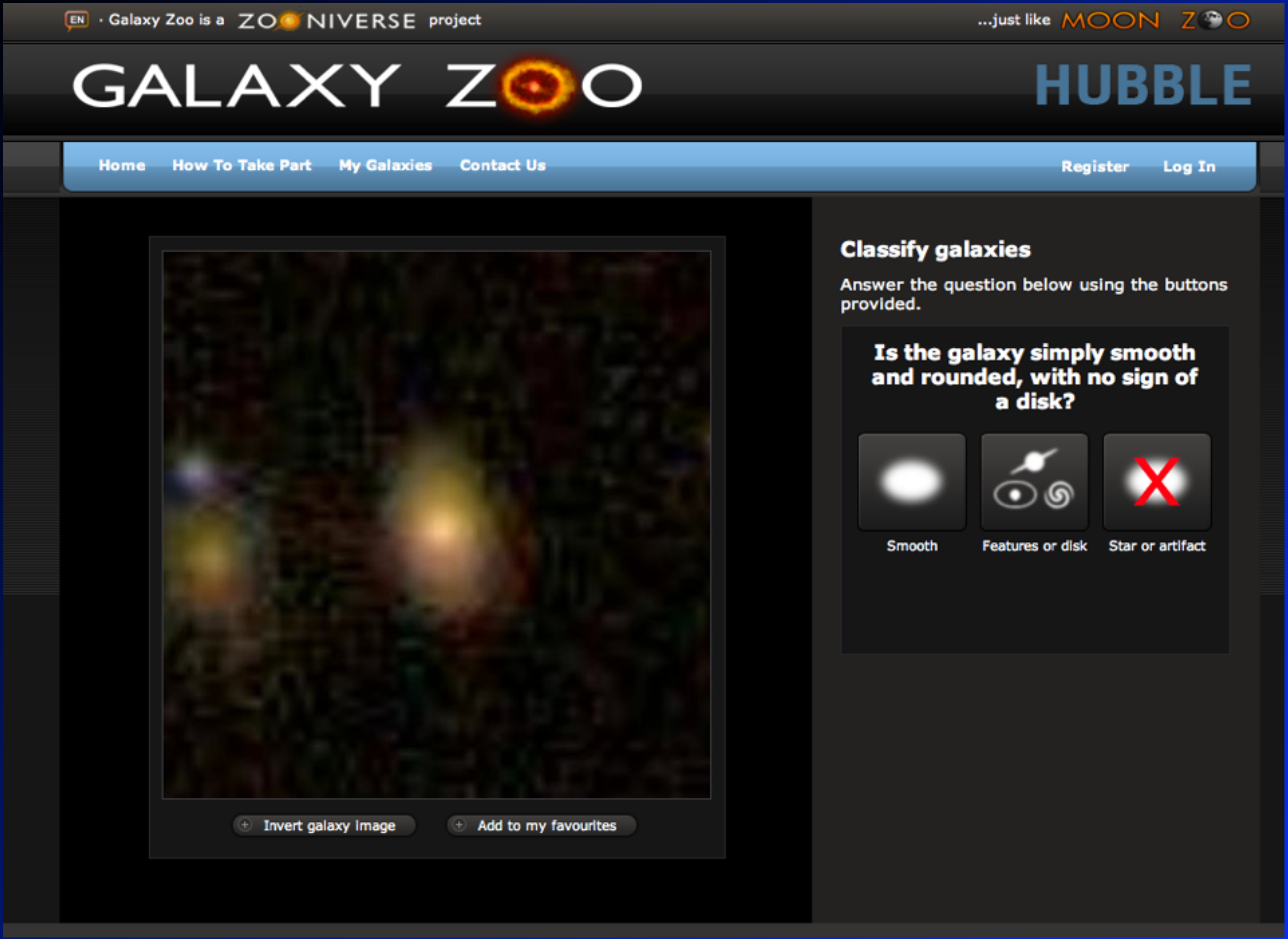
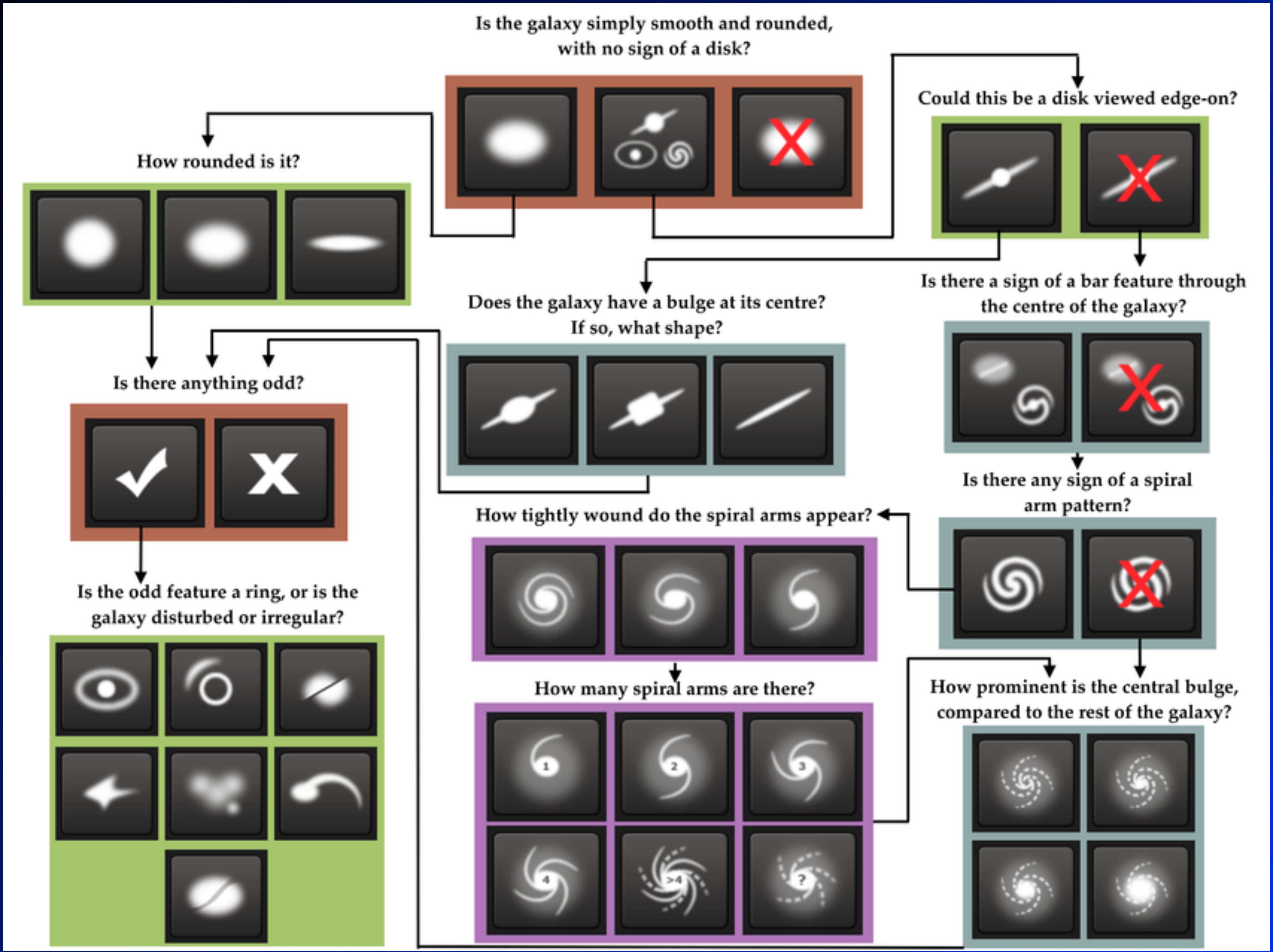


Figure 3. Montage of $I > 23$ galaxies from the HDF with: irregulars/peculiars/mergers – columns 1 and 2; spirals – columns 3 and 4; and E/S0 – columns 5 and 6. Images were selected on the basis of the A–C classifier (see Fig. 1).


EN · Galaxy Zoo is a ZOONIVERSE project
...just like MOON ZOO
GALAXY ZOO
HUBBLE
Home
How To Take Part
My Galaxies
Contact Us
Register
Log In
Classify galaxies
Answer the question below using the buttons provided.
Is the galaxy simply smooth and rounded, with no sign of a disk?
Smooth
Features or disk
Star or artifact
Invert galaxy image
Add to my favourites


Is the galaxy simply smooth and rounded, with no sign of a disk?
Could this be a disk viewed edge-on?
How rounded is it?
Is there a sign of a bar feature through the centre of the galaxy?
Does the galaxy have a bulge at its centre? If so, what shape?
Is there anything odd?
Is there any sign of a spiral arm pattern?
How tightly wound do the spiral arms appear?
Is the odd feature a ring, or is the galaxy disturbed or irregular?
How many spiral arms are there?
How prominent is the central bulge, compared to the rest of the galaxy?
1
2
3
4
>4
?

arXiv.org > astro-ph > arXiv:0908.2033

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Astrophysics > Cosmology and Nongalactic Astrophysics

Galaxy Zoo: Reproducing Galaxy Morphologies Via Machine Learning

Manda Banerji (IoA, Cambridge/UCL), Ofer Lahav (UCL), Chris J. Lintott (Oxford), Filipe B. Abdalla (UCL), Kevin Schawinski, Steven P. Bamford, Dan Andreescu, Phil Murray, M. Jordan Raddick, Anze Slosar, Alex Szalay, Daniel Thomas, Jan Vandenberg

(Submitted on 14 Aug 2009 (v1), last revised 22 Mar 2010 (this version, v2))

We present morphological classifications obtained using machine learning for objects in SDSS DR6 that have been classified by Galaxy Zoo into three classes, namely early types, spirals and point sources/artifacts. An artificial neural network is trained on a subset of objects classified by the human eye and we test whether the machine learning algorithm can reproduce the human classifications for the rest of the sample. We find that the success of the neural network in matching the human classifications depends crucially on the set of input parameters chosen for the machine-learning algorithm. The colours and parameters associated with profile-fitting are reasonable in separating the objects into three classes. However, these results are considerably improved when adding adaptive shape parameters as well as concentration and texture. The adaptive moments, concentration and texture parameters alone cannot distinguish between early type galaxies and the point sources/artifacts. Using a set of twelve parameters, the neural network is able to reproduce the human classifications to better than 90% for all three morphological classes. We find that using a training set that is incomplete in magnitude does not degrade our results given our particular choice of the input parameters to the network. We conclude that it is promising to use machine- learning algorithms to perform morphological classification for the next generation of wide-field imaging surveys and that the Galaxy Zoo catalogue provides an invaluable training set for such purposes.

Class	Button	Description
1		Elliptical galaxy
2		Clockwise/Z-wise spiral galaxy
3		Anti-clockwise/S-wise spiral galaxy
4		Spiral galaxy other (eg. edge on)
5		Star or Don't Know (eg. artefact)
6		Merger

Table 1. Galaxy Zoo classification categories showing schematic symbols as used on the site.

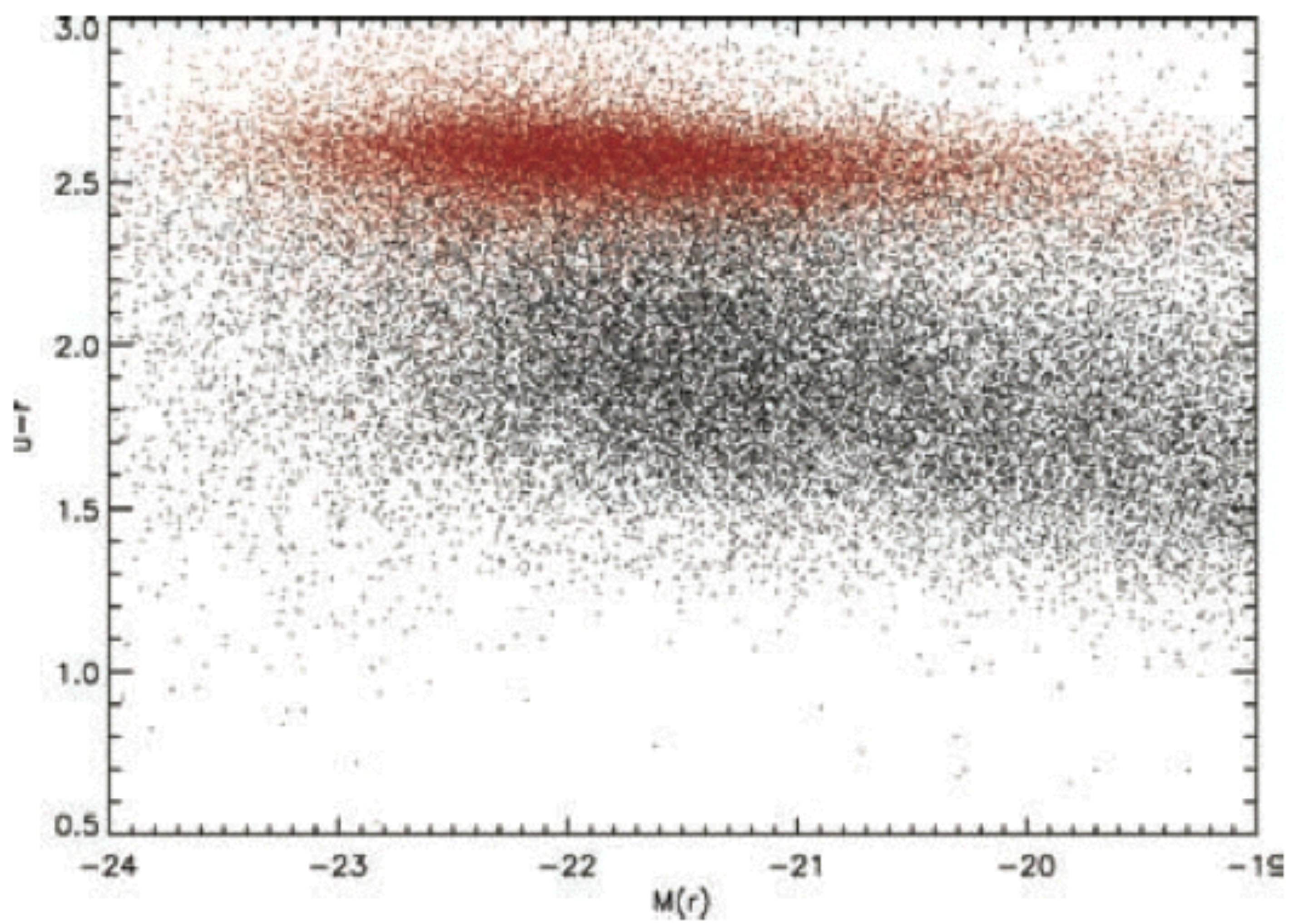
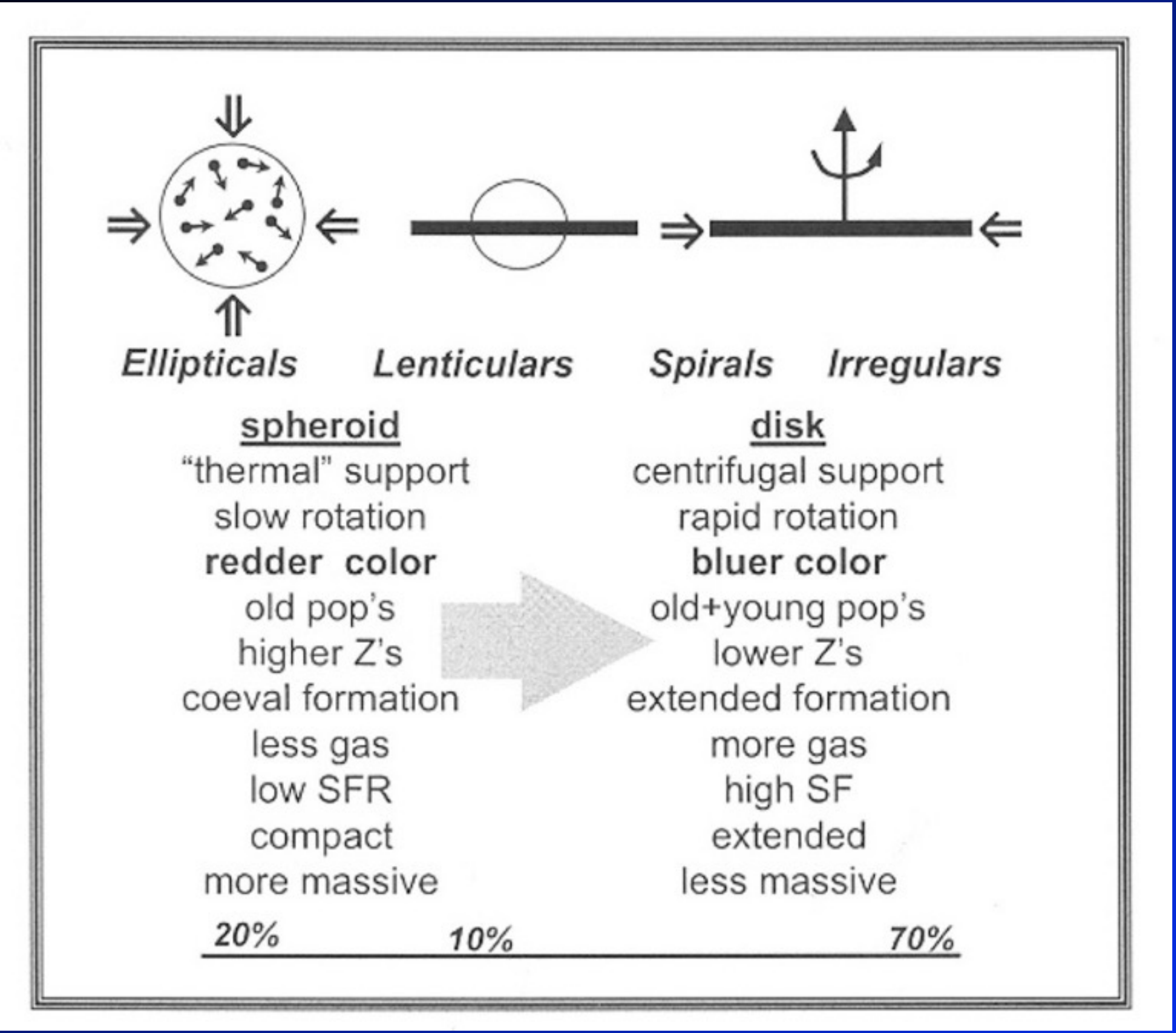
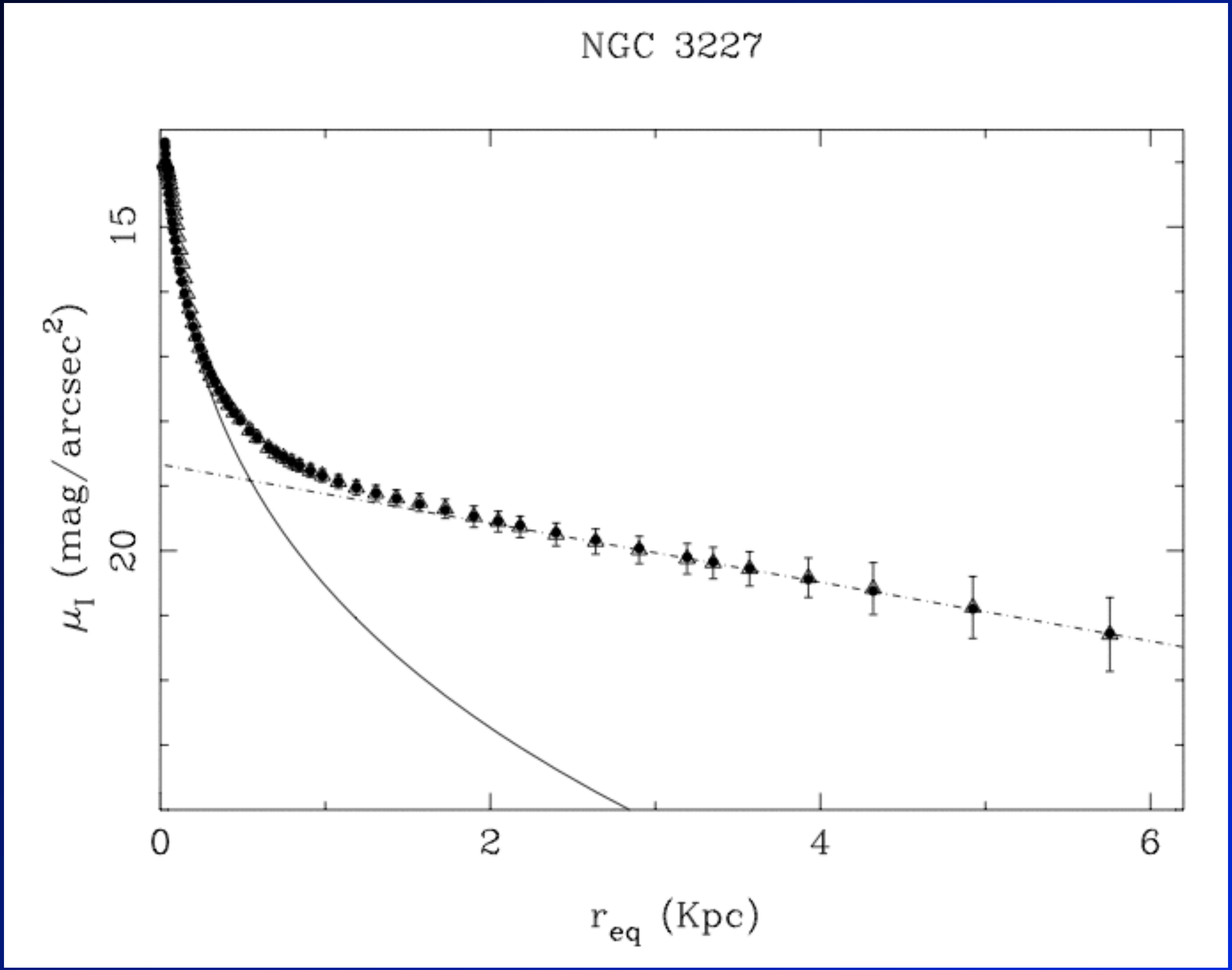
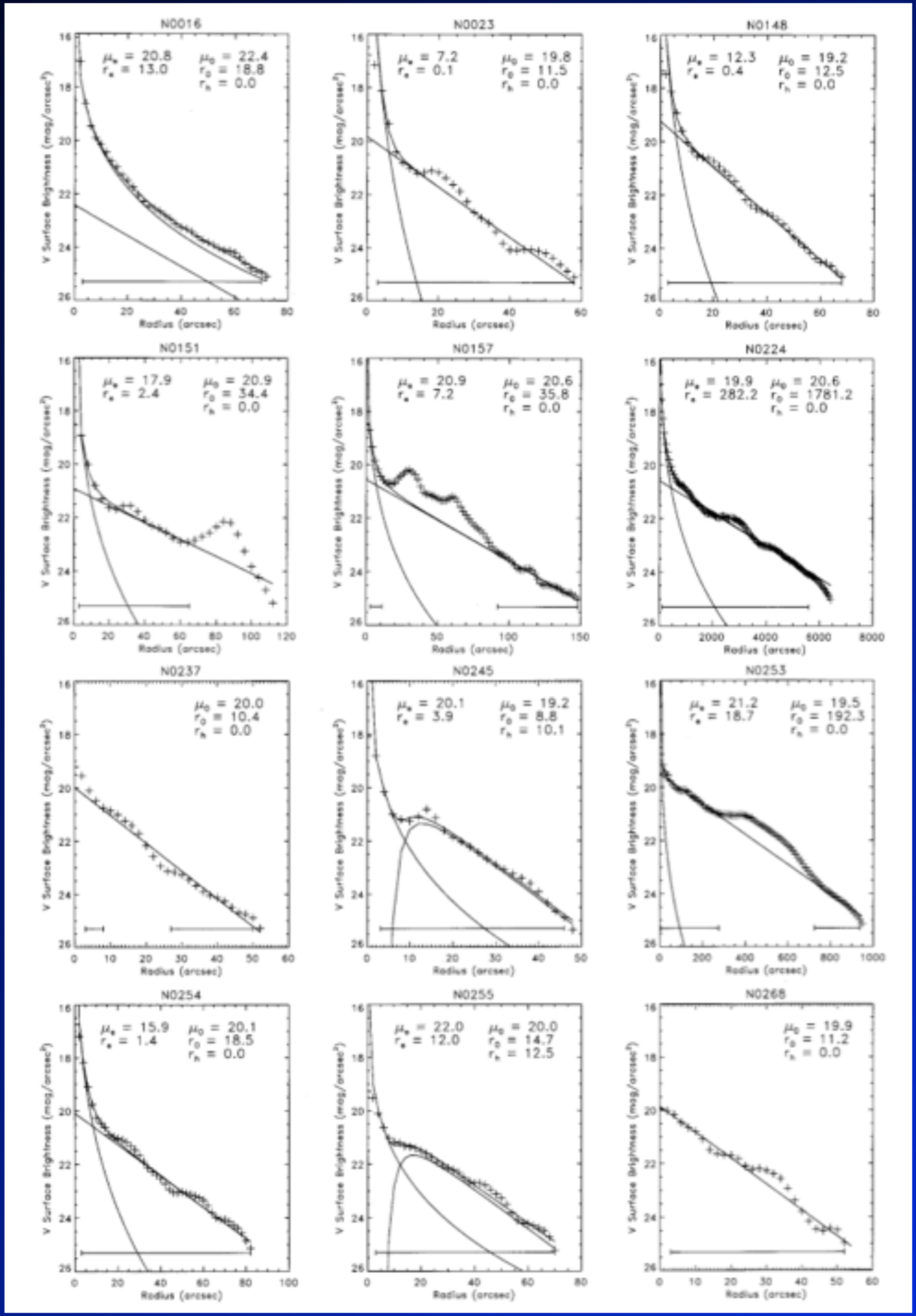


Figure 9. Colour–magnitude diagram for galaxies in the weighted super-clean combined spirals sample. Systems classified as spiral are shown in black, those classified as elliptical in red.

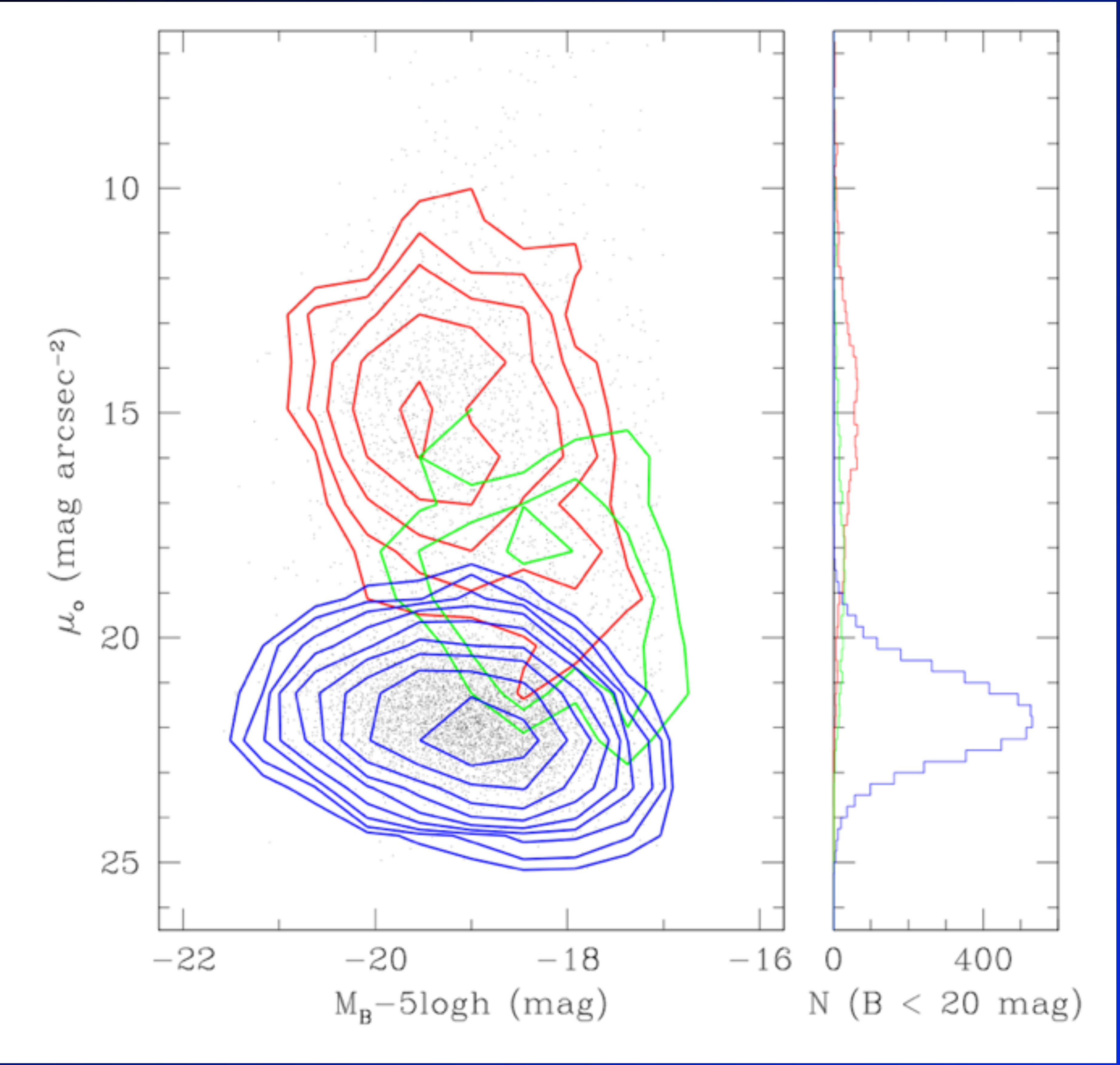

Ellipticals
Lenticulars
Spirals
Irregulars
spheroid
"thermal" support
slow rotation
redder color
old pop's
higher Z's
coeval formation
less gas
low SFR
compact
more massive
disk
centrifugal support
rapid rotation
bluer color
old+young pop's
lower Z's
extended formation
more gas
high SF
extended
less massive
20%
10%
70%

Surface brightness profiles

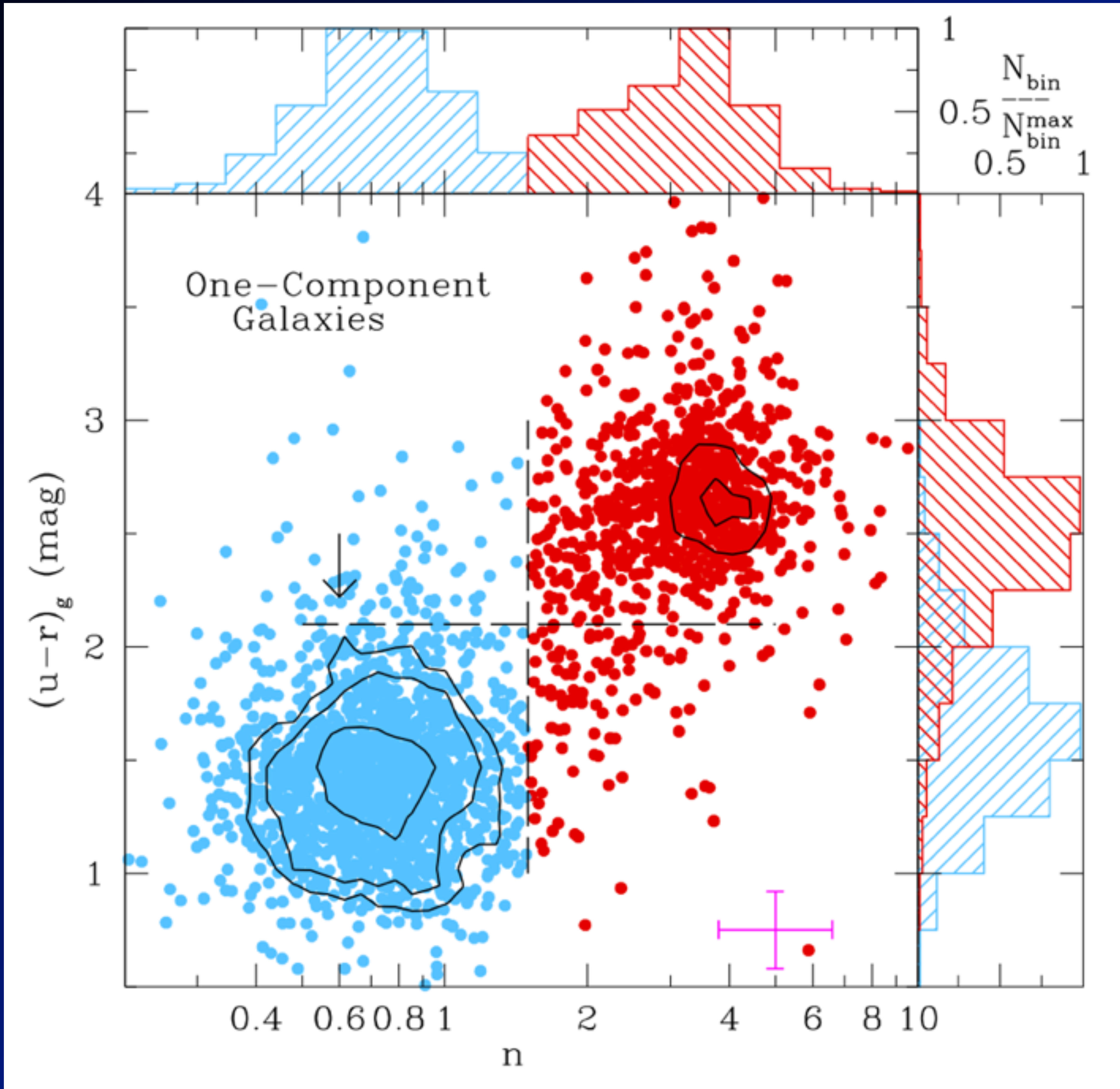




N0016
μe = 20.8 re = 13.0
μ0 = 22.4 r0 = 18.8 rh = 0.0
N0023
μe = 7.2 re = 0.1
μ0 = 19.8 r0 = 11.5 rh = 0.0
N0148
μe = 12.3 re = 0.4
μ0 = 19.2 r0 = 12.5 rh = 0.0
N0151
μe = 17.9 re = 2.4
μ0 = 20.9 r0 = 34.4 rh = 0.0
N0157
μe = 20.9 re = 7.2
μ0 = 20.6 r0 = 35.8 rh = 0.0
N0224
μe = 19.9 re = 282.2
μ0 = 20.6 r0 = 1781.2 rh = 0.0
N0237
μ0 = 20.0 r0 = 10.4 rh = 0.0
N0245
μe = 20.1 re = 3.9
μ0 = 19.2 r0 = 8.8 rh = 10.1
N0253
μe = 21.2 re = 18.7
μ0 = 19.5 r0 = 192.3 rh = 0.0
N0254
μe = 15.9 re = 1.4
μ0 = 20.1 r0 = 18.5 rh = 0.0
N0255
μe = 22.0 re = 12.0
μ0 = 20.0 r0 = 14.7 rh = 12.5
N0268
μ0 = 19.9 r0 = 11.2 rh = 0.0
V Surface Brightness (mag/arcsec²)
Radius (arcsec)

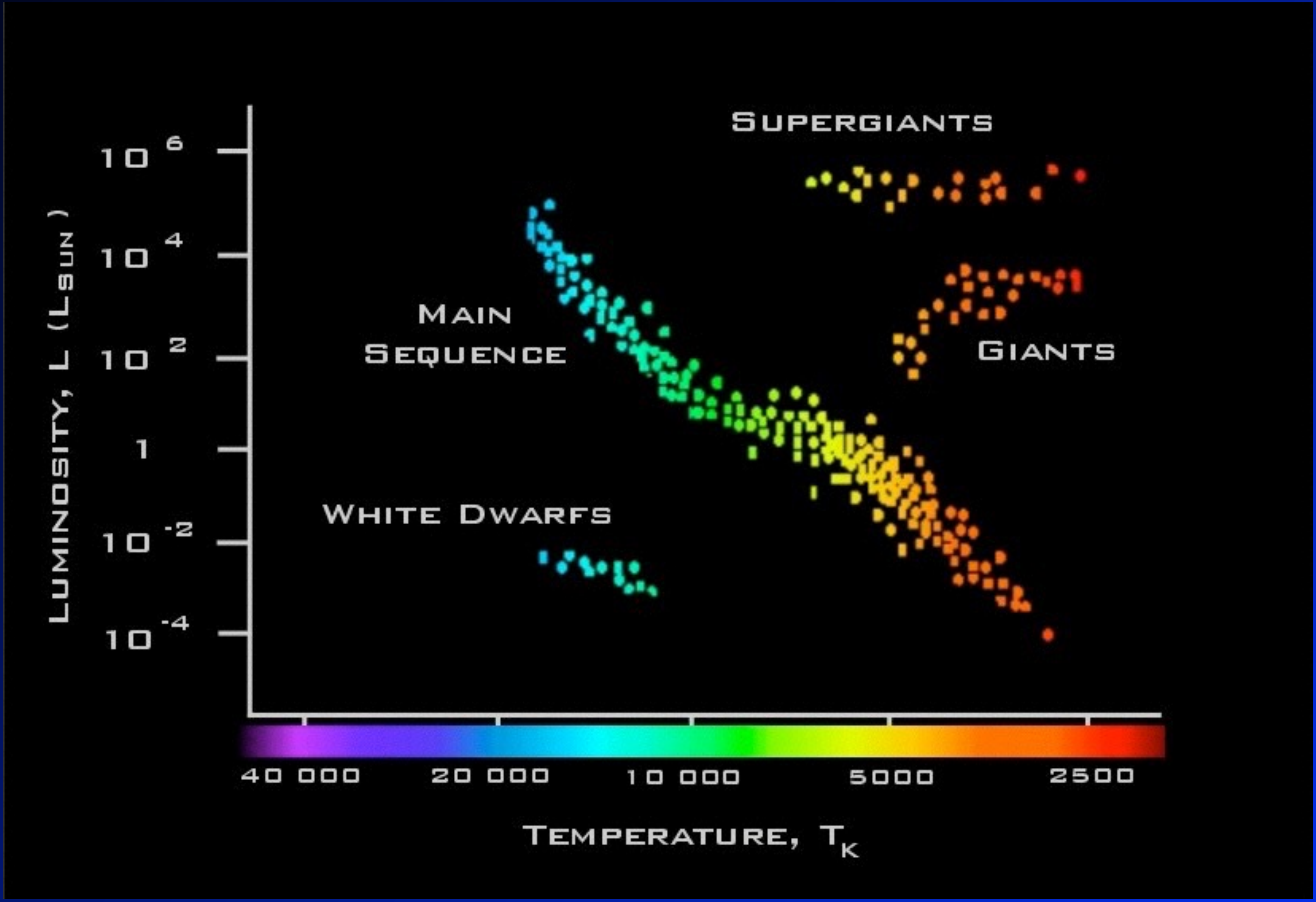


10
15
20
25
μ_o (mag arcsec^{-2})
−22
−20
−18
−16
M_B−5logh (mag)
0
400
N (B < 20 mag)

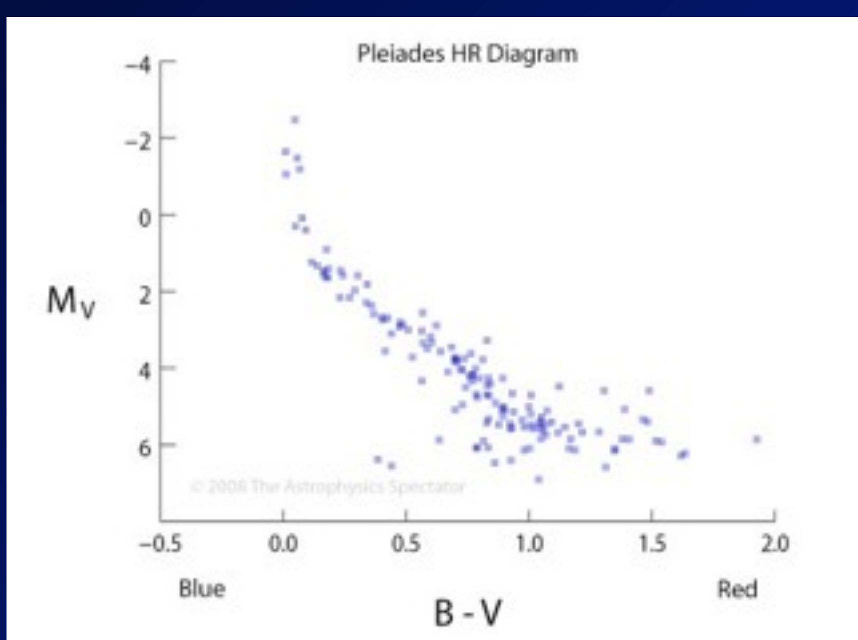


One−Component
Galaxies
(u−r)_g (mag)
n
0.4
0.6
0.8
1
2
4
6
8
10
1
2
3
4
N_bin / N_bin^max
0.5
1

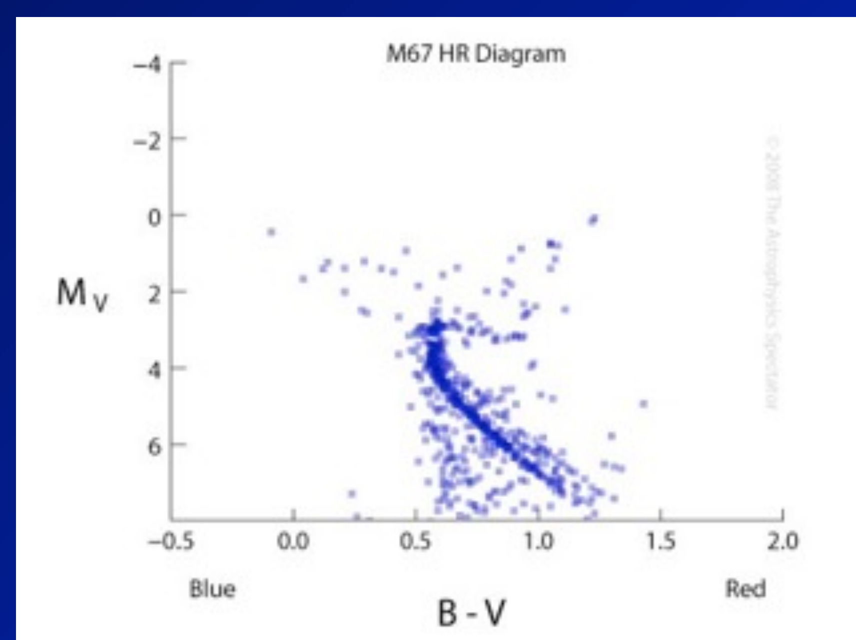
Stellar populations in galaxies



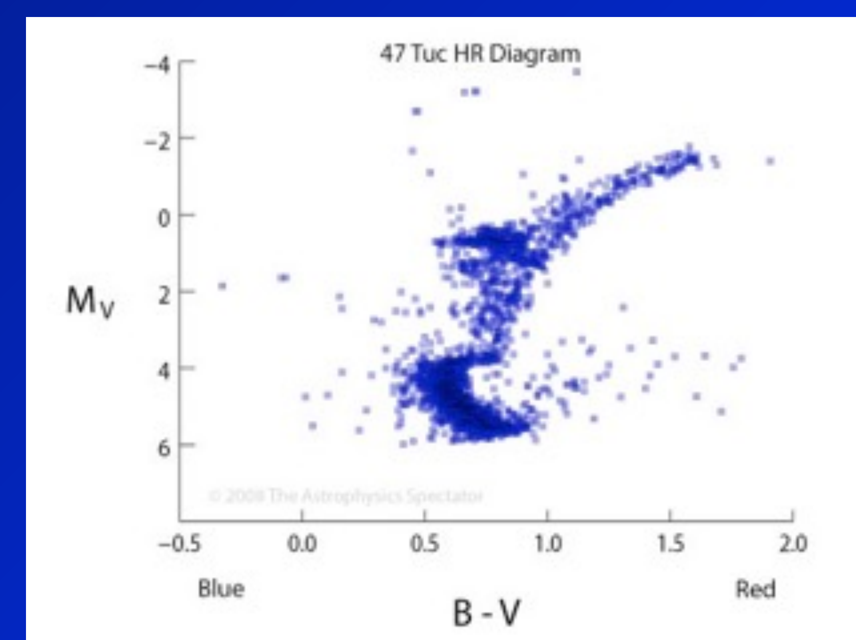
Globular Cluster
47 Tucanae
Ground • AAT
NASA and R. Gilliland (STScI)
STScI-PRC00-33
Hubble Space Telescope • WFPC2



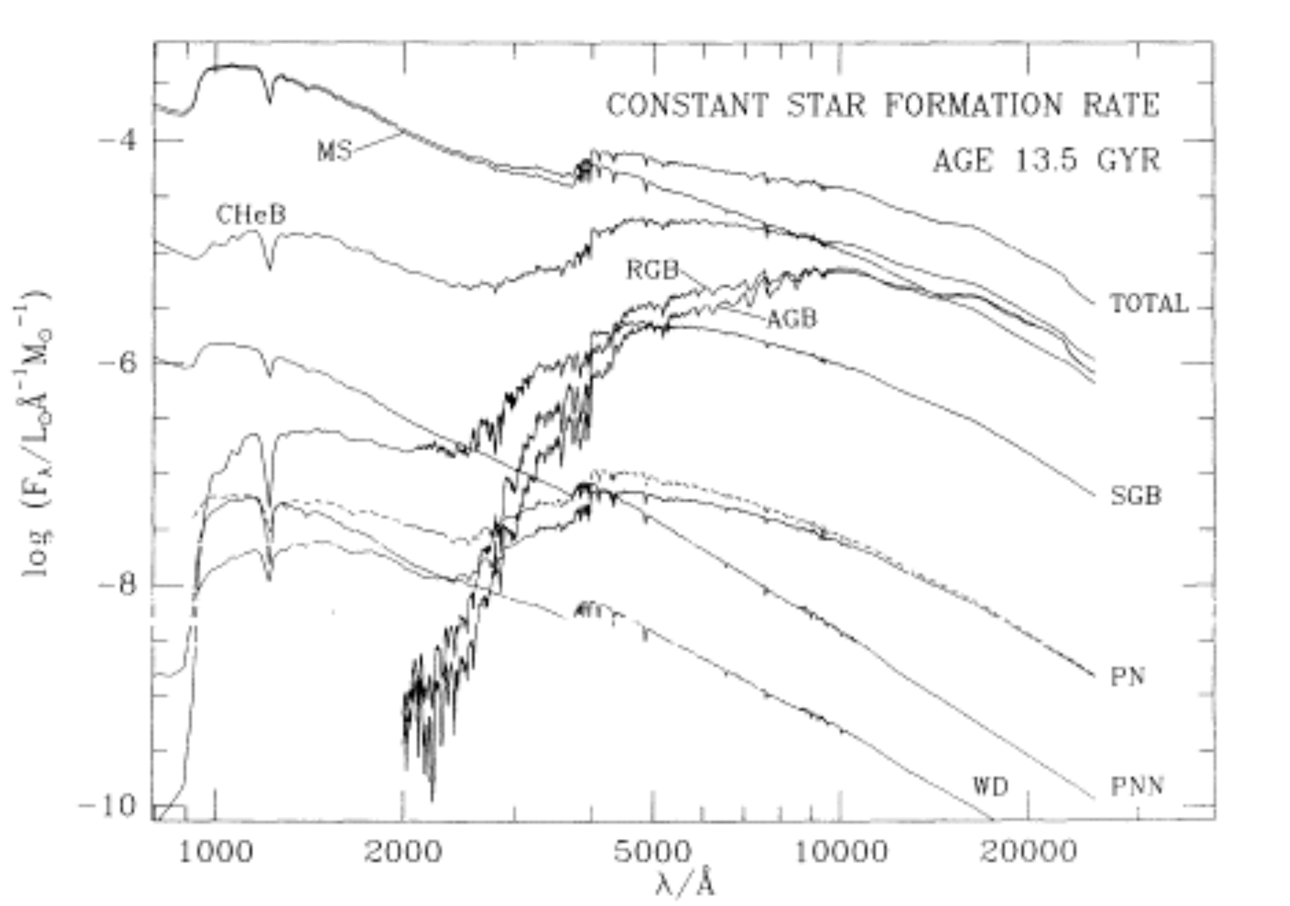
Pleiades HR Diagram
M_V
-4
-2
0
2
4
6
-0.5
0.0
0.5
1.0
1.5
2.0
Blue
Red
B - V



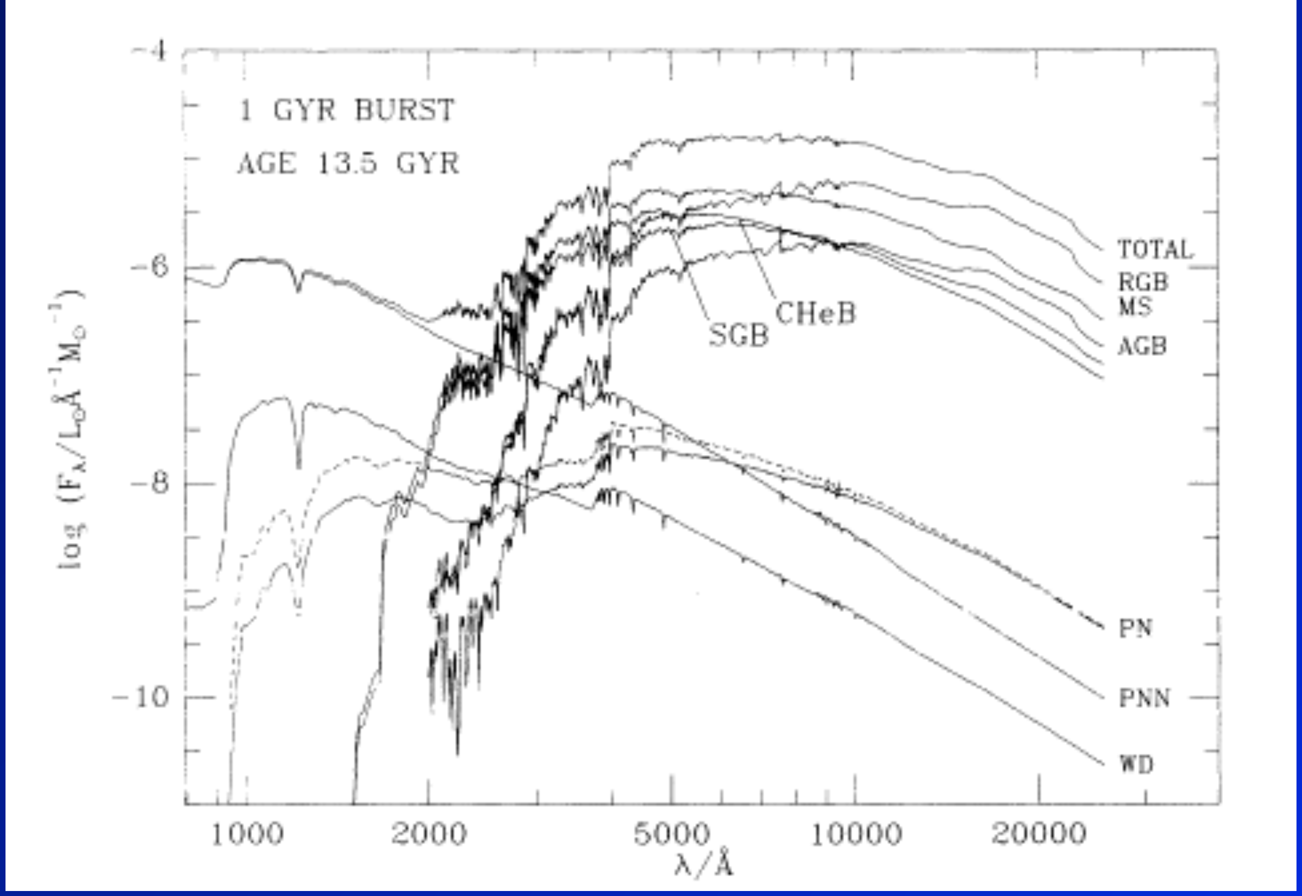
M67 HR Diagram
M_V
-4
-2
0
2
4
6
-0.5
0.0
0.5
1.0
1.5
2.0
Blue
Red
B - V



47 Tuc HR Diagram
M_V
-4
-2
0
2
4
6
-0.5
0.0
0.5
1.0
1.5
2.0
Blue
Red
B - V



CONSTANT STAR FORMATION RATE
AGE 13.5 GYR
MS
CHeB
RGB
AGB
TOTAL
SGB
PN
WD
PNN
−4
−6
−8
−10
1000
2000
5000
10000
20000
λ/Å
log ($F_\lambda/L_\odot Å^{-1} M_\odot^{-1}$)



1 GYR BURST
AGE 13.5 GYR
TOTAL
RGB
MS
AGB
SGB
CHeB
PN
PNN
WD
−4
−6
−8
−10
1000
2000
5000
10000
20000
λ/Å
log ($F_\lambda/L_\odot Å^{-1} M_\odot^{-1}$)

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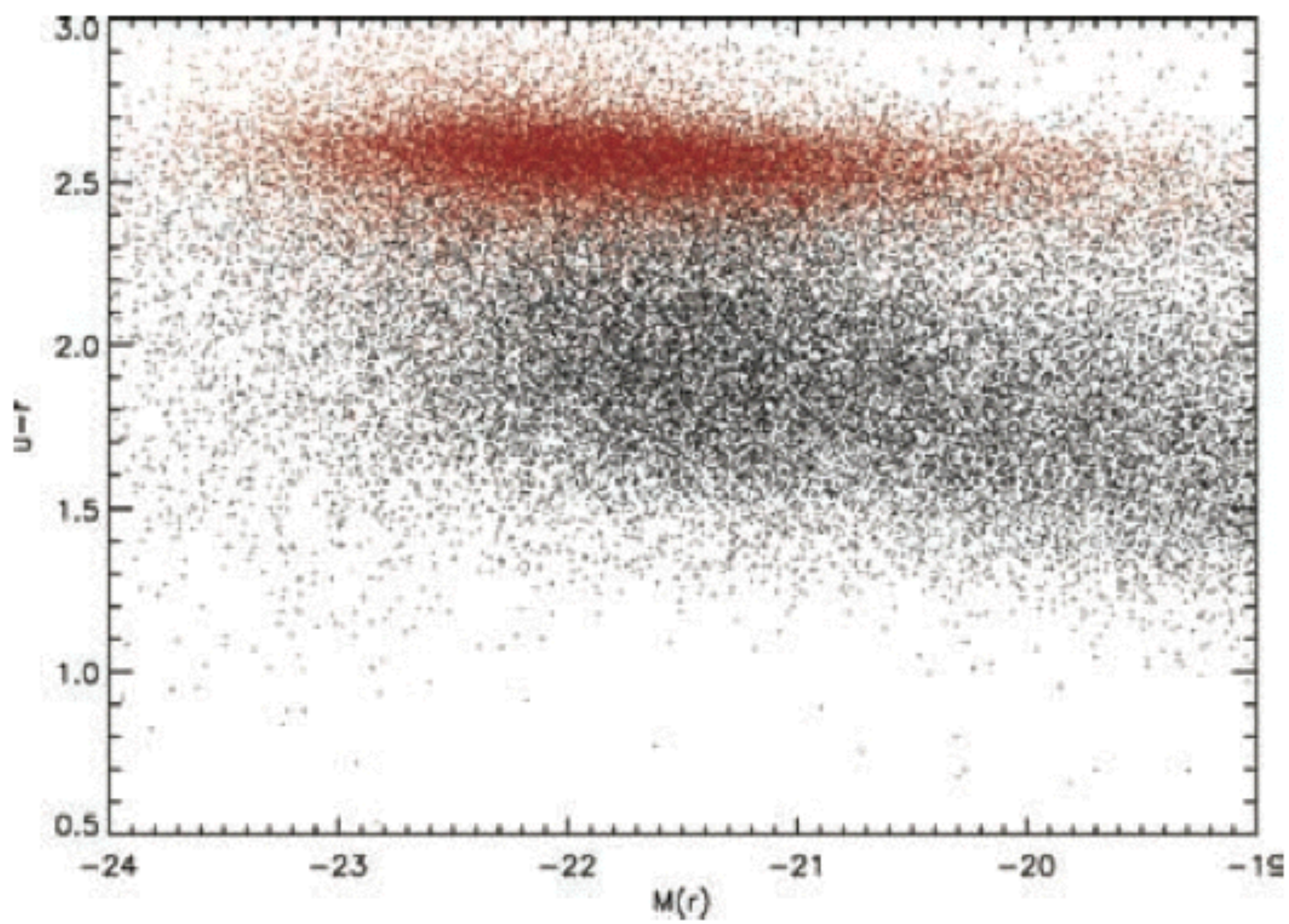
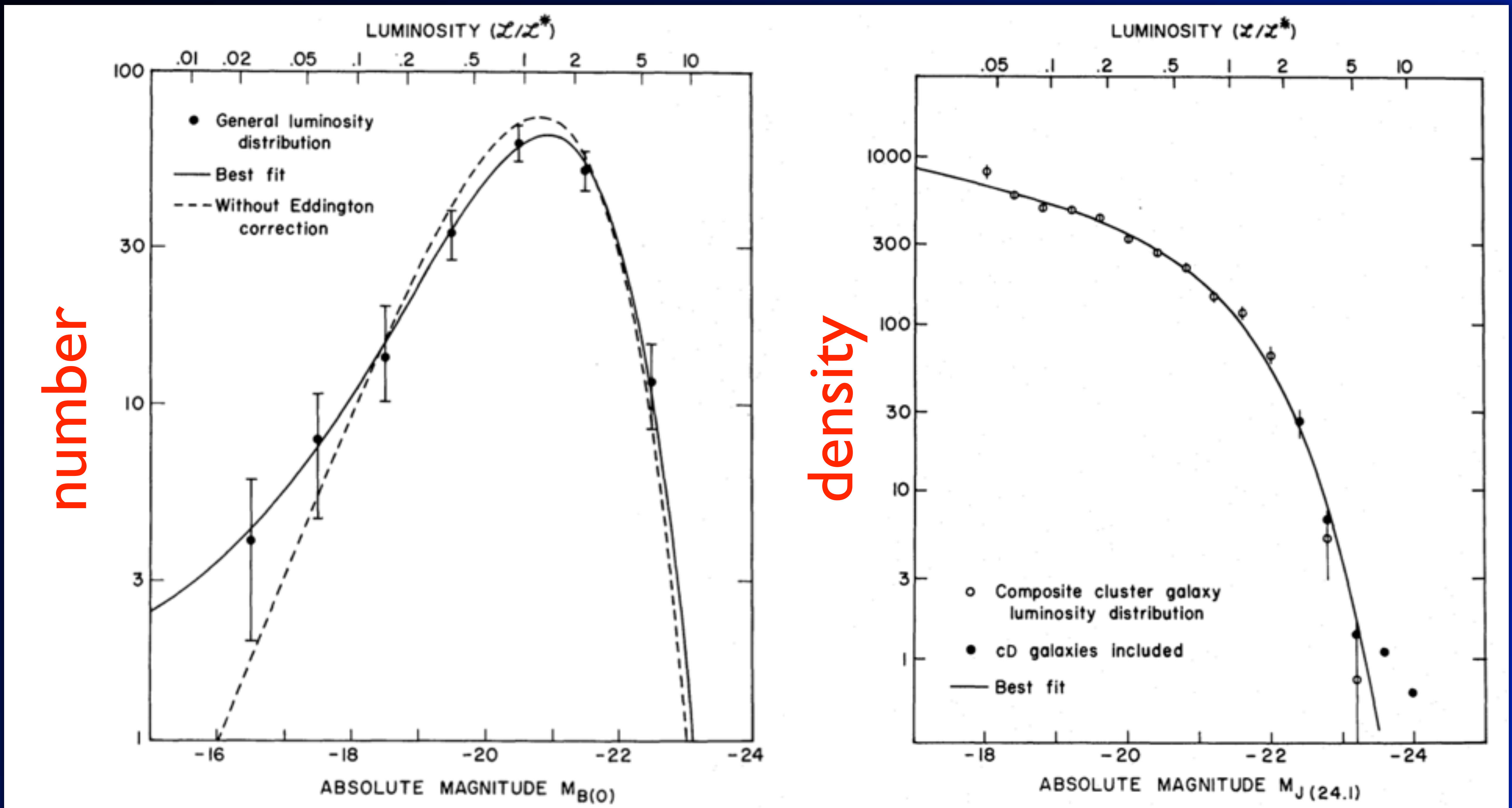
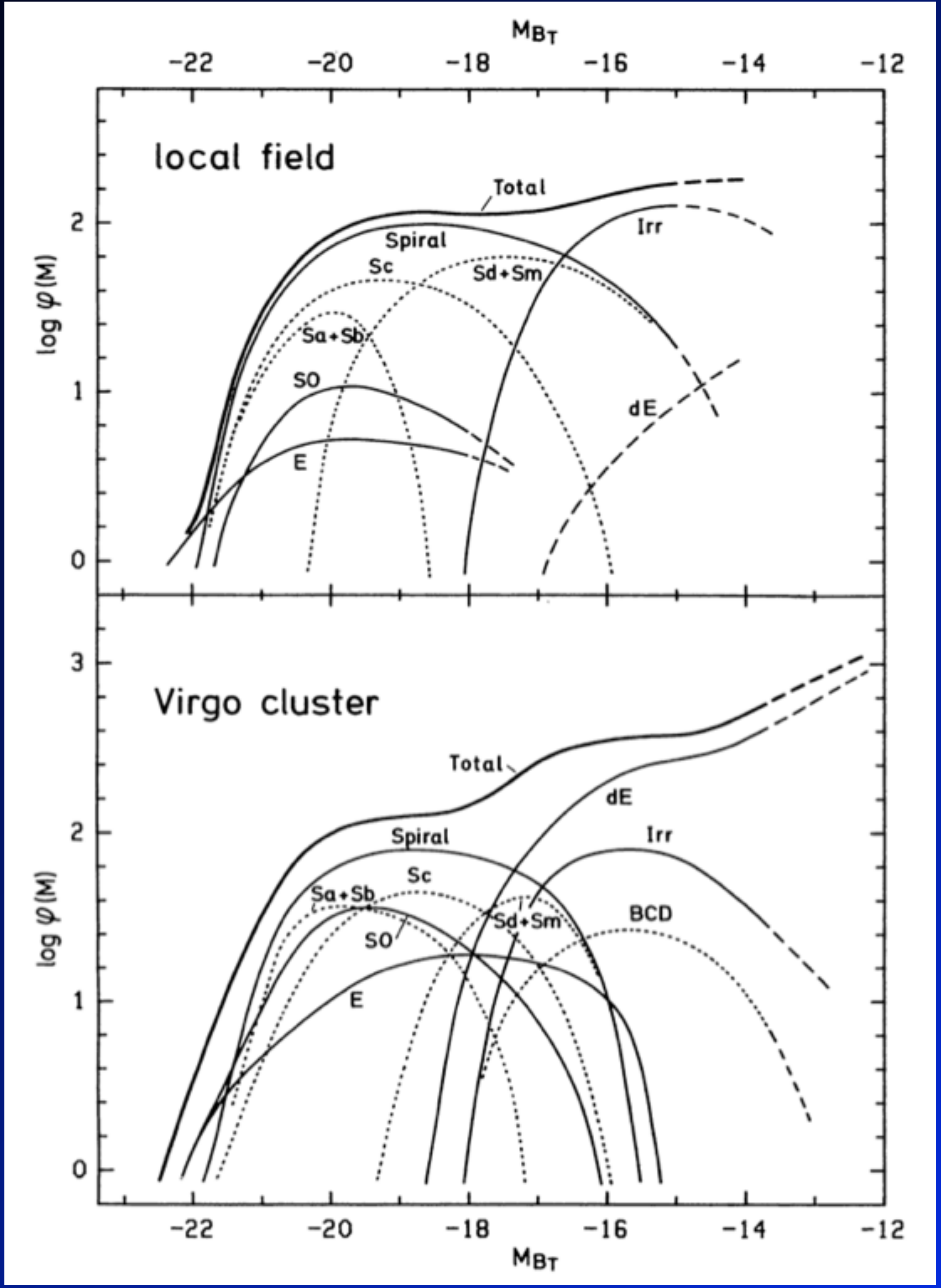


Figure 9. Colour–magnitude diagram for galaxies in the weighted super-clean combined spirals sample. Systems classified as spiral are shown in black, those classified as elliptical in red.

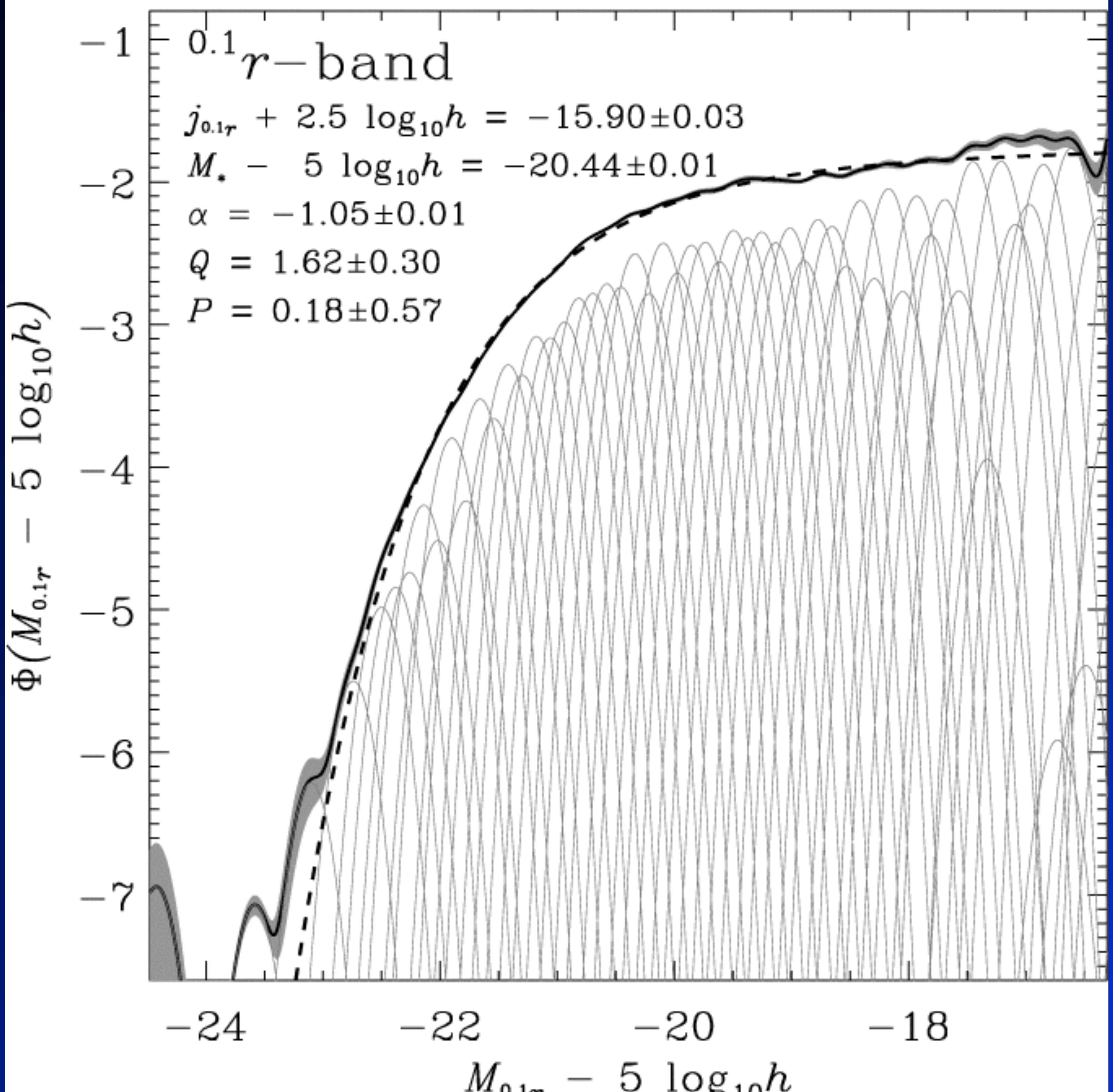
The luminosity function

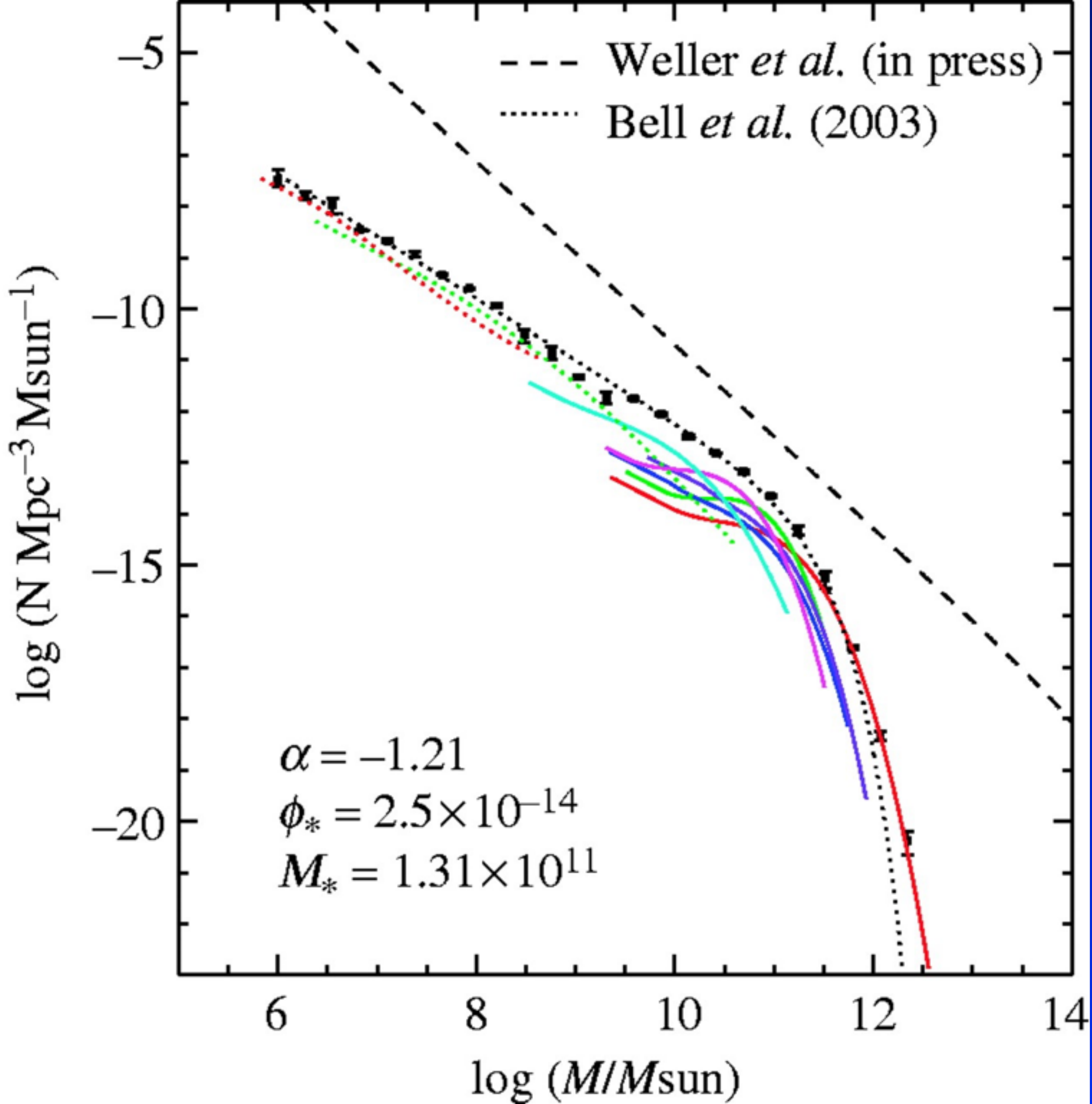




M_{BT}
-22
-20
-18
-16
-14
-12
local field
Total
Spiral
Irr
Sc
Sd+Sm
Sa+Sb
S0
dE
E
log φ(M)
0
1
2
3
Virgo cluster
Total
dE
Spiral
Irr
Sc
Sa+Sb
Sd+Sm
BCD
S0
E

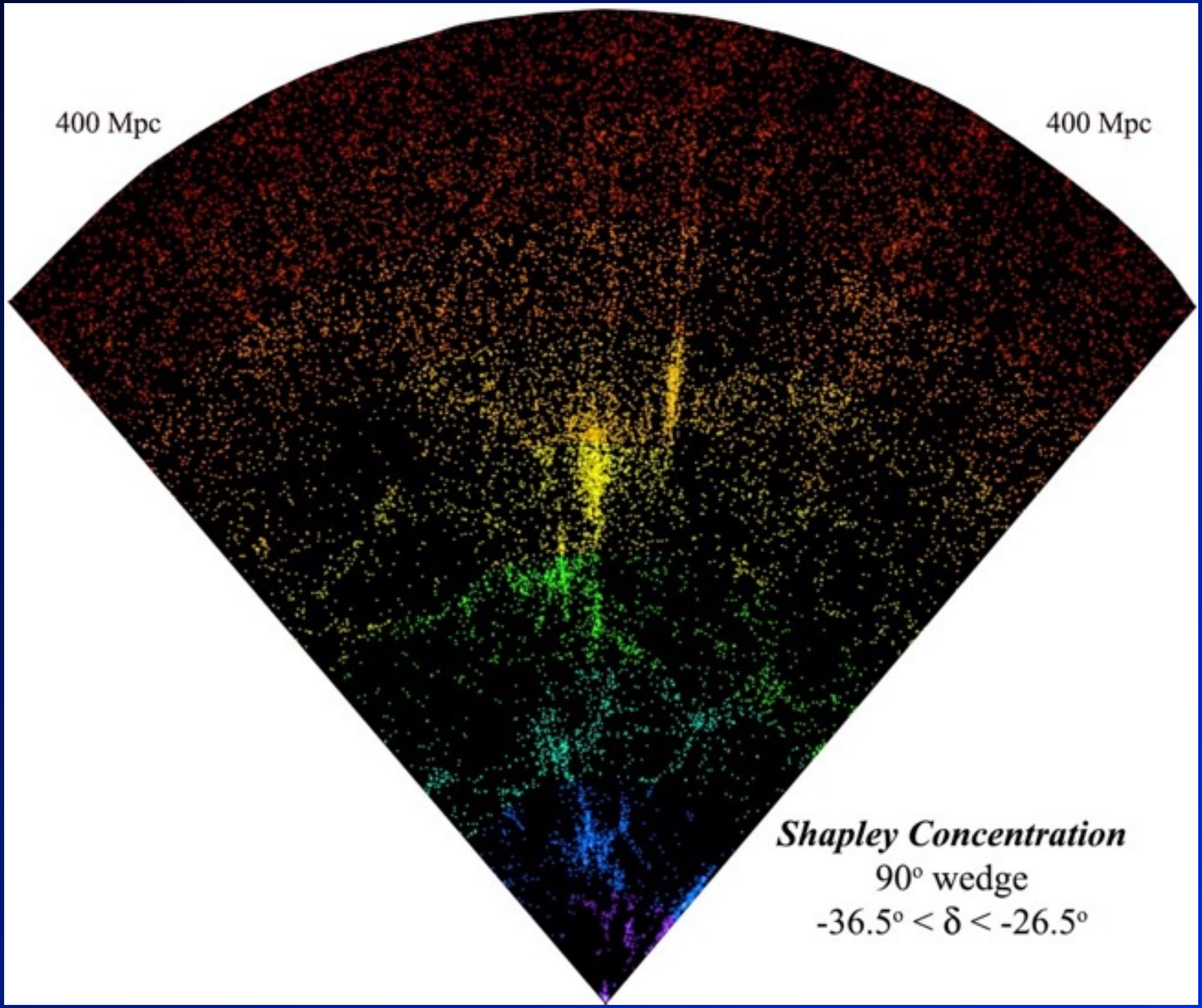
Blanton et al. (2003) (astro-ph/0210215)



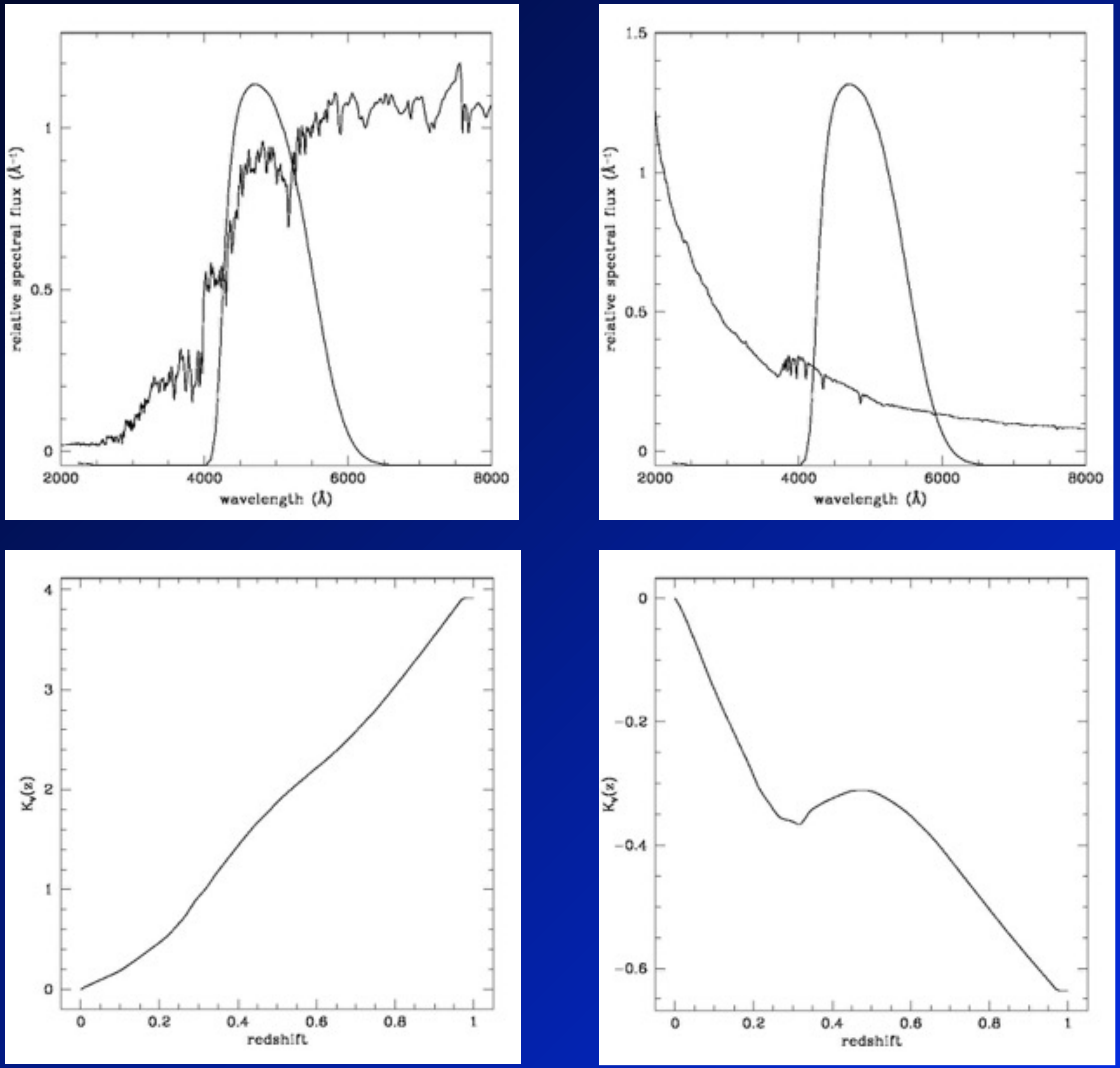


Weller et al. (in press)
Bell et al. (2003)
$\alpha = -1.21$
$\phi_* = 2.5\times10^{-14}$
$M_* = 1.31\times10^{11}$
log (N Mpc^{-3} Msun^{-1})
log (M/Msun)
-5
-10
-15
-20
6
8
10
12
14

galaxy redshift surveys



k-corrections



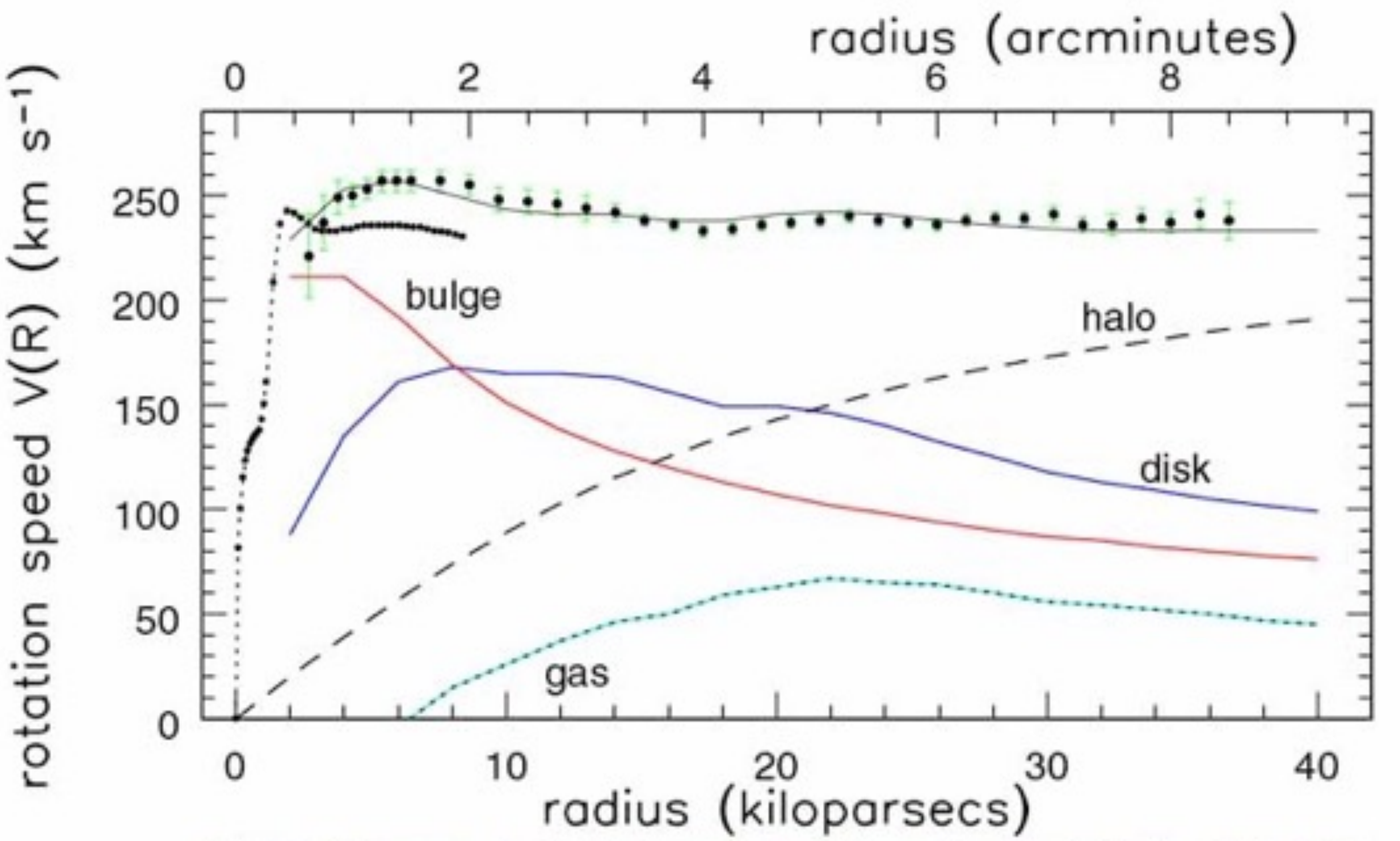


Fig 5.20 (Begeman, Sofue) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

dark matter revealed by rotation curves

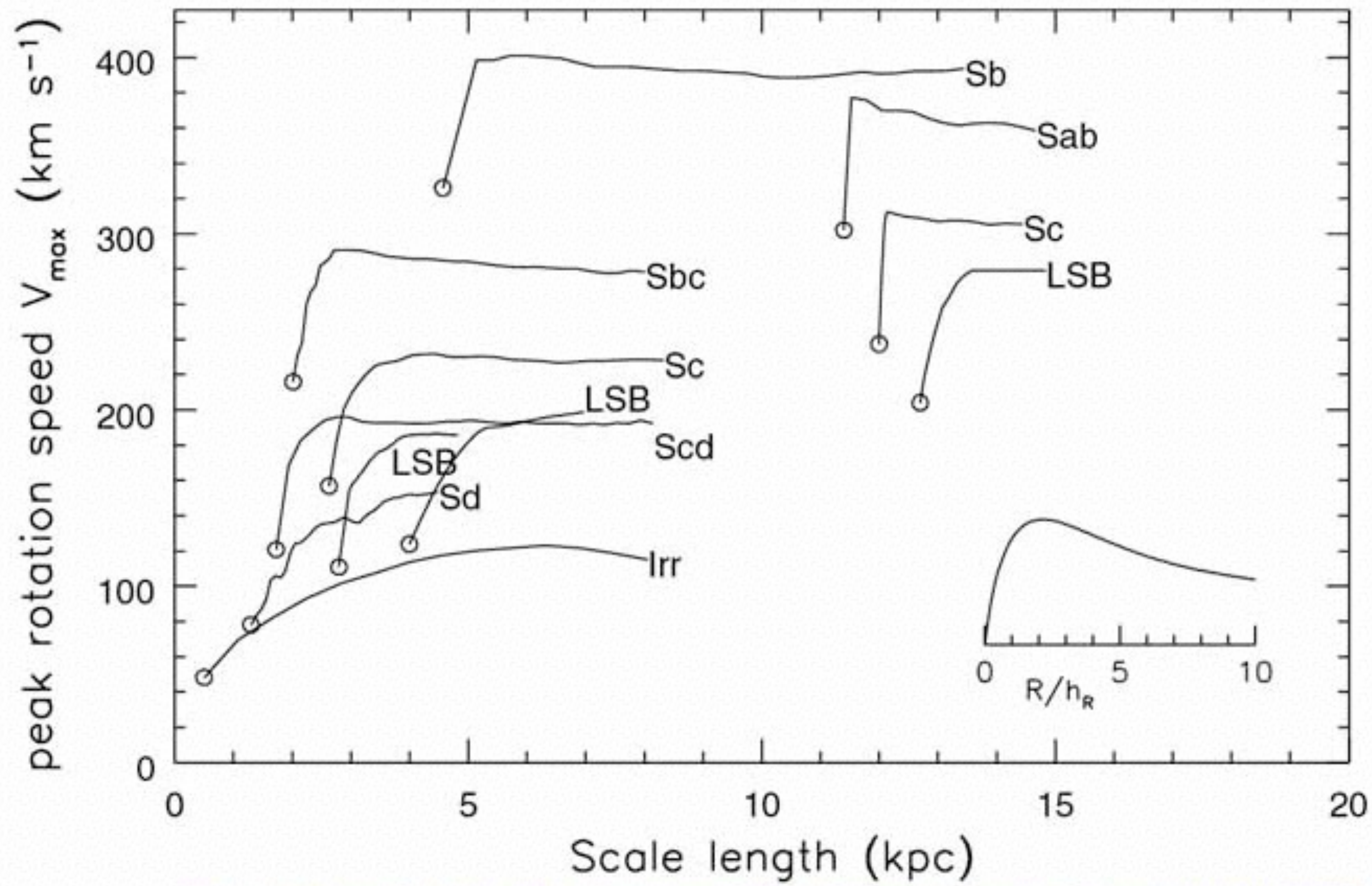
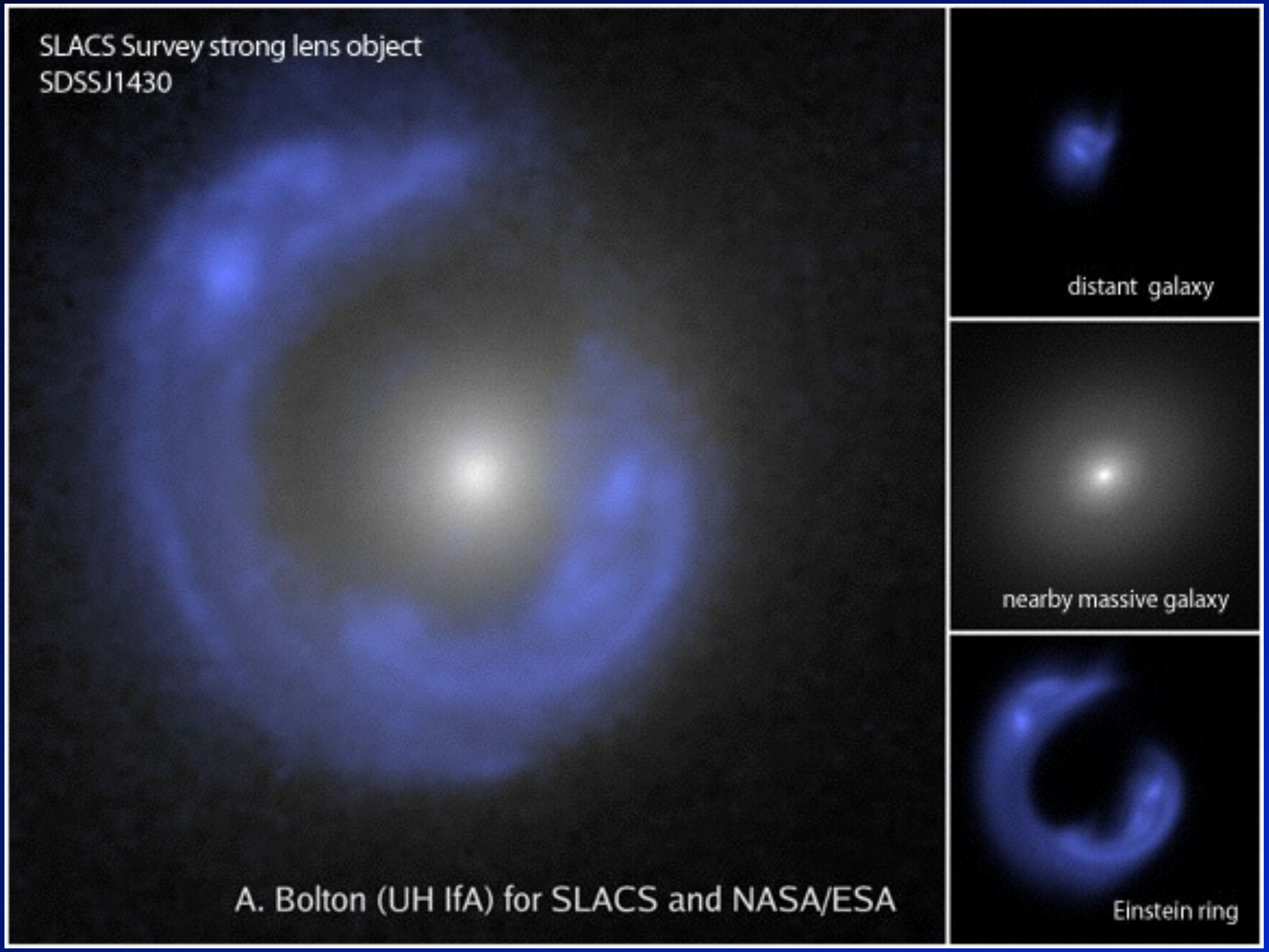


Fig 5.21 (Broeils & de Blok) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

dark matter revealed by gravitational lensing



structural outline of a galaxy

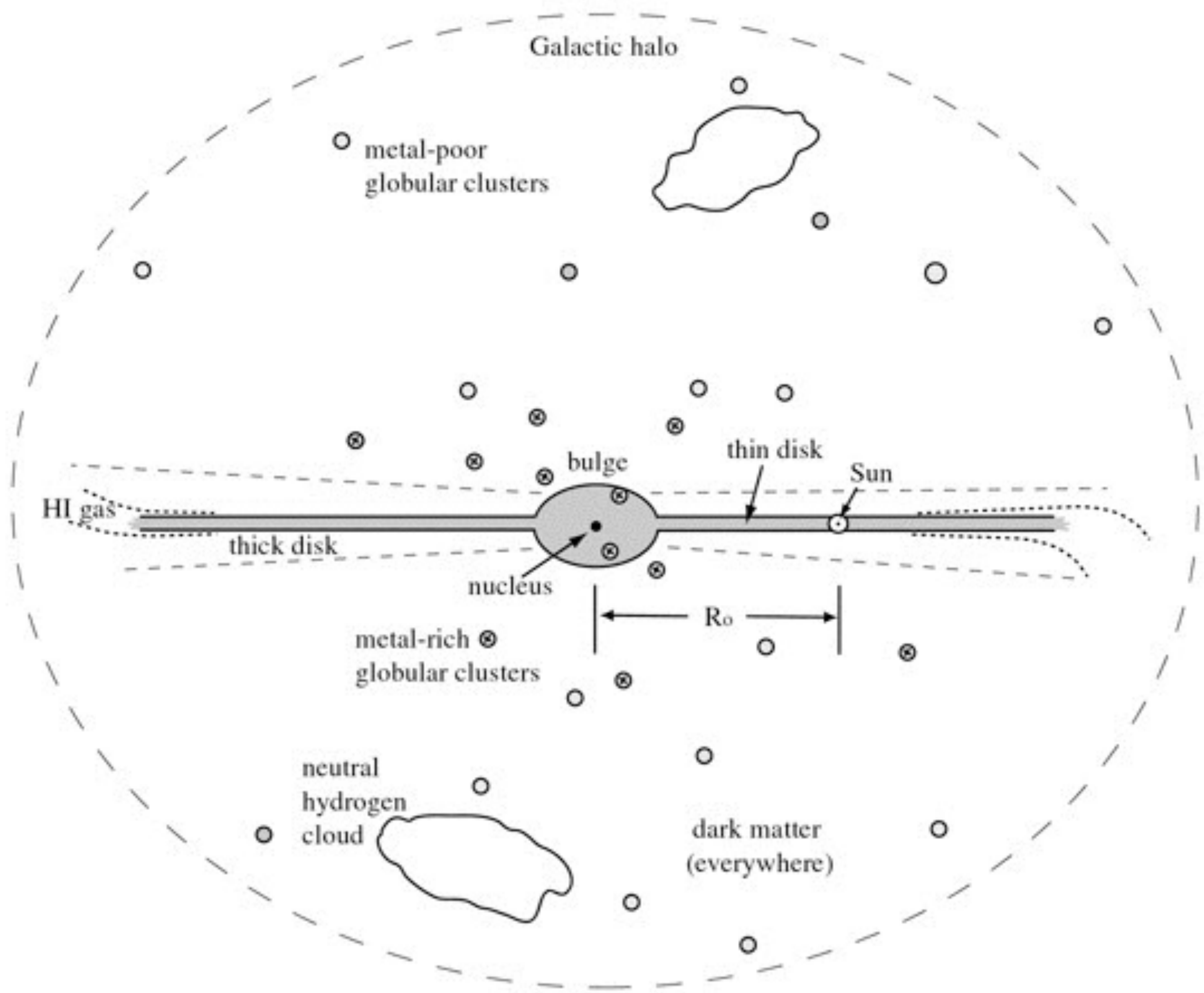
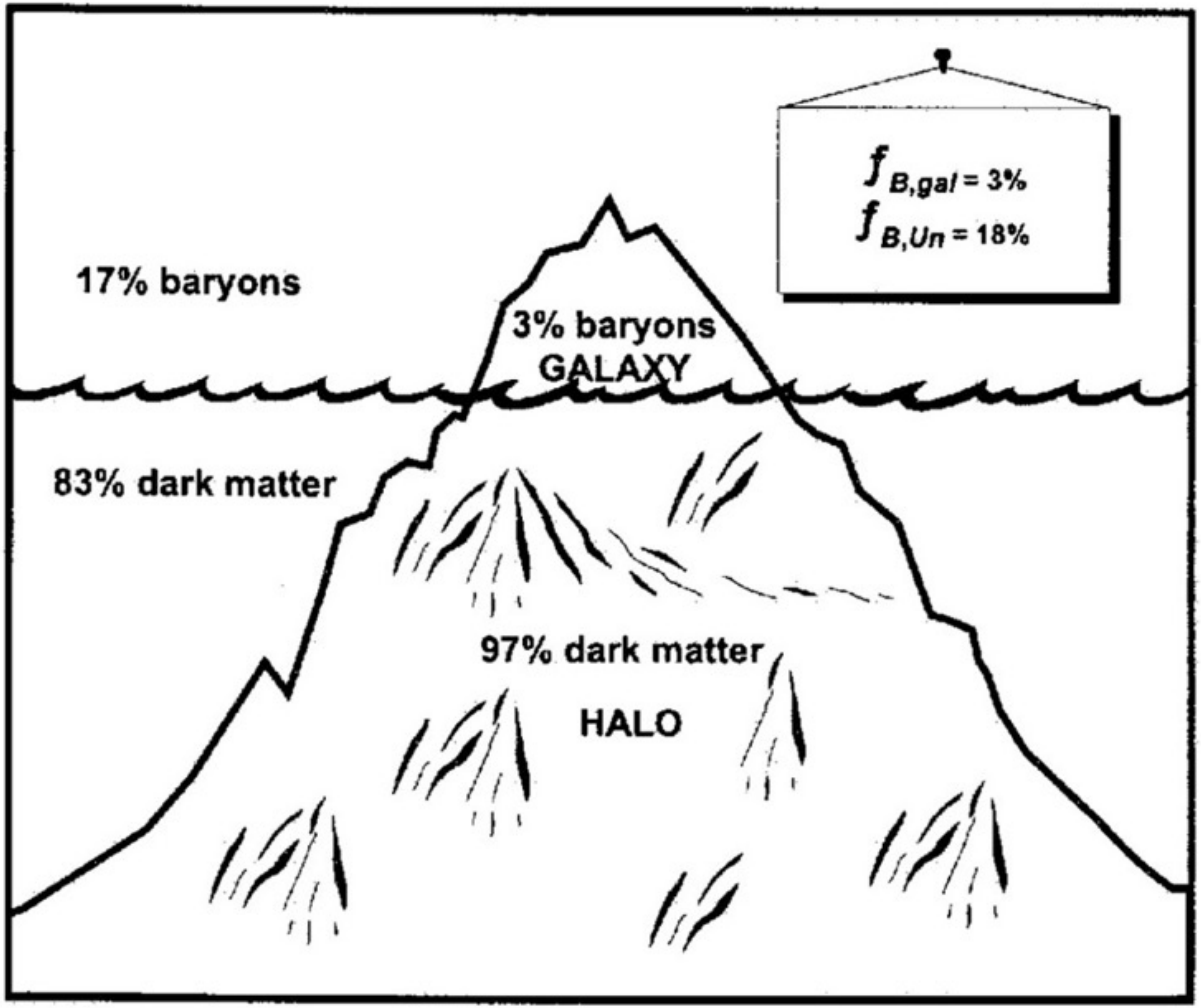
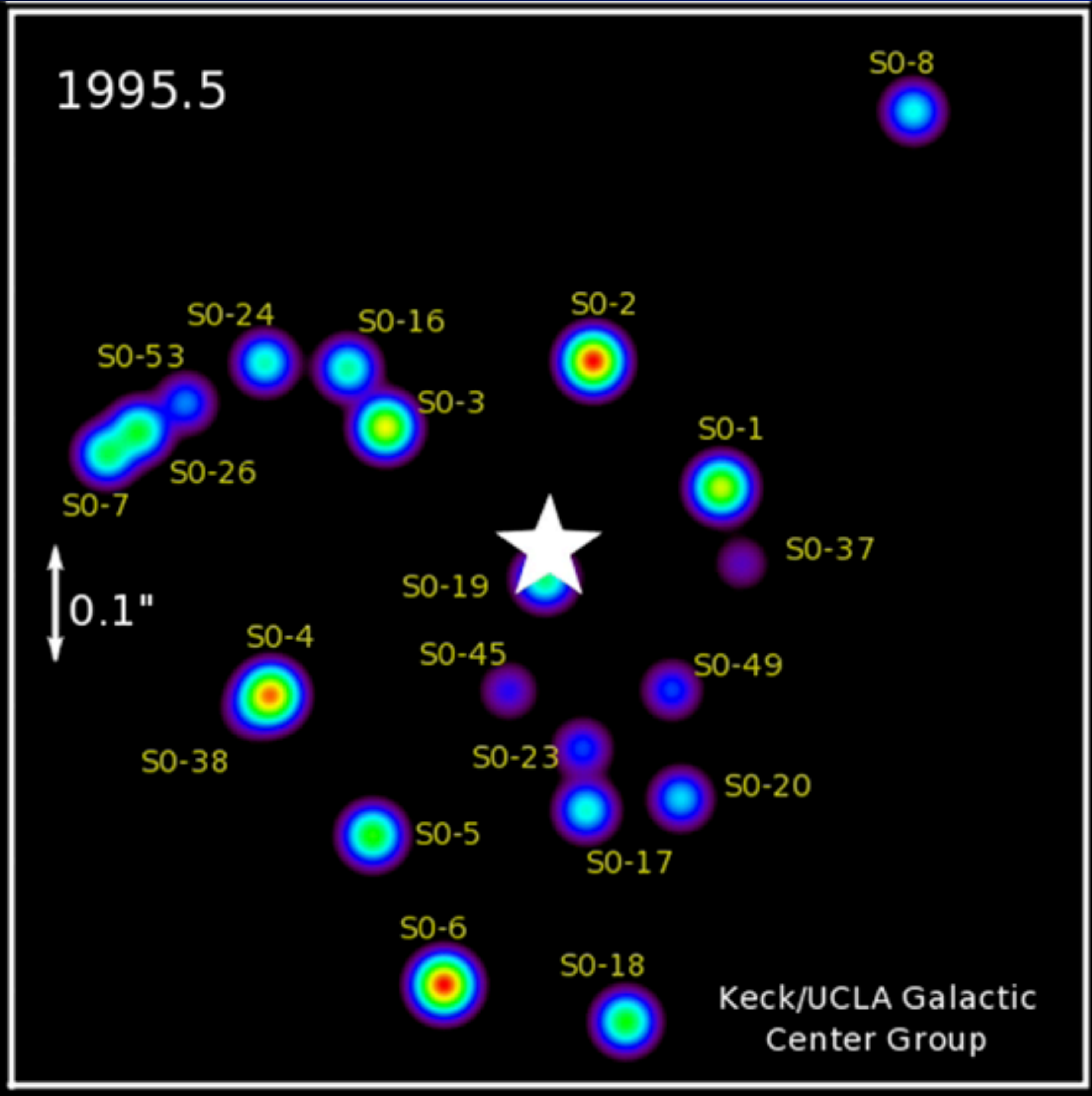


Fig 1.8 'Galaxies in the Universe' Sparke/Gallagher CUP 2007



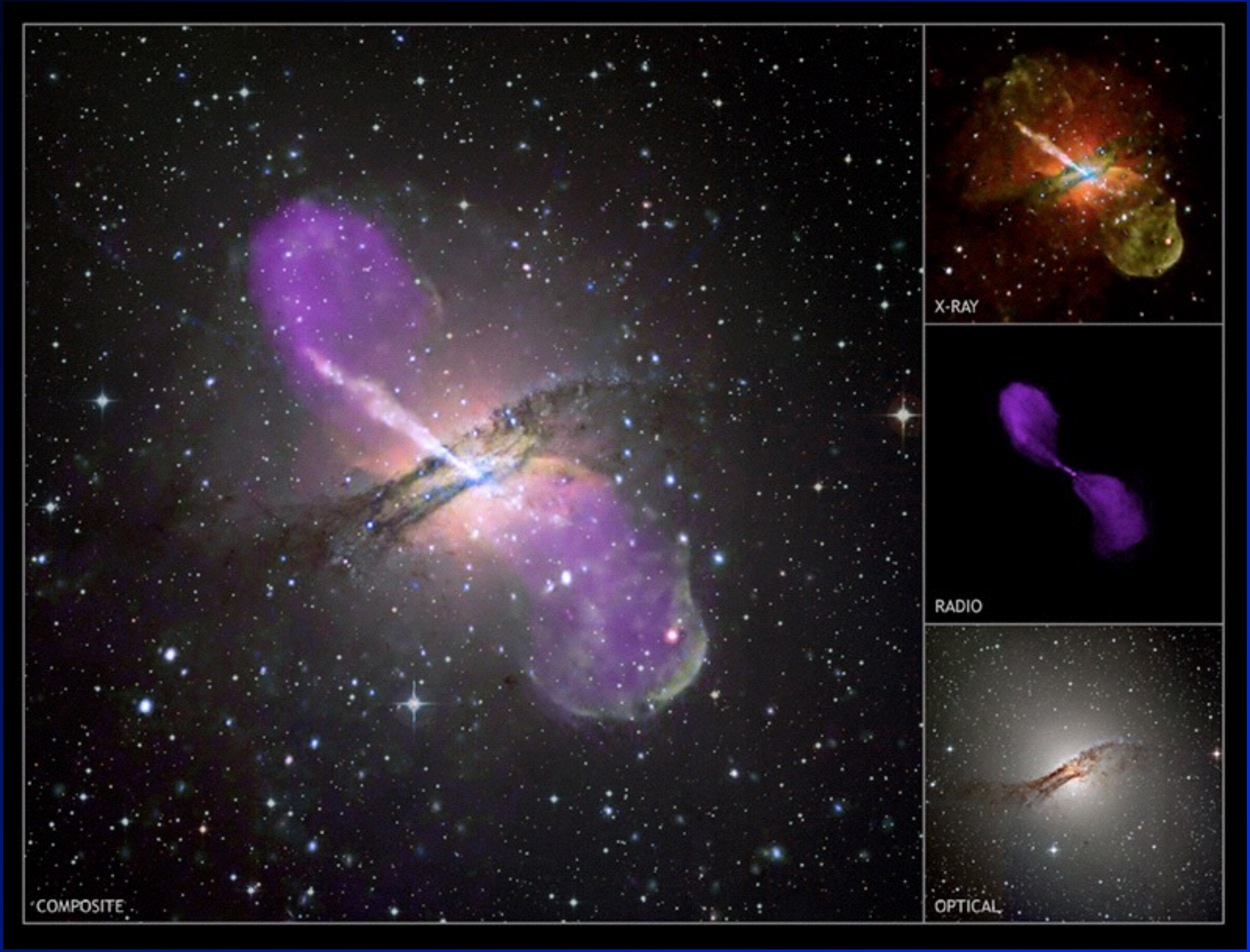
$f_{B,gal} = 3\%$
$f_{B,Un} = 18\%$
17% baryons
3% baryons
GALAXY
83% dark matter
97% dark matter
HALO

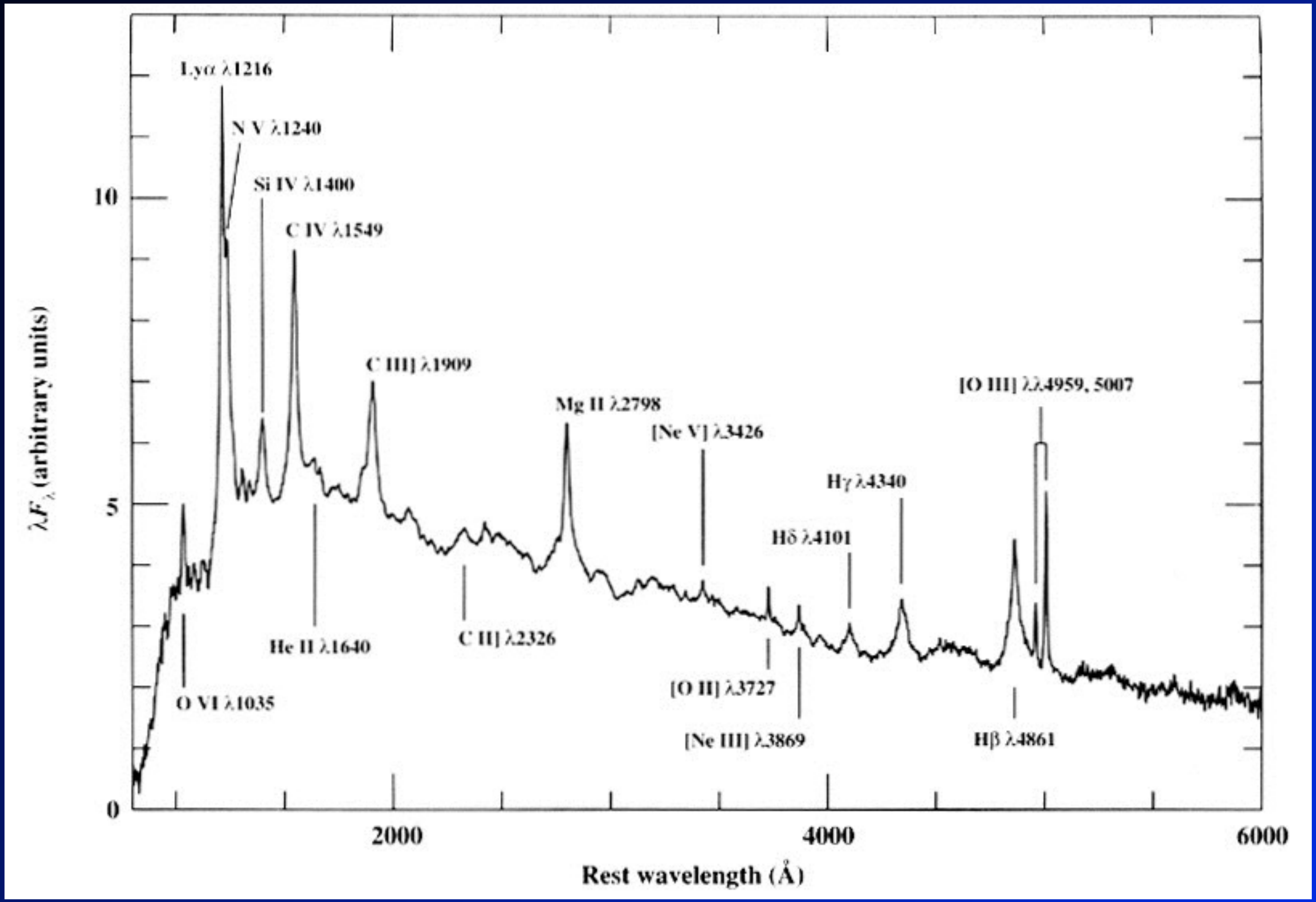
The black hole at the centre of the Milky Way



Sgr A* in X-rays (Chandra)

Active nuclei

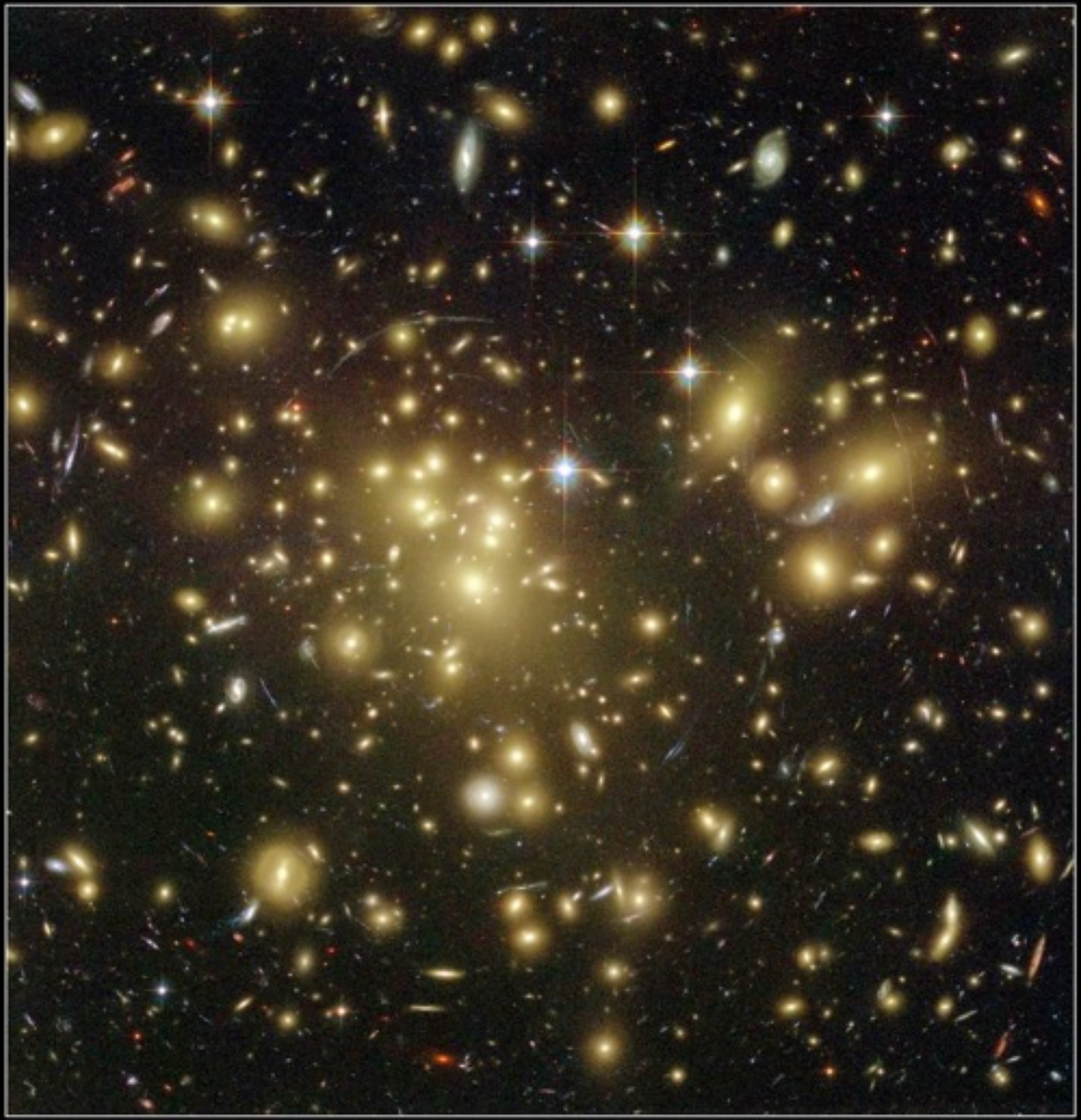




Lyα λ1216
N V λ1240
Si IV λ1400
C IV λ1549
C III] λ1909
Mg II λ2798
[Ne V] λ3426
Hγ λ4340
Hδ λ4101
[O III] λλ4959, 5007
O VI λ1035
He II λ1640
C II] λ2326
[O II] λ3727
[Ne III] λ3869
Hβ λ4861
λF_λ (arbitrary units)
Rest wavelength (Å)
0
5
10
2000
4000
6000

groups of galaxies

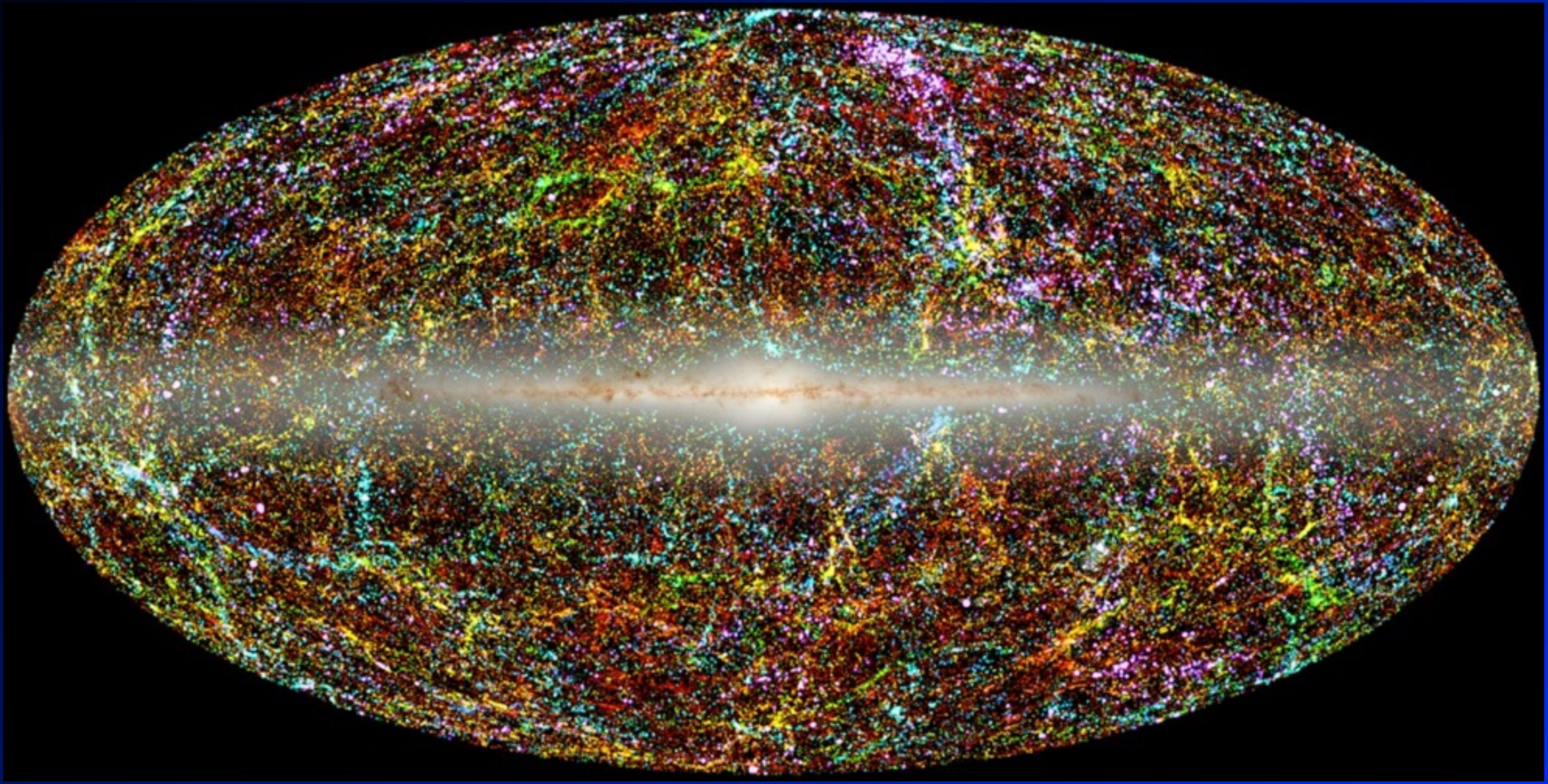
clusters of galaxies



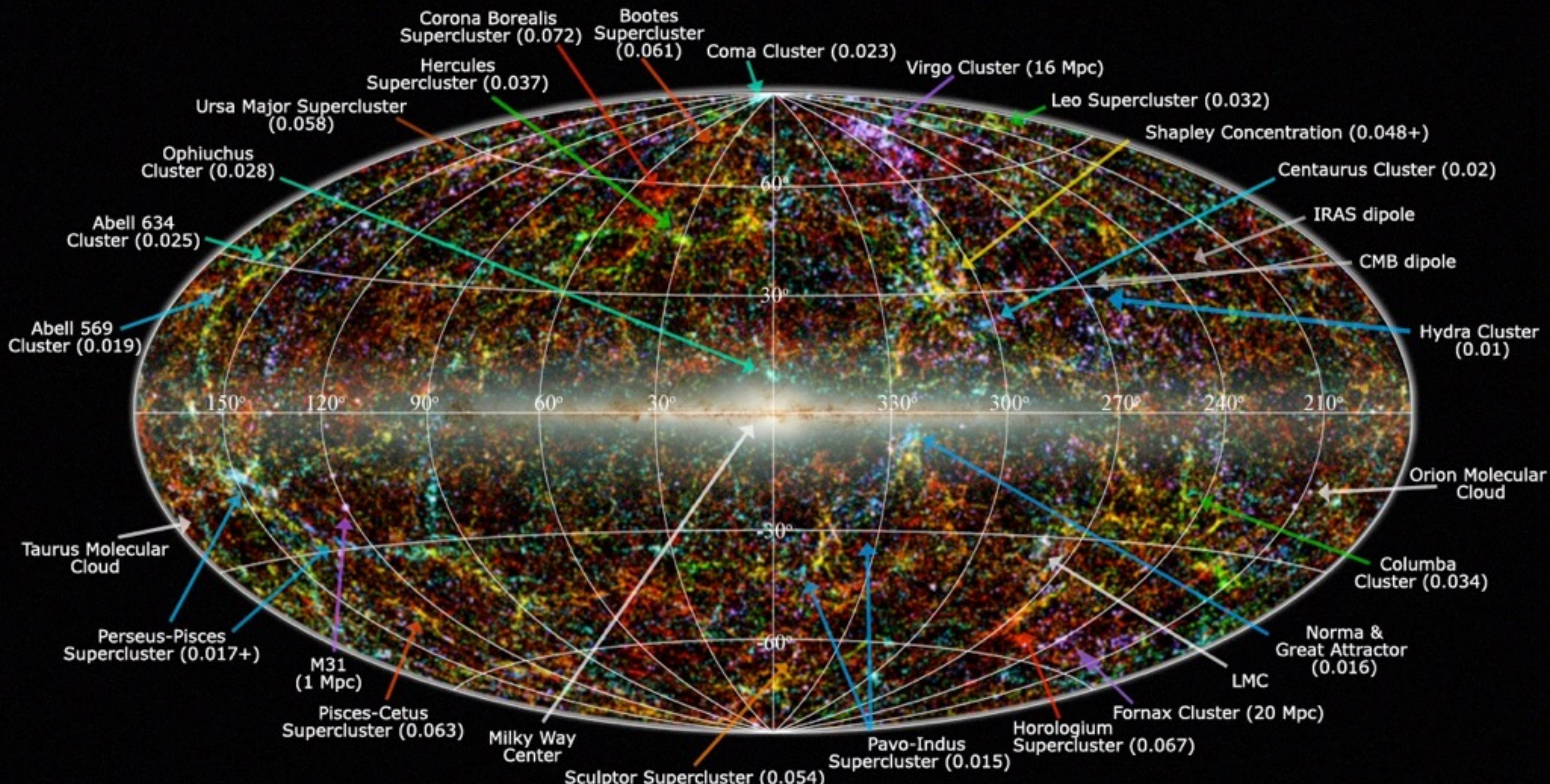
Galaxy Cluster Abell 1689
Hubble Space Telescope • Advanced Camera for Surveys

NASA, N. Benitez (JHU), T. Broadhurst (The Hebrew University), H. Ford (JHU), M. Clampin(STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA
STScI-PRC03-01a

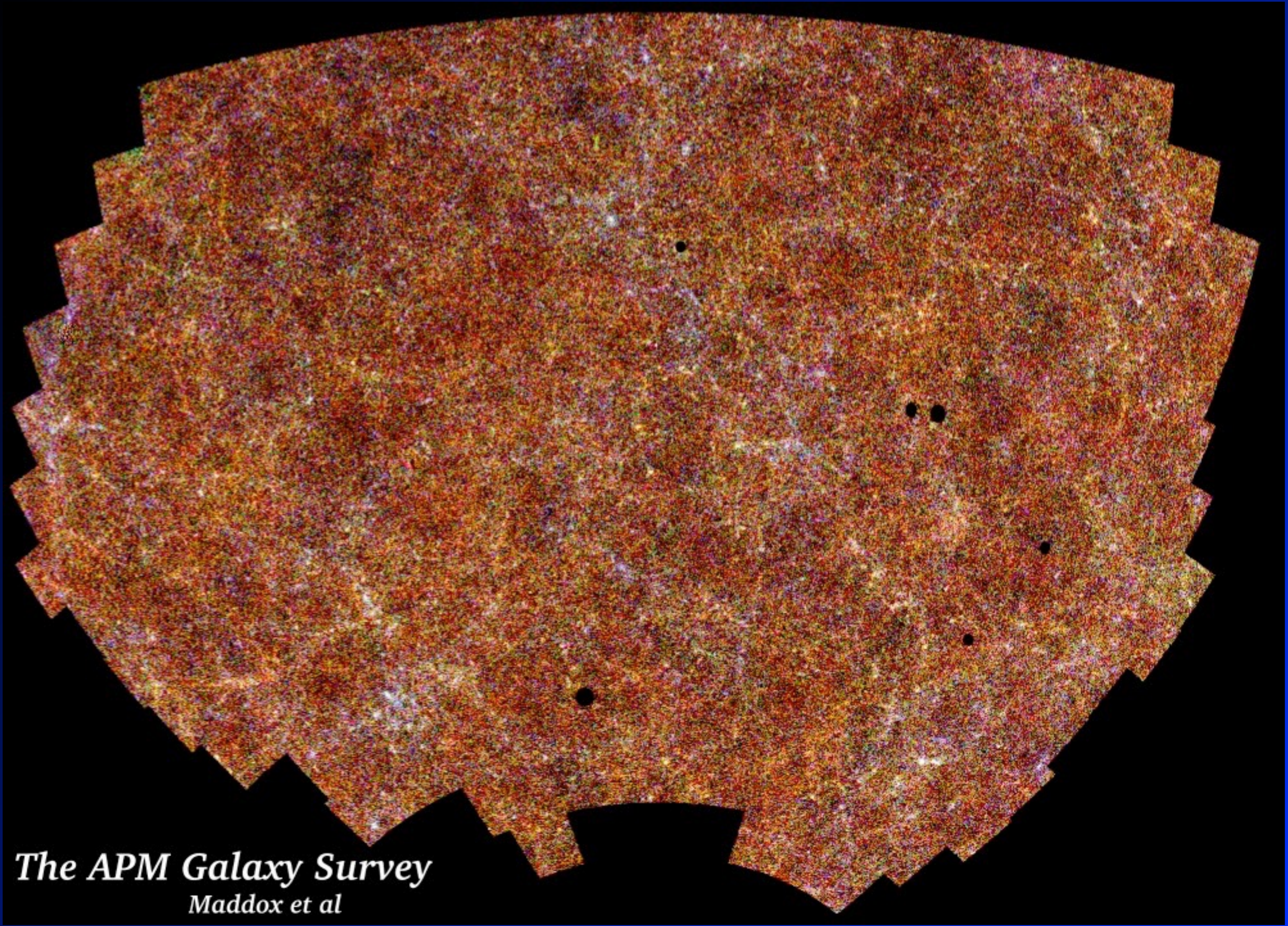
large scale structure as traced by galaxies



Large Scale Structure in the Local Universe



Legend: image shows 2MASS galaxies color coded by redshift (Jarrett 2004); familiar galaxy clusters/superclusters are labeled (numbers in parenthesis represent redshift). Graphic created by T. Jarrett (IPAC/Caltech)


The APM Galaxy Survey
Maddox et al

ABSTRACT

Using a catalog of 147,986 galaxy redshifts and fluxes from the Sloan Digital Sky Survey (SDSS) we measure the galaxy luminosity density at $z = 0.1$ in five optical bandpasses corresponding to the SDSS bandpasses shifted to match their restframe shape at $z = 0.1$. We denote the bands ${}^{0.1}u$, ${}^{0.1}g$, ${}^{0.1}r$, ${}^{0.1}i$, ${}^{0.1}z$, with $\lambda_{\rm eff} = [3216, 4240, 5595, 6792, 8111$ Å$]$ respectively. To estimate the luminosity function, we use a maximum likelihood method which allows for a general form for the shape of the luminosity function, simple luminosity and number evolution, incorporates the flux uncertainties, and accounts for the flux limits of the survey. We find luminosity densities at $z = 0.1$ expressed in absolute AB magnitudes in a Mpc^3 to be $[-14.10 \pm 0.15, -15.18 \pm 0.03, -15.90 \pm 0.03, -16.24 \pm 0.03, -16.56 \pm 0.02]$ in $[{}^{0.1}u, {}^{0.1}g, {}^{0.1}r, {}^{0.1}i, {}^{0.1}z]$, respectively, for a cosmological model with $\Omega_0 = 0.3$, $\Omega_\Lambda = 0.7$, and $h = 1$, and using SDSS Petrosian magnitudes. Similar results are obtained using Sérsic model magnitudes, suggesting that flux from outside the Petrosian apertures is not a major correction. In the ${}^{0.1}r$ band, the best fit Schechter function to our results has $\phi_* = (1.49 \pm 0.04) \times 10^{-2}\ h^3$ Mpc^{-3}, $M_* - 5\log_{10} h = -20.44 \pm 0.01$, and $\alpha = -1.05 \pm 0.01$. In solar luminosities, the luminosity density in ${}^{0.1}r$ is $(1.84 \pm 0.04)\ h\ 10^8\ L_{{}^{0.1}r,\odot}$ Mpc^{-3}. Our results are consistent with other estimates of the luminosity density, from the Two-degree Field Galaxy Redshift Survey and the Millenium Galaxy Catalog. They represent a substantial change (~ 0.5 mag) from earlier SDSS luminosity density results based on commissioning data, almost entirely because of the inclusion of evolution in the luminosity function model.