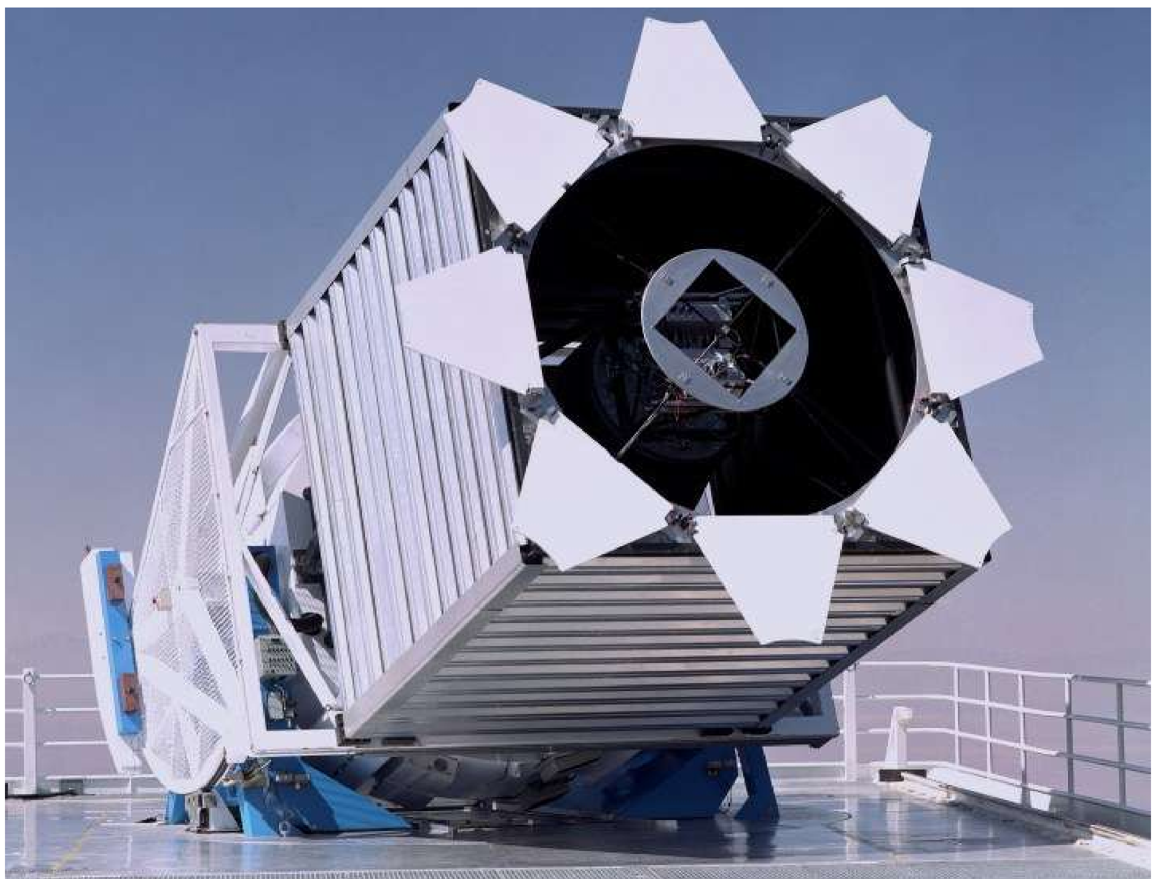
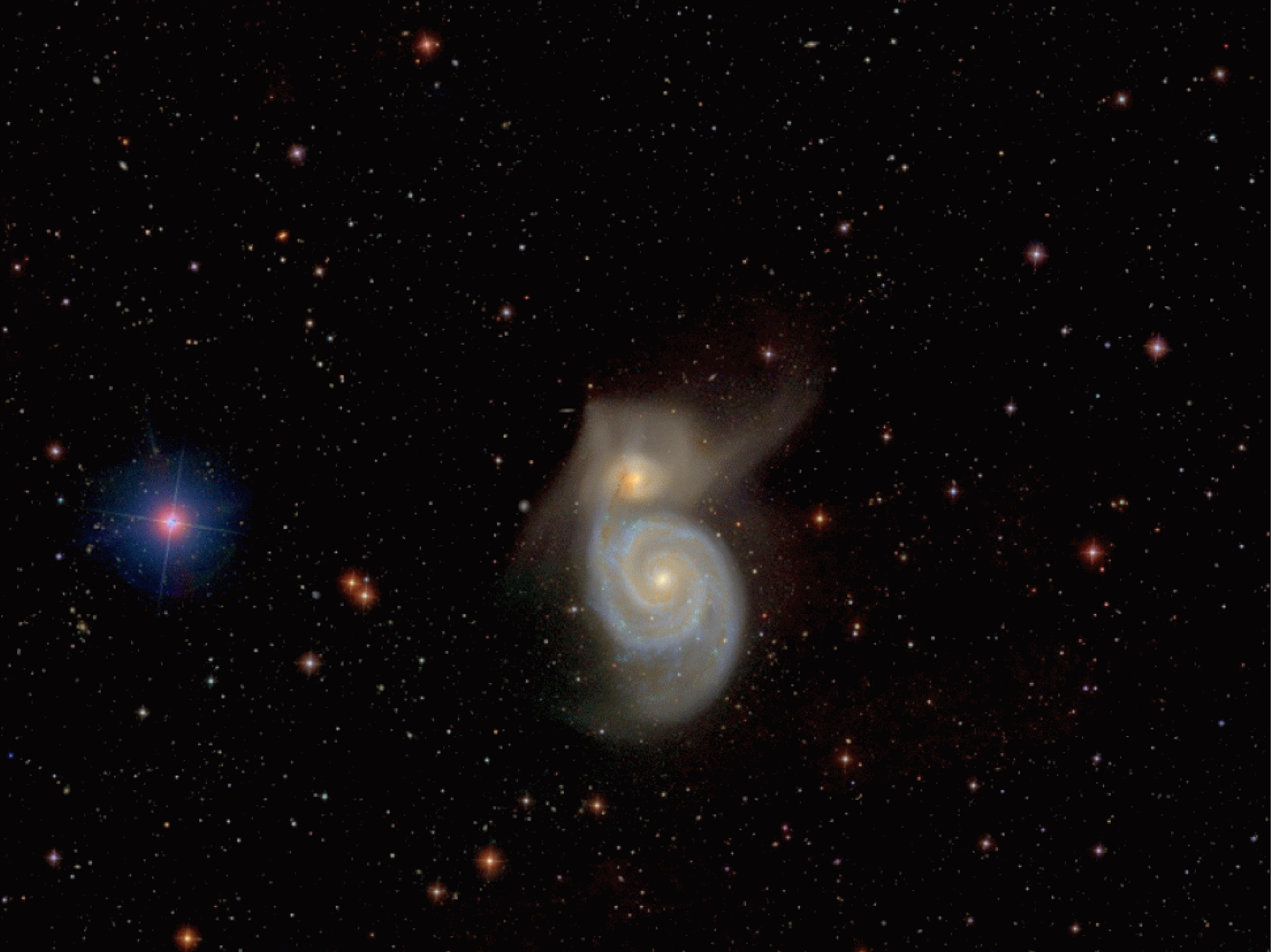
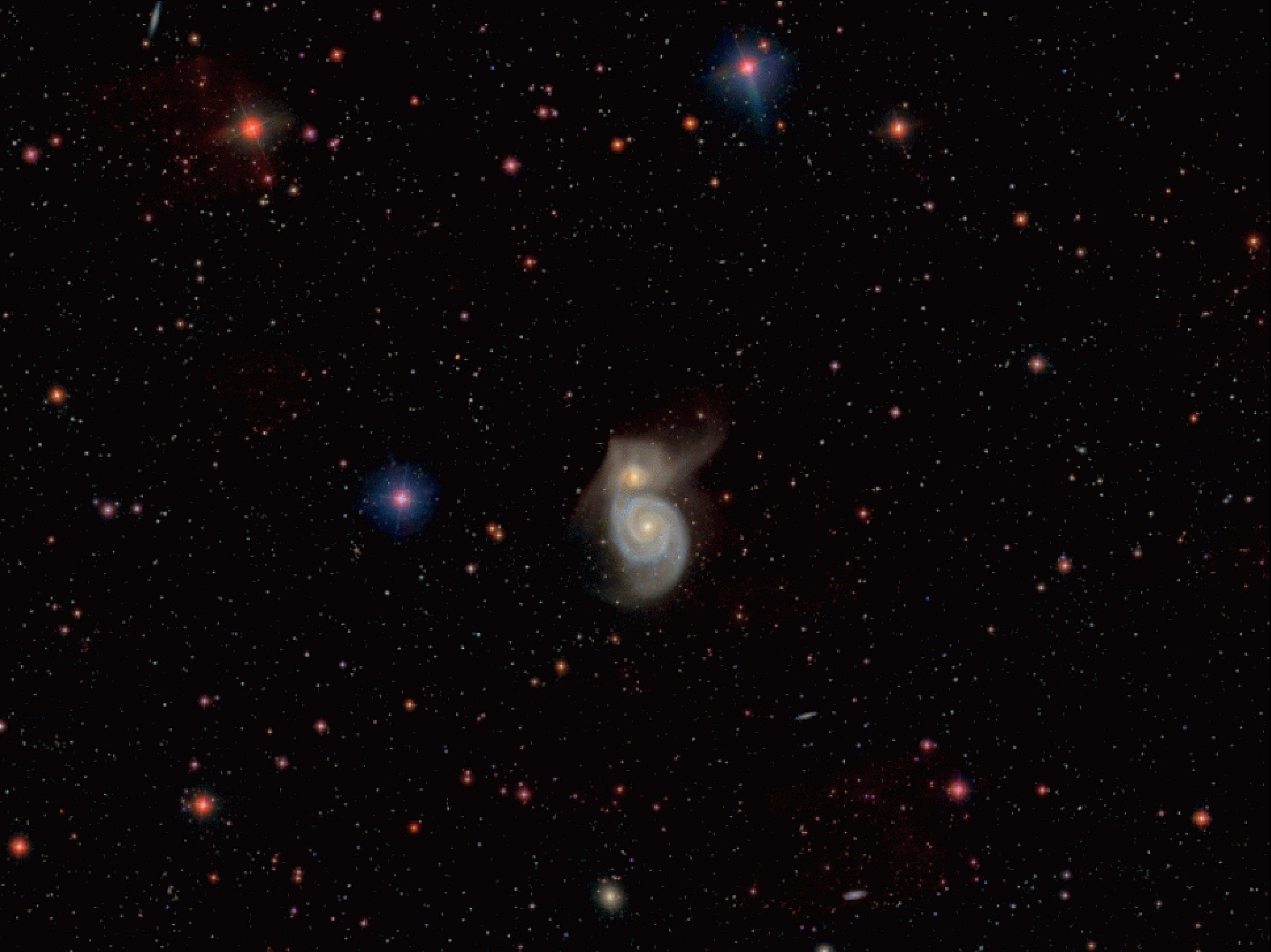
WHAT DO WE LEARN ABOUT GALAXY FORMATION FROM A NEW GENERATION OF LARGE SKY SURVEYS?

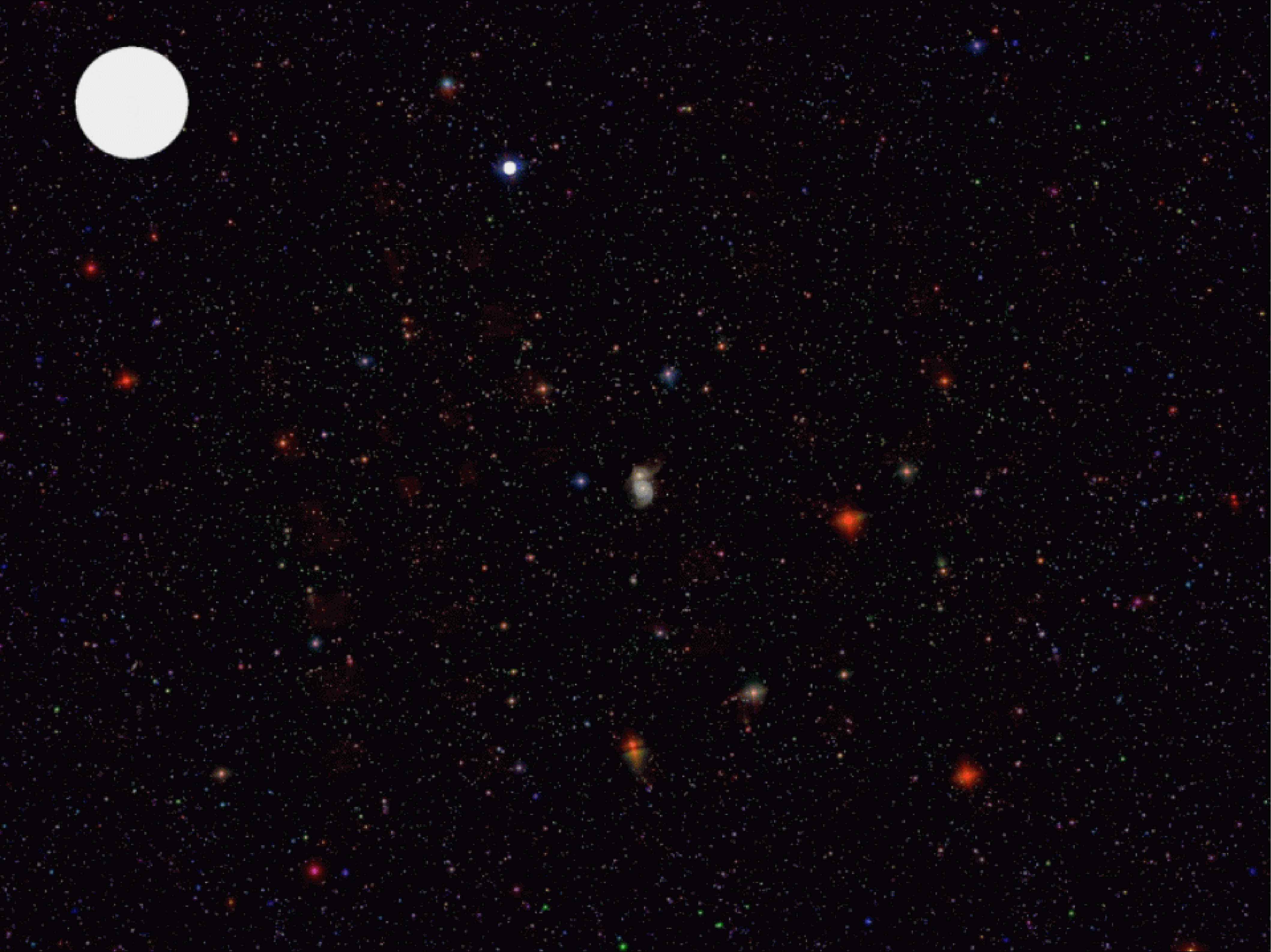
SDSS Sloan Digital Sky Survey

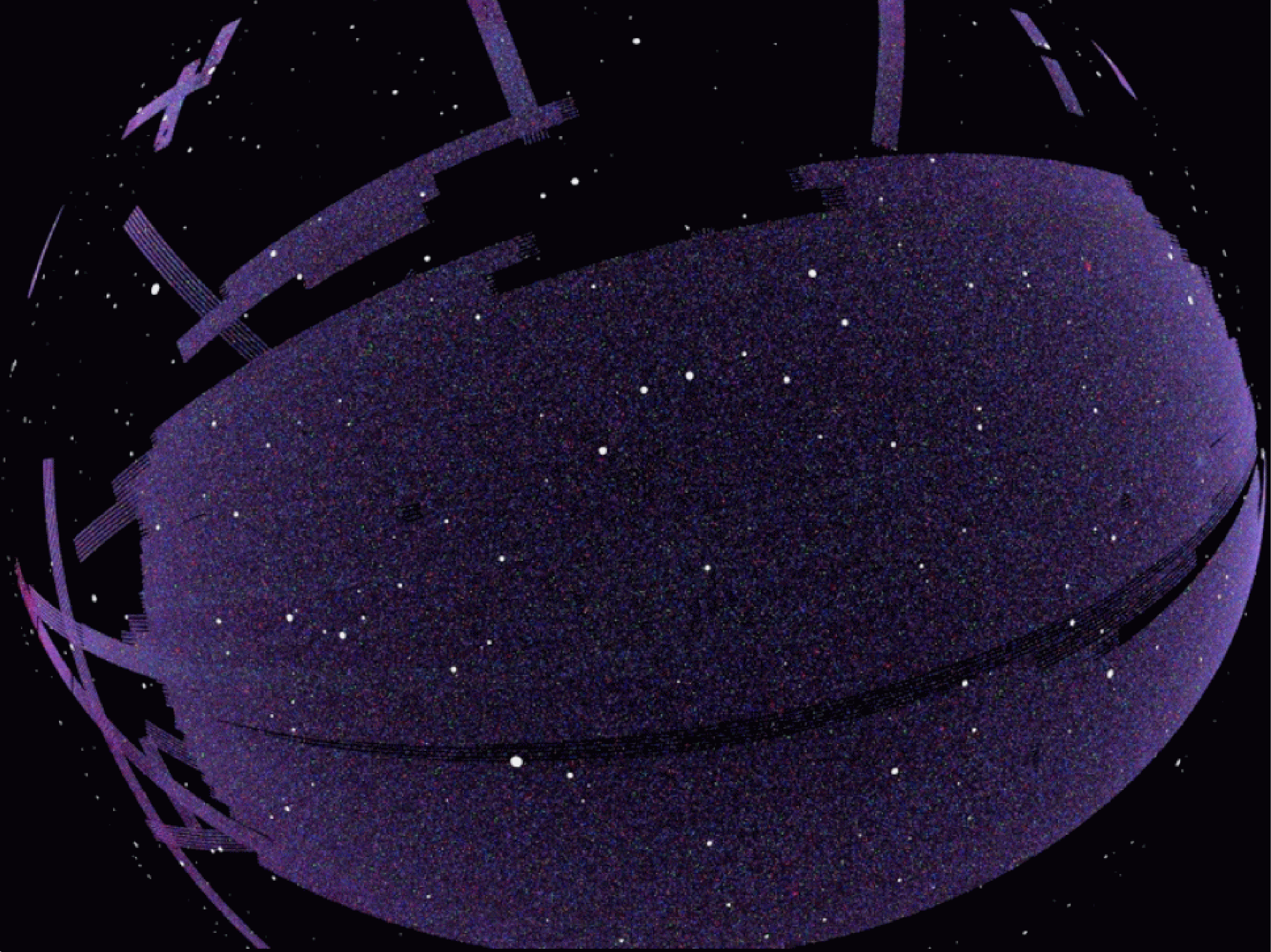
http://www.sdss.org

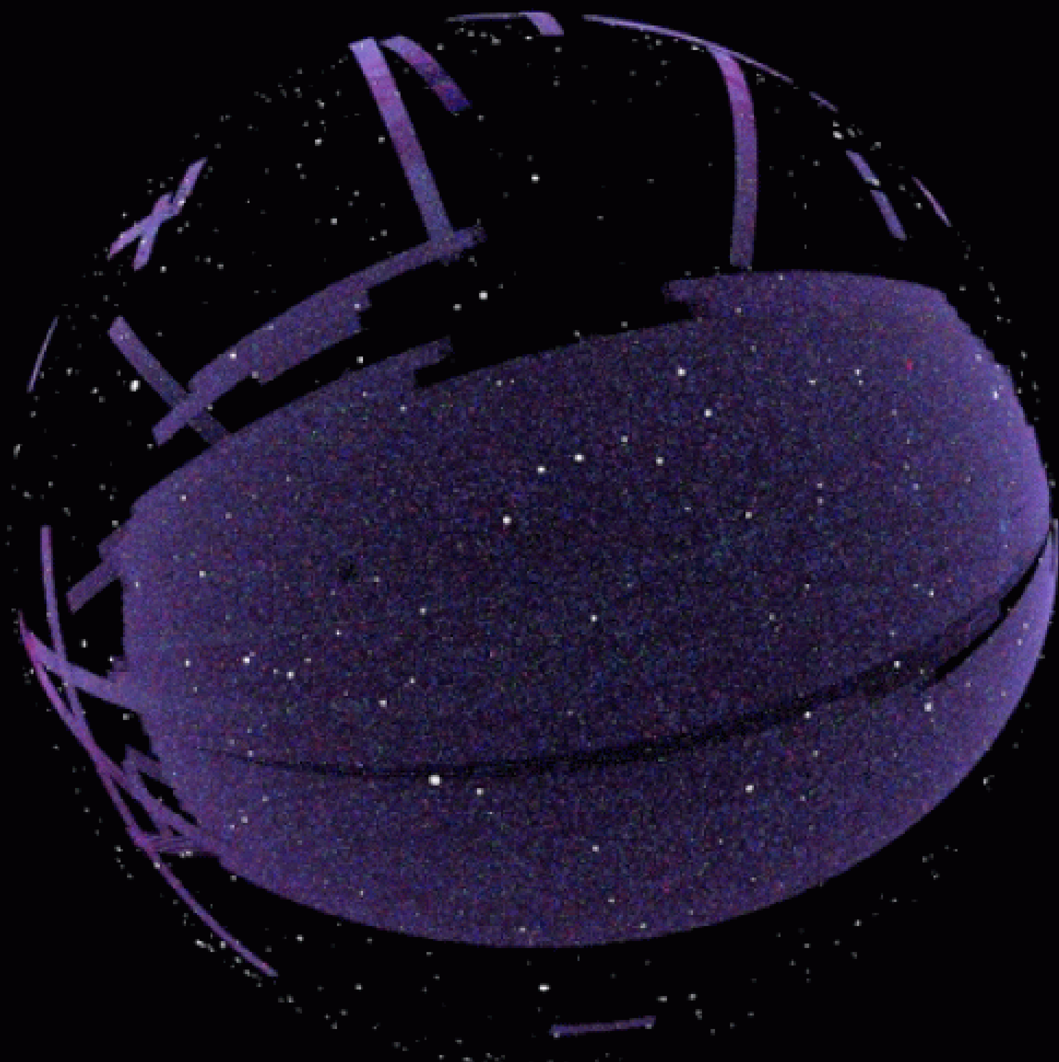




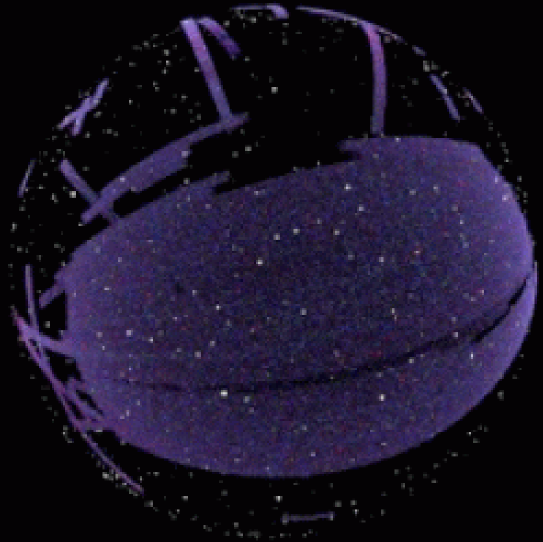








data: **Sloan Digital Sky Survey**
and **the Bright Star Catalog**



visualization: **David W. Hogg** (NYU)
with help from **Blanton, Finkbeiner,**
Padmanabhan, Schlegel, Wherry

To make a 3-dimensional map of the galaxy distribution, we need to be able to measure the DISTANCES to the galaxies.

Hubble's Law

Hubble's law is a statement of a direct correlation between the distance to a galaxy and its recessional velocity as determined by the red shift. It can be stated as

$$v = H_0 r$$

v = recessional velocity

H_0 = Hubble constant

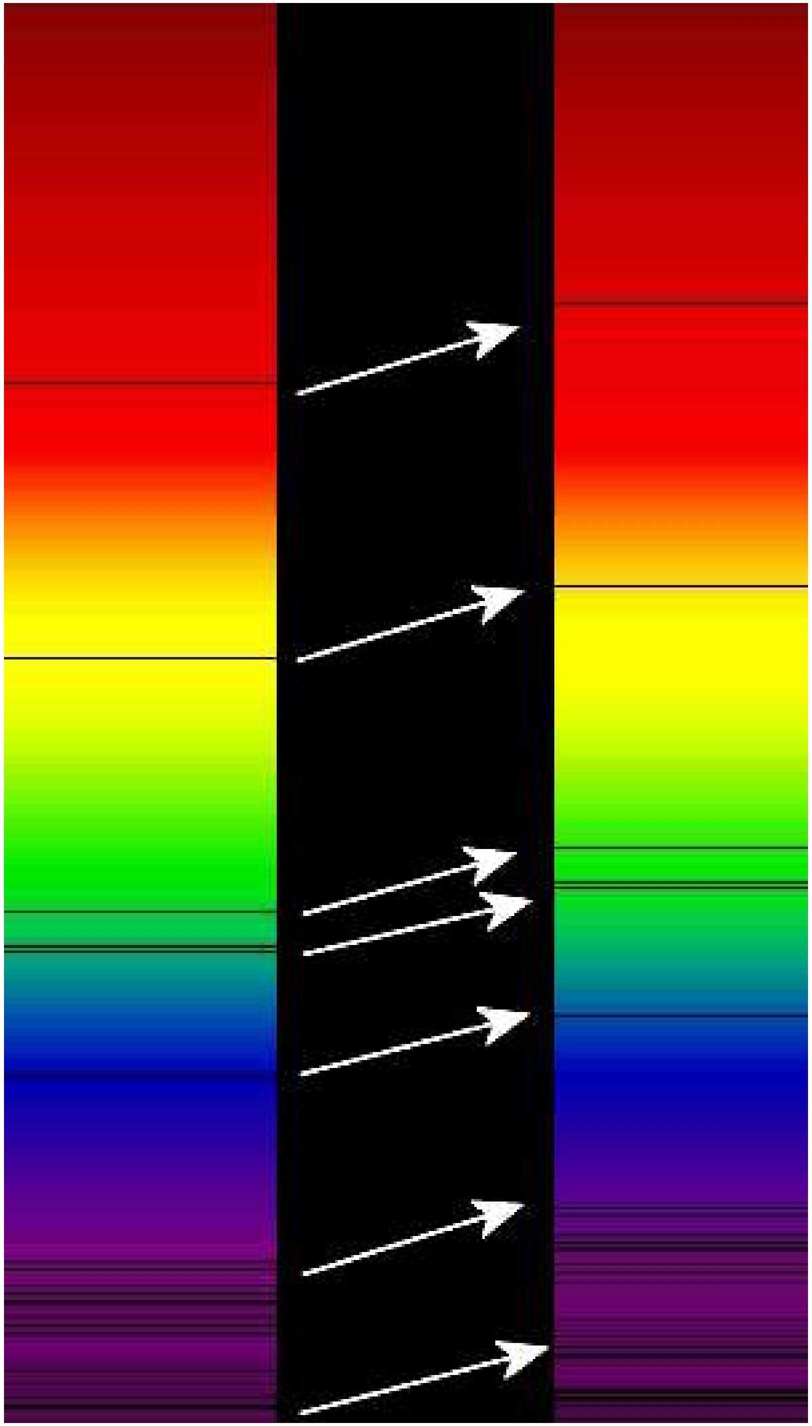
r = distance

The value of the Hubble constant is in constant debate, but a current value is

$$H_0 = \frac{70 km/s}{Mpc} \approx \frac{20 km/s}{Mly}$$

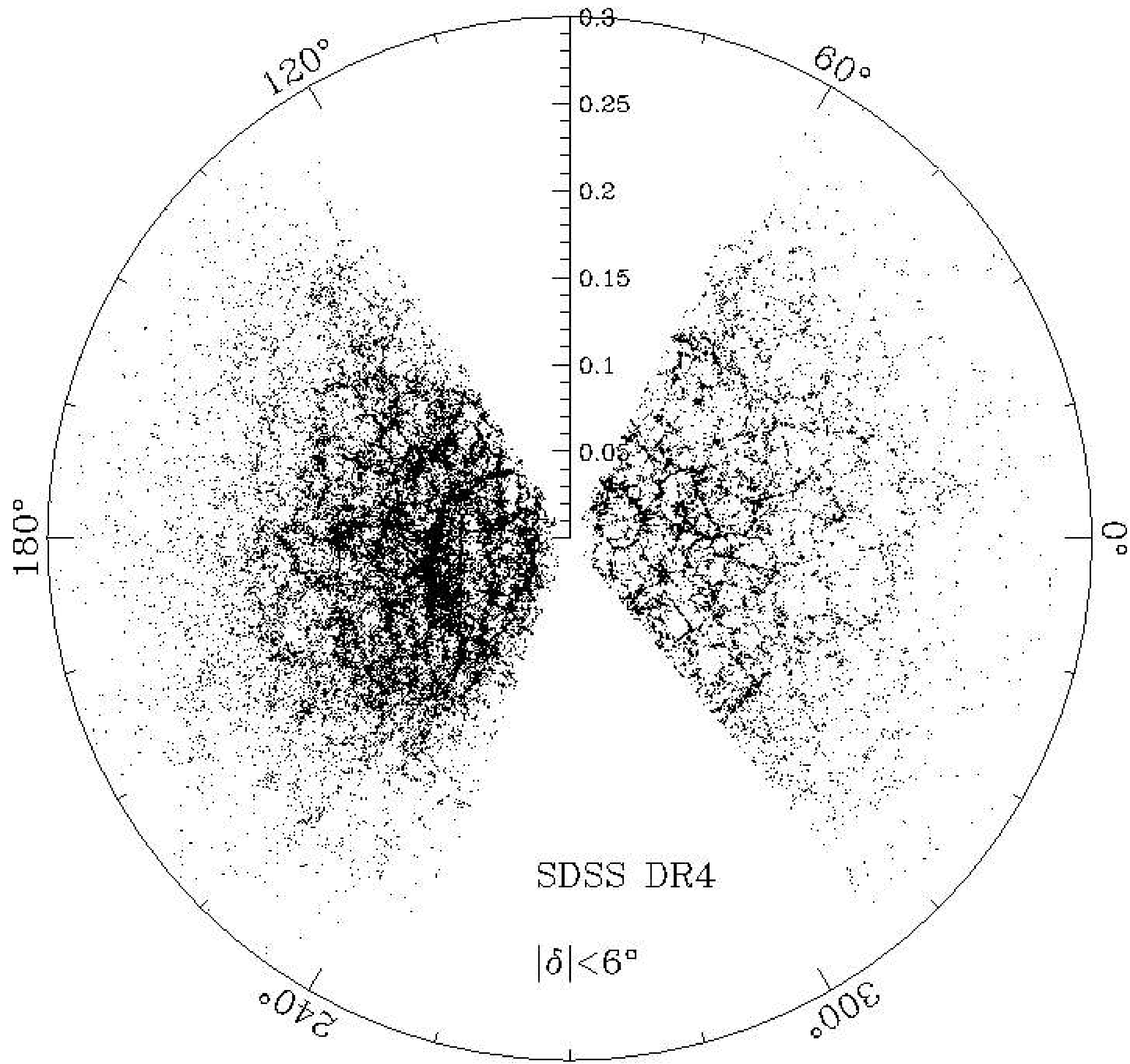
$Mpc = million\ parsecs$

$Mly = million\ light\ years$

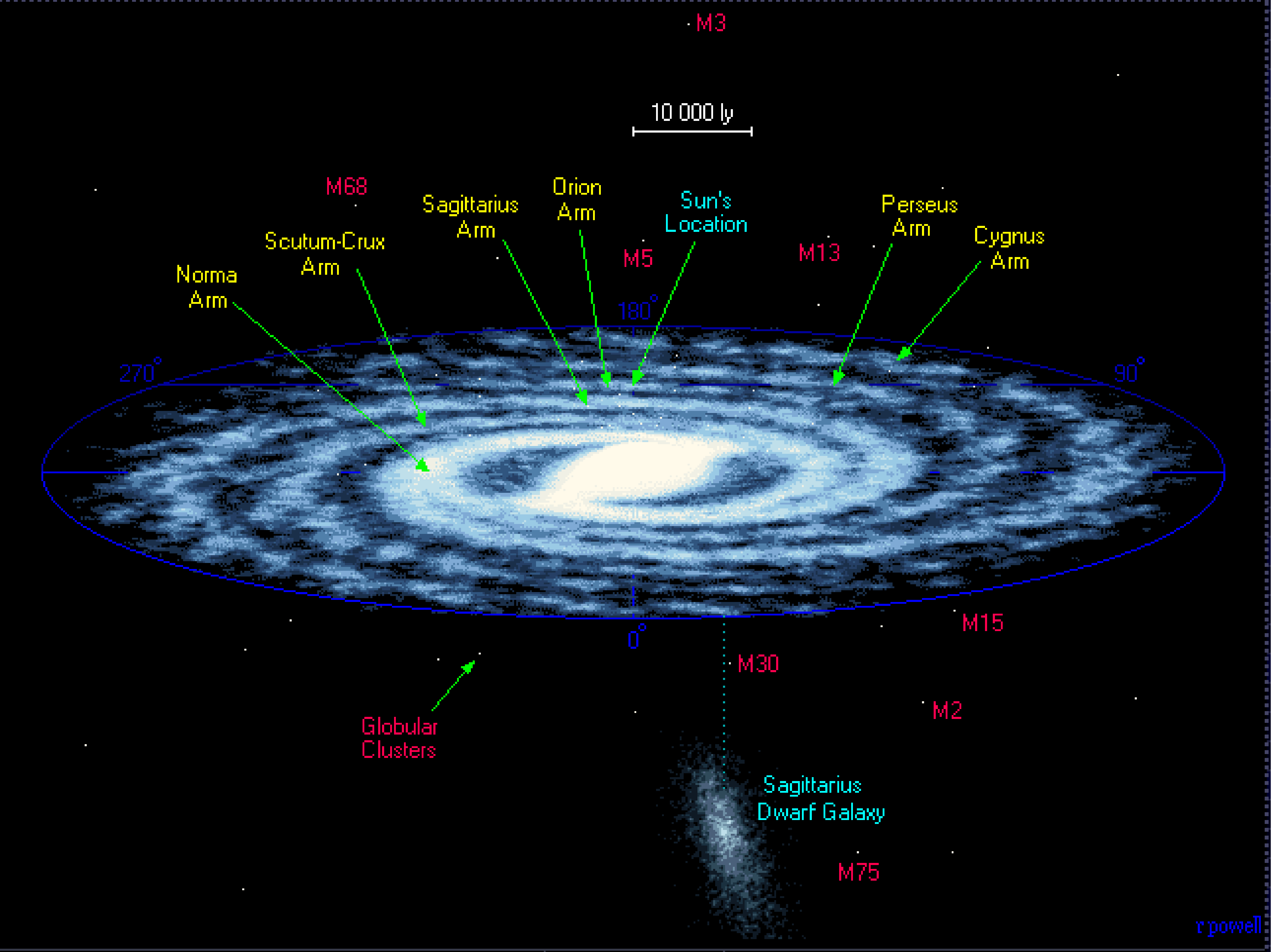


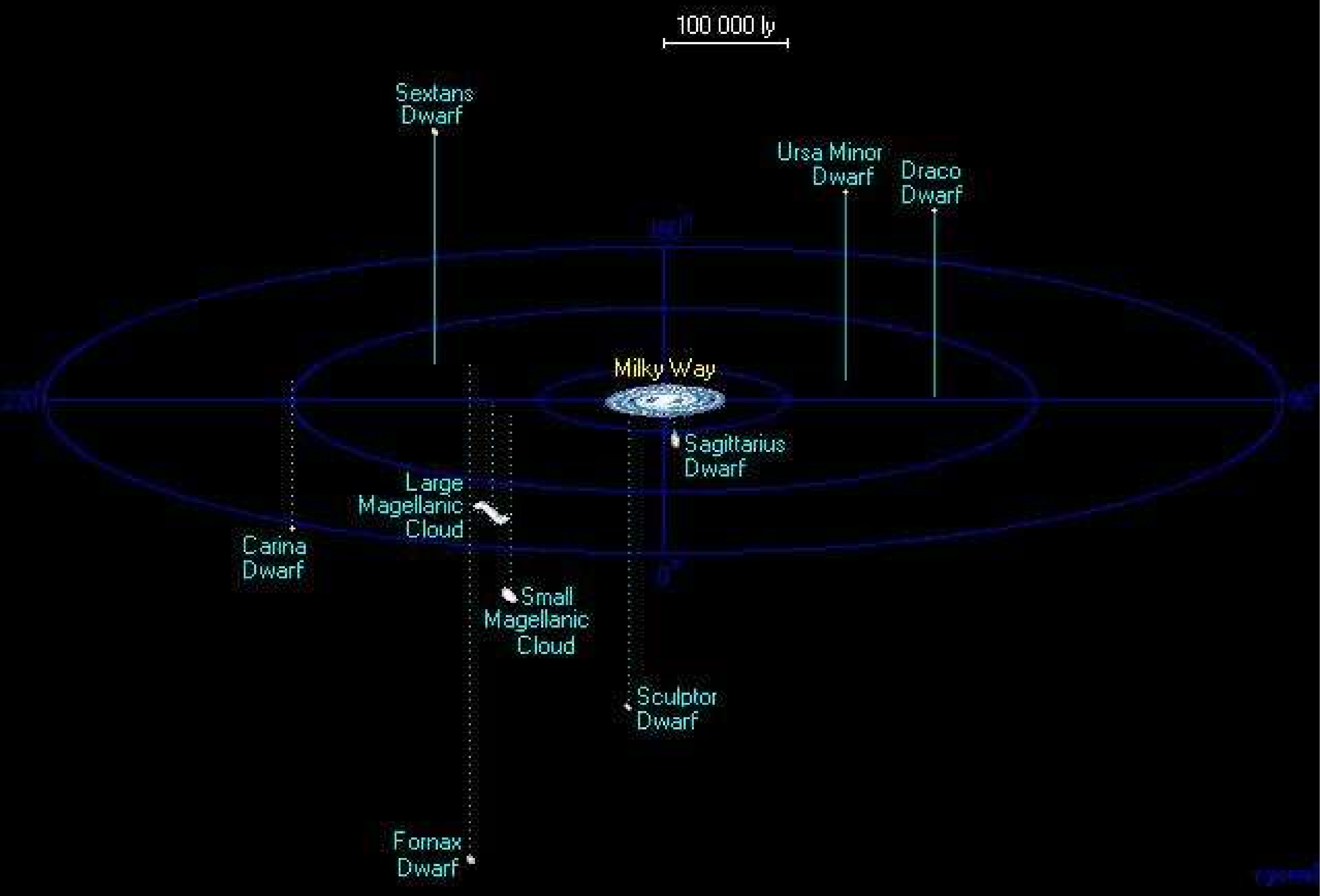
Astrophysical redshift occurs when a light source moves away from an observer.

By taking a SPECTRUM of a galaxy and measuring the shift of spectral lines that arise from known atomic transitions with respect to its expected wavelength, as measured in a laboratory on Earth, we measure the recessional velocity and hence distance to a galaxy.

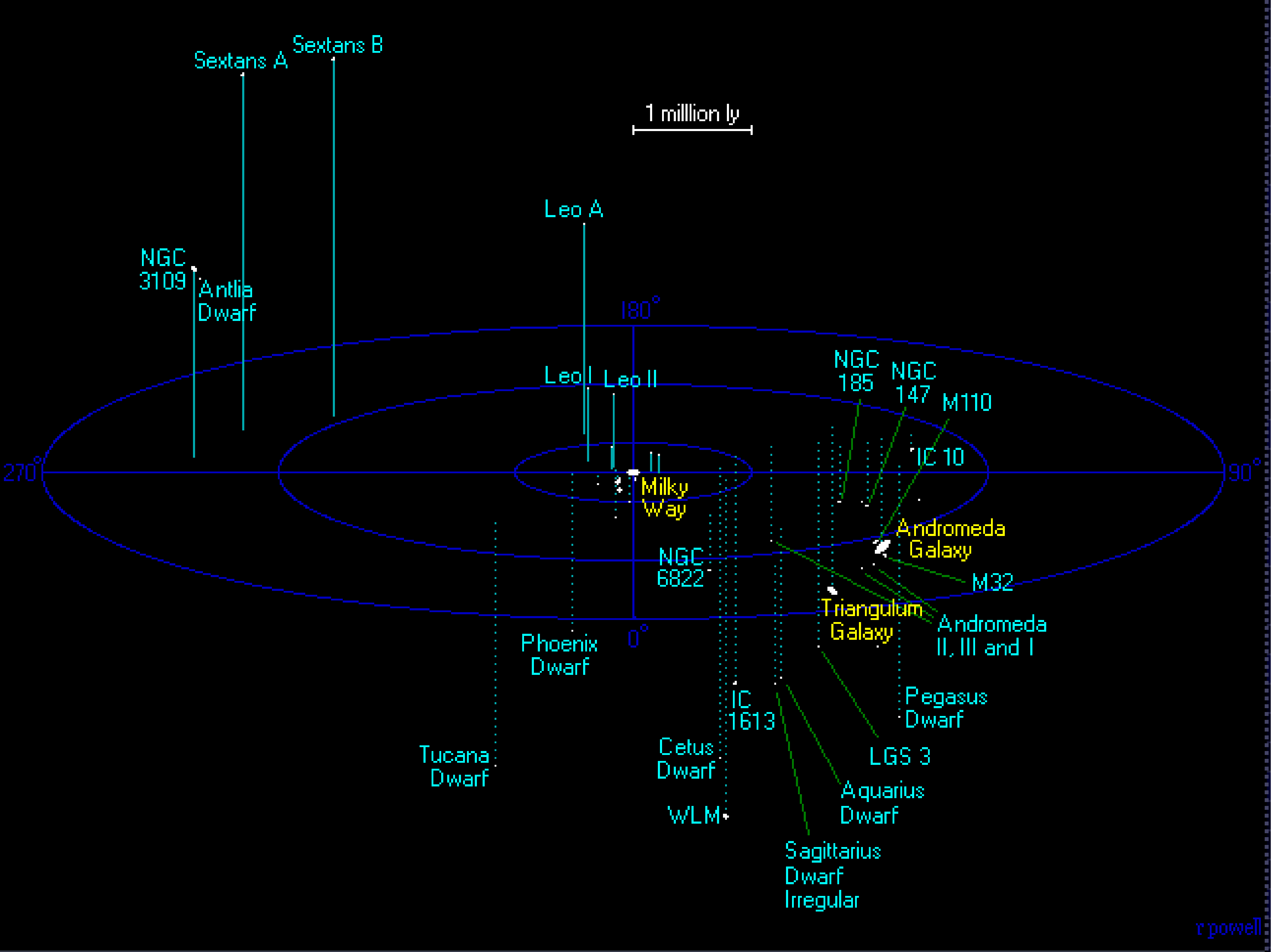


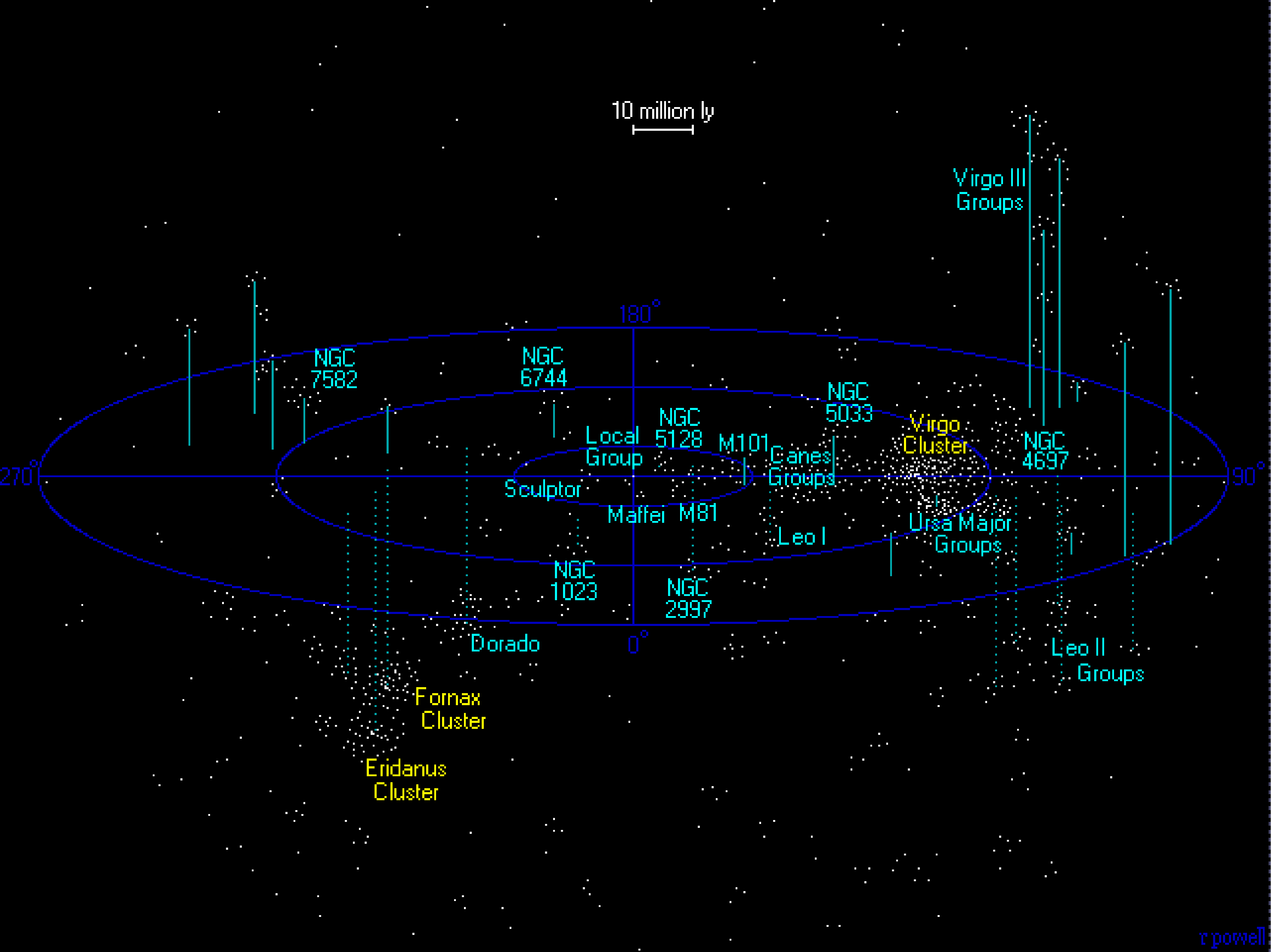
0.3
0.25
0.2
0.15
0.1
0.05
120°
60°
180°
0°
240°
300°
SDSS DR4
|δ|<6°


M3
10 000 ly
M68
Sagittarius Arm
Orion Arm
Sun's Location
Perseus Arm
Cygnus Arm
Scutum-Crux Arm
M5
M13
Norma Arm
180°
270°
90°
M15
0°
M30
M2
Globular Clusters
Sagittarius Dwarf Galaxy
M75
r powell

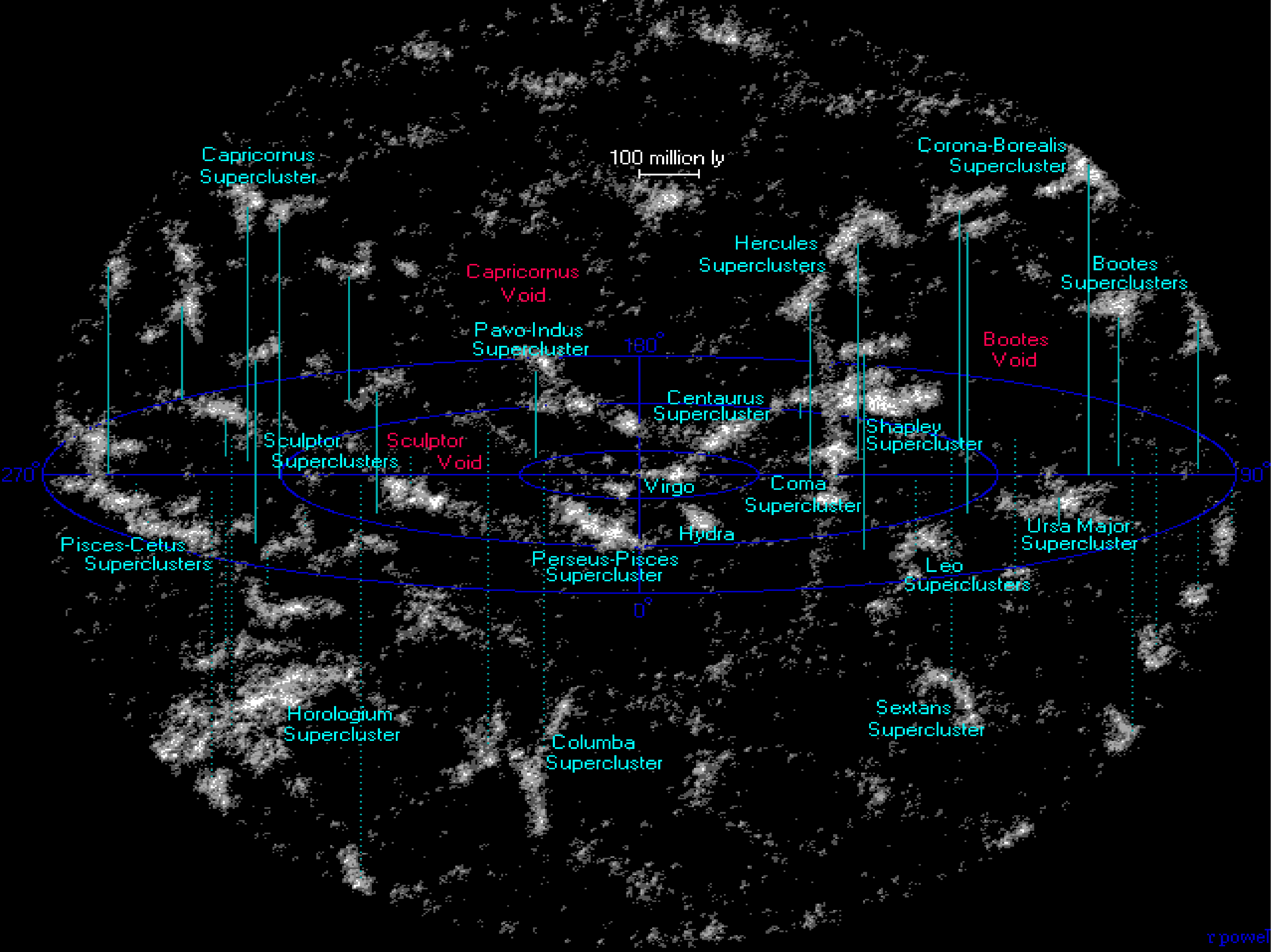


100 000 ly
Sextans Dwarf
Ursa Minor Dwarf
Draco Dwarf
Milky Way
Sagittarius Dwarf
Large Magellanic Cloud
Carina Dwarf
Small Magellanic Cloud
Sculptor Dwarf
Fornax Dwarf


Sextans A
Sextans B
1 milllion ly
Leo A
NGC 3109
Antlia Dwarf
180°
Leo I
Leo II
NGC 185
NGC 147
M110
270°
IC 10
90°
Milky Way
Andromeda Galaxy
NGC 6822
M32
Triangulum Galaxy
Andromeda II, III and I
0°
Phoenix Dwarf
IC 1613
Pegasus Dwarf
Tucana Dwarf
Cetus Dwarf
LGS 3
WLM
Aquarius Dwarf
Sagittarius Dwarf Irregular
r powell

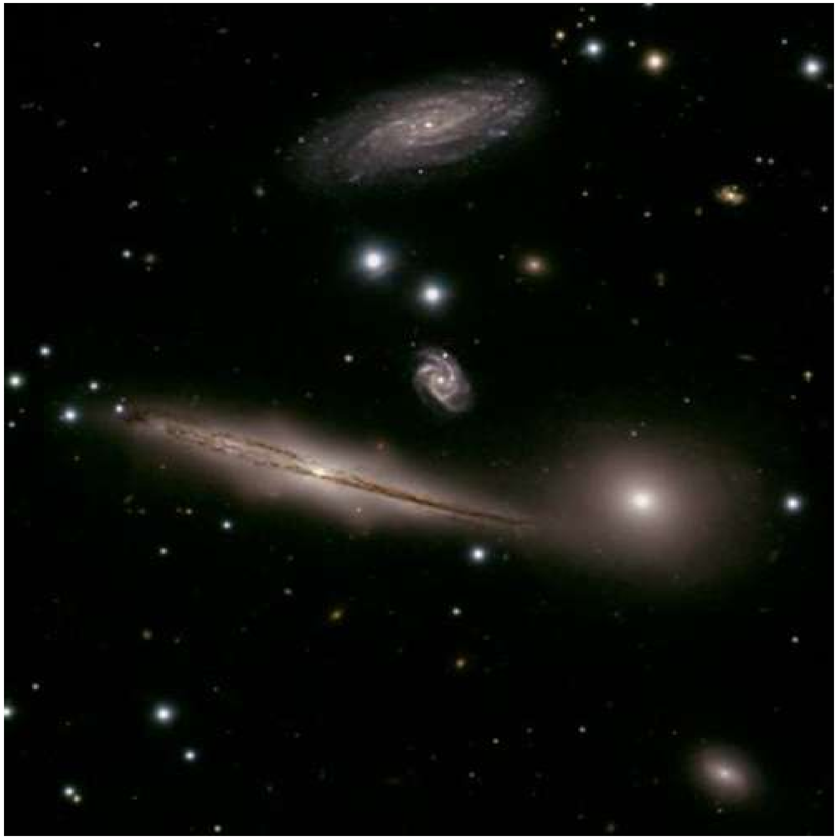


10 million ly
Virgo III Groups
180°
NGC 7582
NGC 6744
NGC 5033
NGC 5128
Local Group
M101
Virgo Cluster
Canes Groups
NGC 4697
270°
90°
Sculptor
Maffei
M81
Leo I
Ursa Major Groups
NGC 1023
NGC 2997
Dorado
0°
Leo II Groups
Fornax Cluster
Eridanus Cluster
r powell

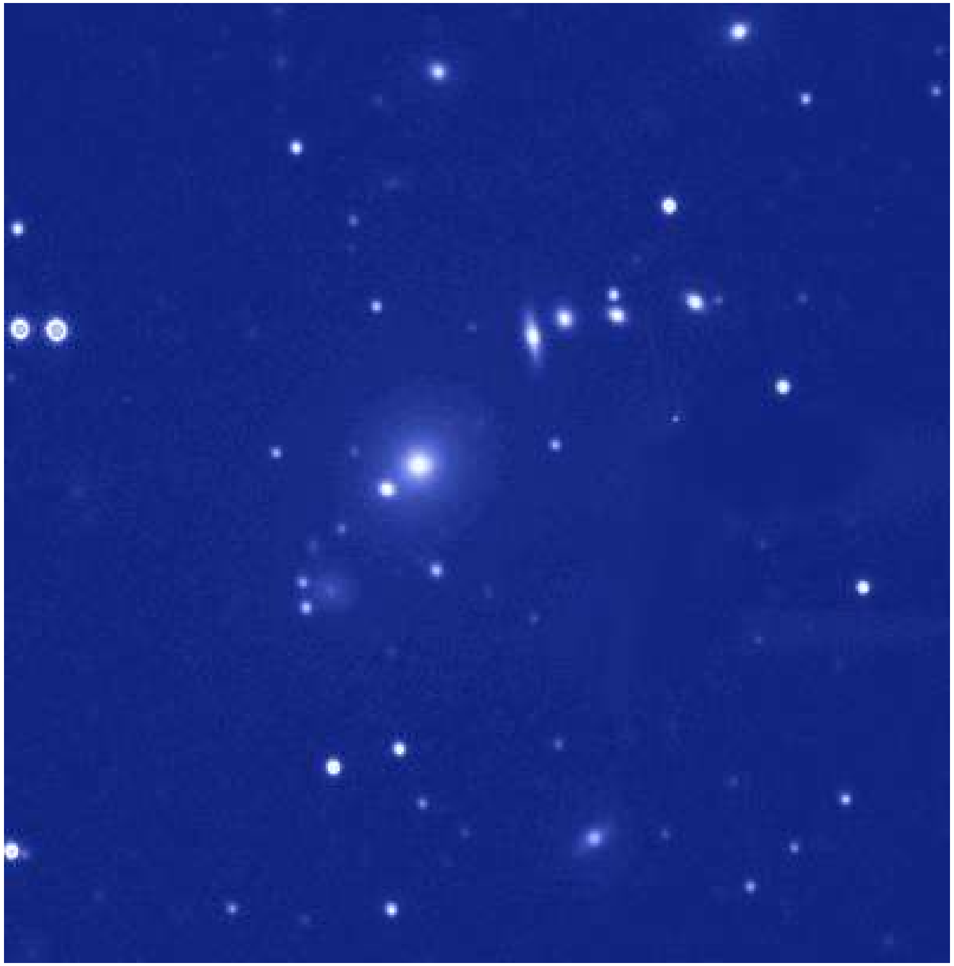


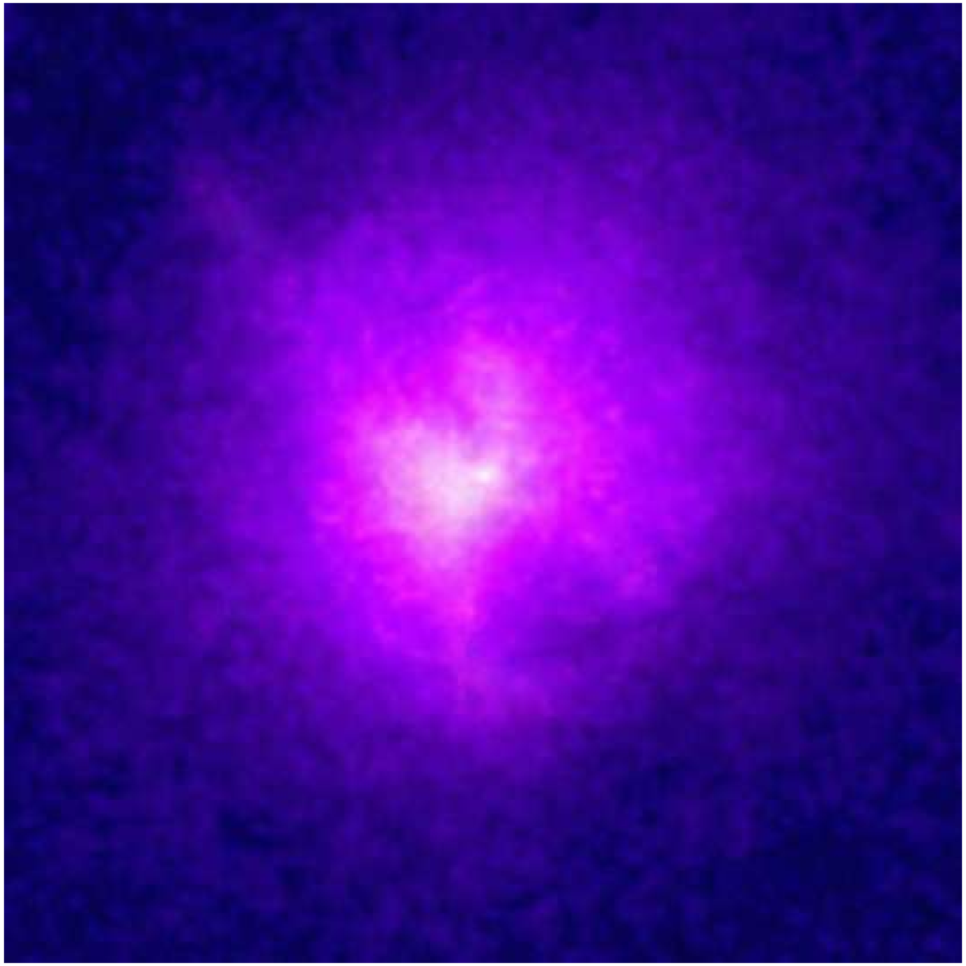
100 million ly
Capricornus Supercluster
Capricornus Void
Corona-Borealis Supercluster
Hercules Superclusters
Bootes Superclusters
Bootes Void
Pavo-Indus Supercluster
180°
Centaurus Supercluster
Shapley Supercluster
Sculptor Superclusters
Sculptor Void
270°
90°
Virgo
Coma Supercluster
Hydra
Ursa Major Supercluster
Pisces-Cetus Superclusters
Perseus-Pisces Supercluster
Leo Superclusters
0°
Horologium Supercluster
Columba Supercluster
Sextans Supercluster
r powell

Gravitationally bound structures: Galaxy Groups and Clusters



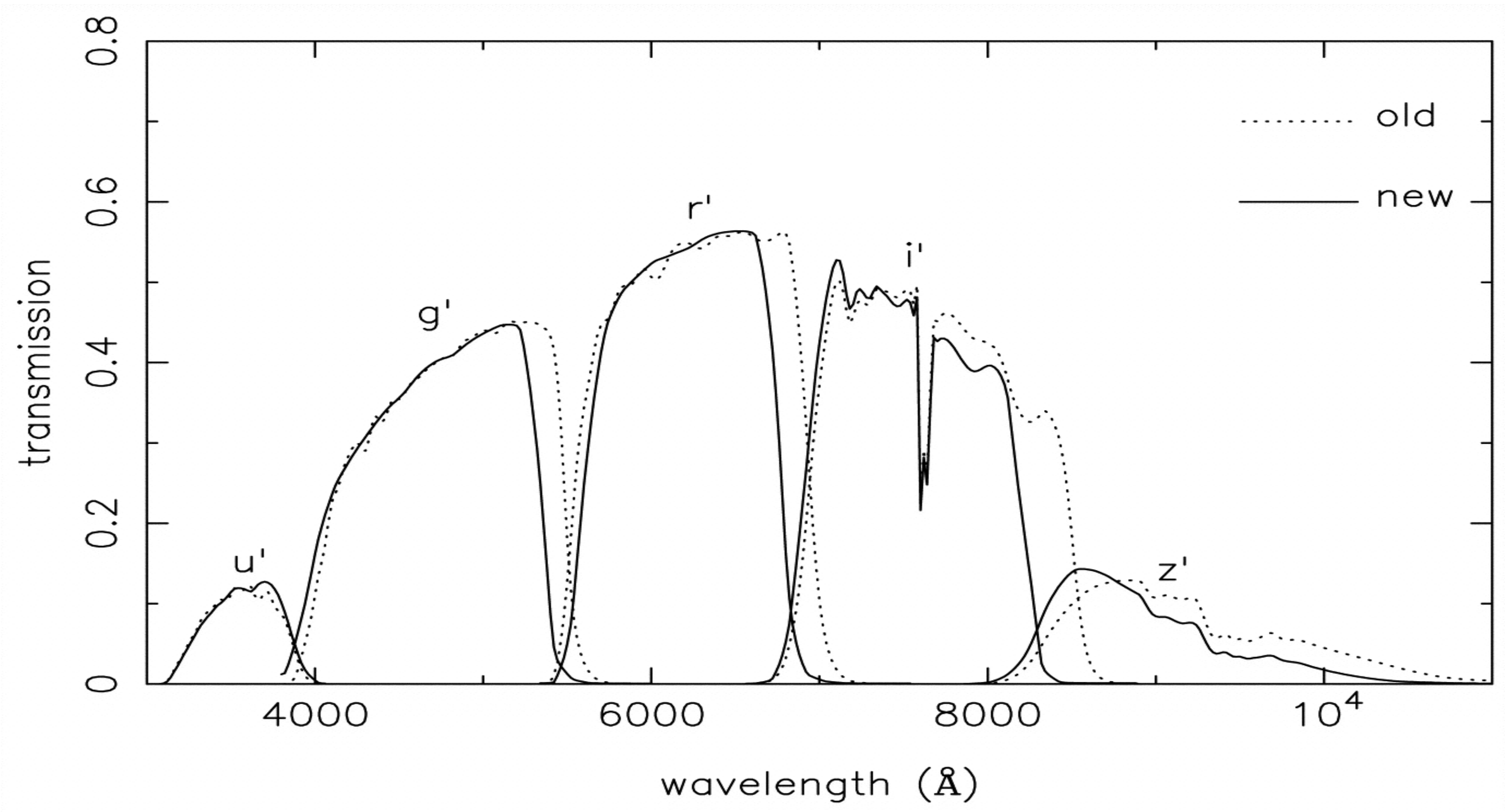
In galaxy clusters, there is 10 times more gas between the galaxies than there is in the galaxies themselves. This gas is very hot (10^6 – 10^7 K) so it shines in the x-rays.



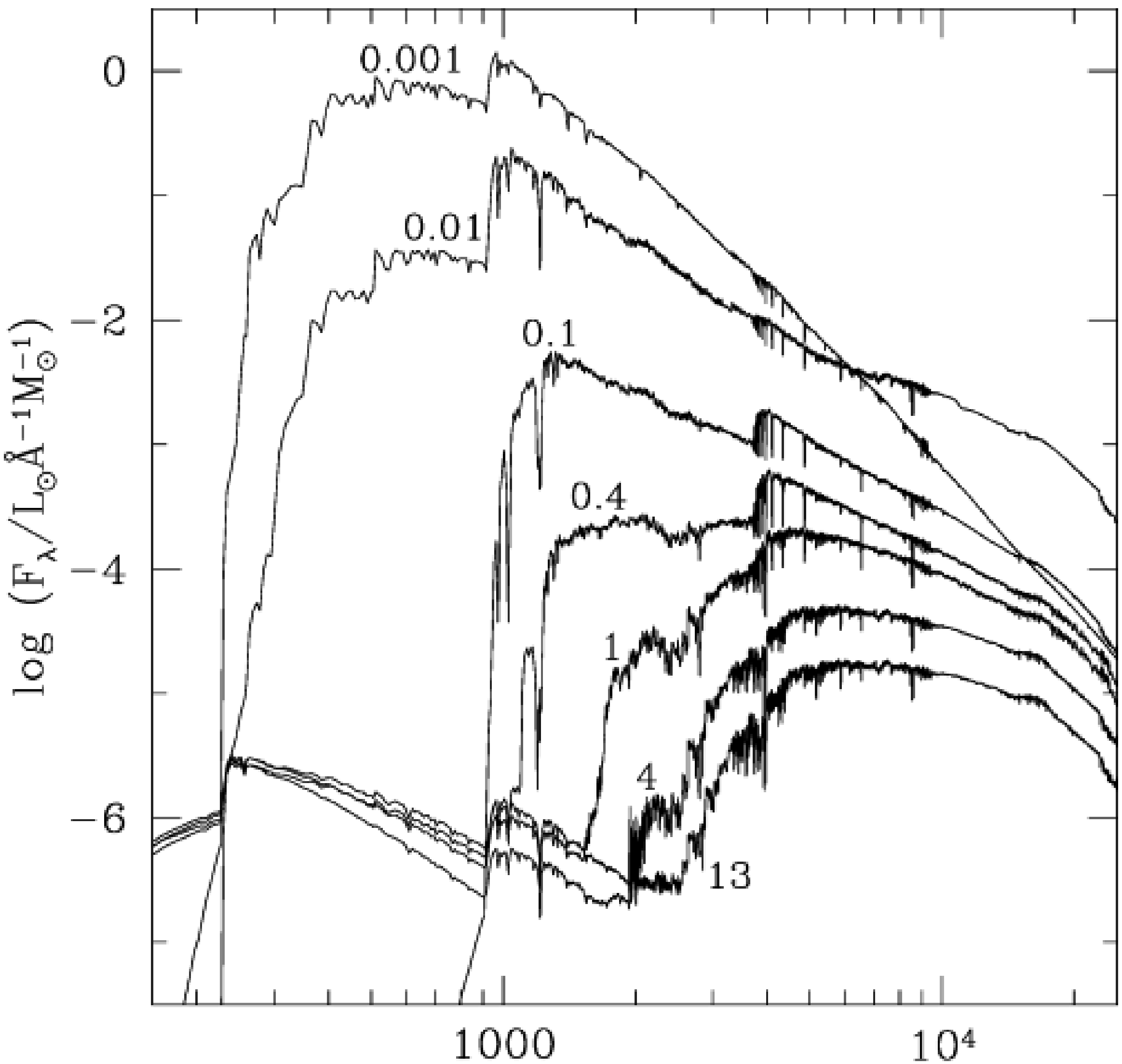


Which galaxy properties can we measure in these large surveys?

1) The total luminosity of the galaxy (in 5 different photometric bands for the SDSS)



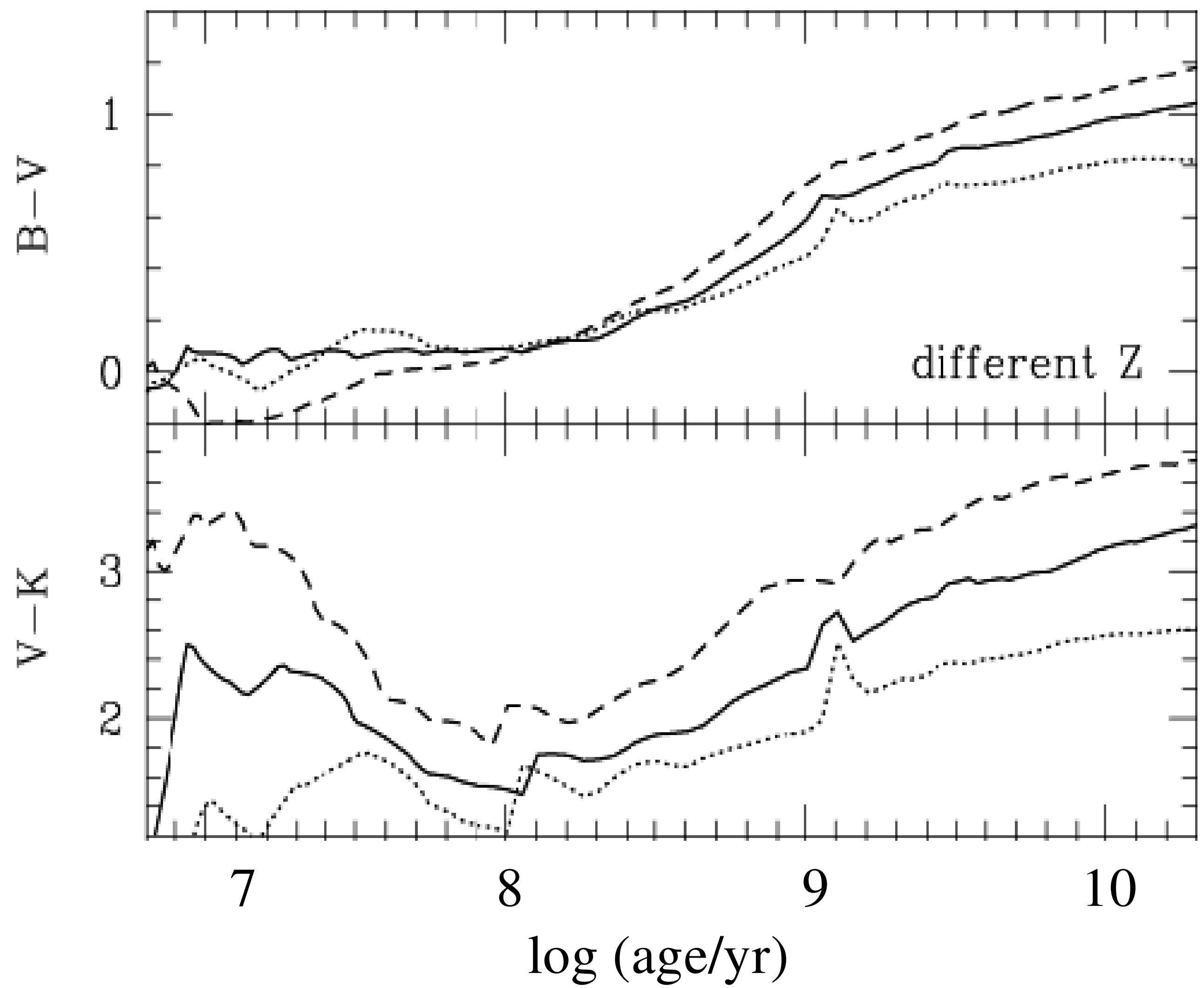
Evolution of the Spectral Energy Distribution of a Collection of Stars as a function of age (in Gigayears)



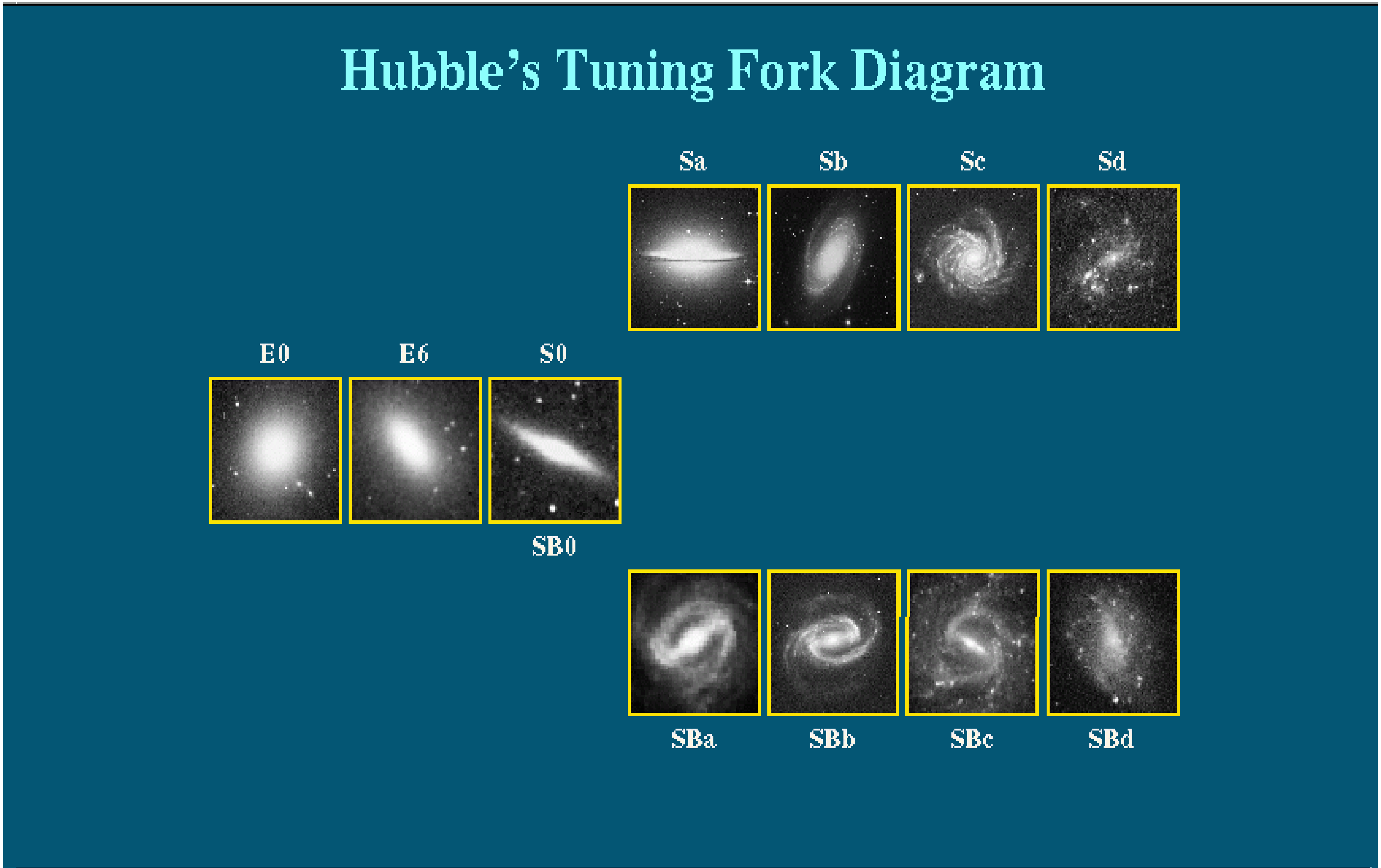
Young galaxies are **BLUE** (more flux at shorter wavelengths)

Older galaxies are **RED** (more flux at longer wavelengths)

Galaxy Colour as a Function of Age and Metallicity



Galaxy "Morphology"



Today's large galaxy surveys require the morphology of the galaxy to be measured not "by eye", but in an automatic fashion.

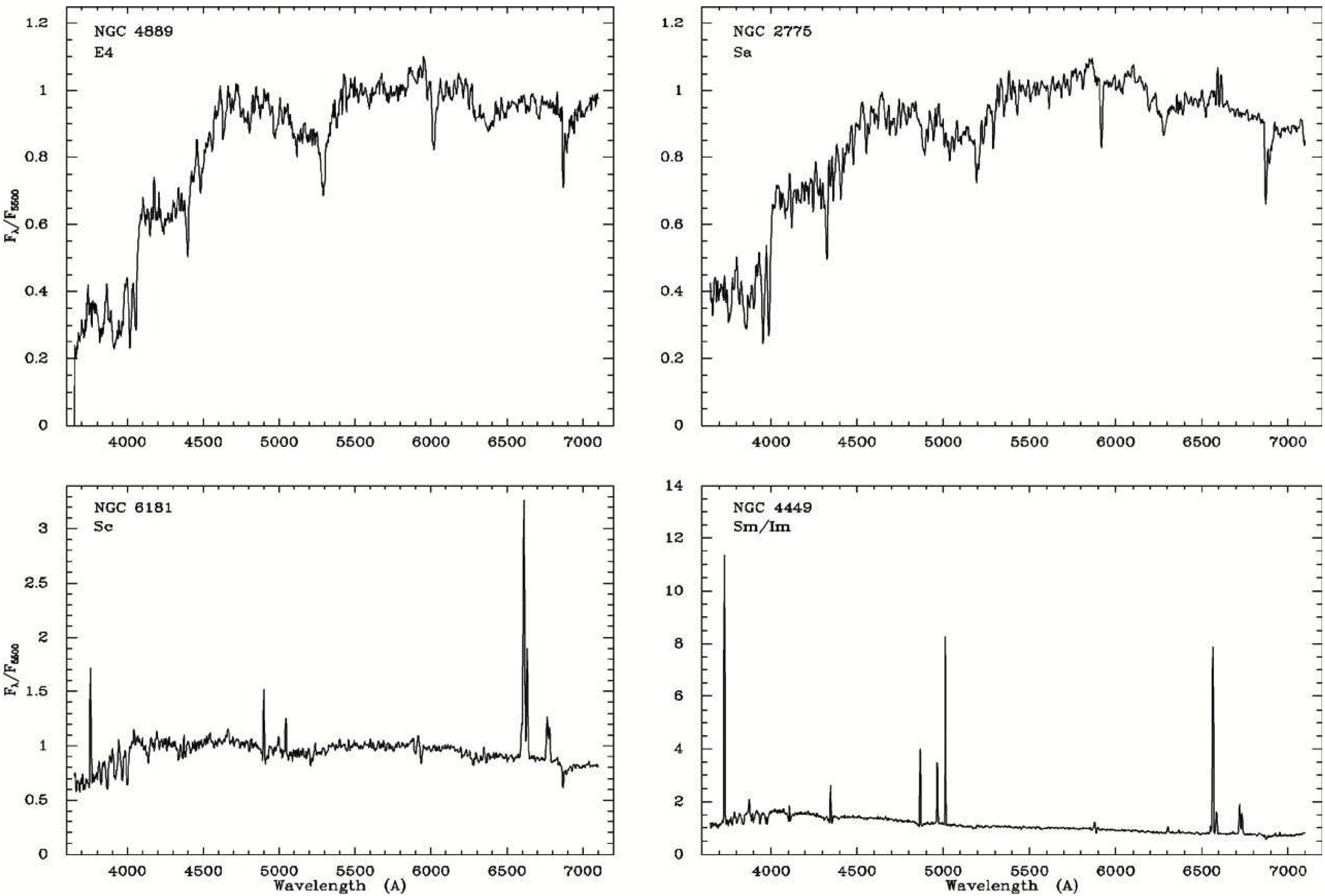
Physical parameters versus revised Hubble type

Type	gE	L	S0/a	Sa	Sab	Sb	Sbc	Sc	Scd	Sd	Sdm	Sm	Im
T	-5	-2	0	1	2	3	4	5	6	7	8	9	10
Δm_I	(a)	0.60	0.74	1.13	1.22	1.62	1.85	2.52	3.43	4.06	> 5	-	-
log C_{31}	0.80	0.74	0.675	0.635	0.595	0.555	0.52	0.50	0.48	0.46	0.45	0.44	0.435

$\Delta m_I = 2.5 \log(L_T/L_I)$ = B-band magnitude difference between total integrated luminosity of $r^{1/4}$ spheroidal component and total luminosity of galaxy. (a) = 0.0 to 0.5:, depending on strength of faint disk component. From Simien and de Vaucouleurs 1986, Table 3A.

C_{31} = B-band concentration index, being the ratio of the diameters of the (circular) apertures transmitting 3/4 and 1/4 of the B-band flux of the galaxy. Derived from RC3, Table 11.

In addition to images, the SDSS survey is obtaining a million high quality galaxy spectra...



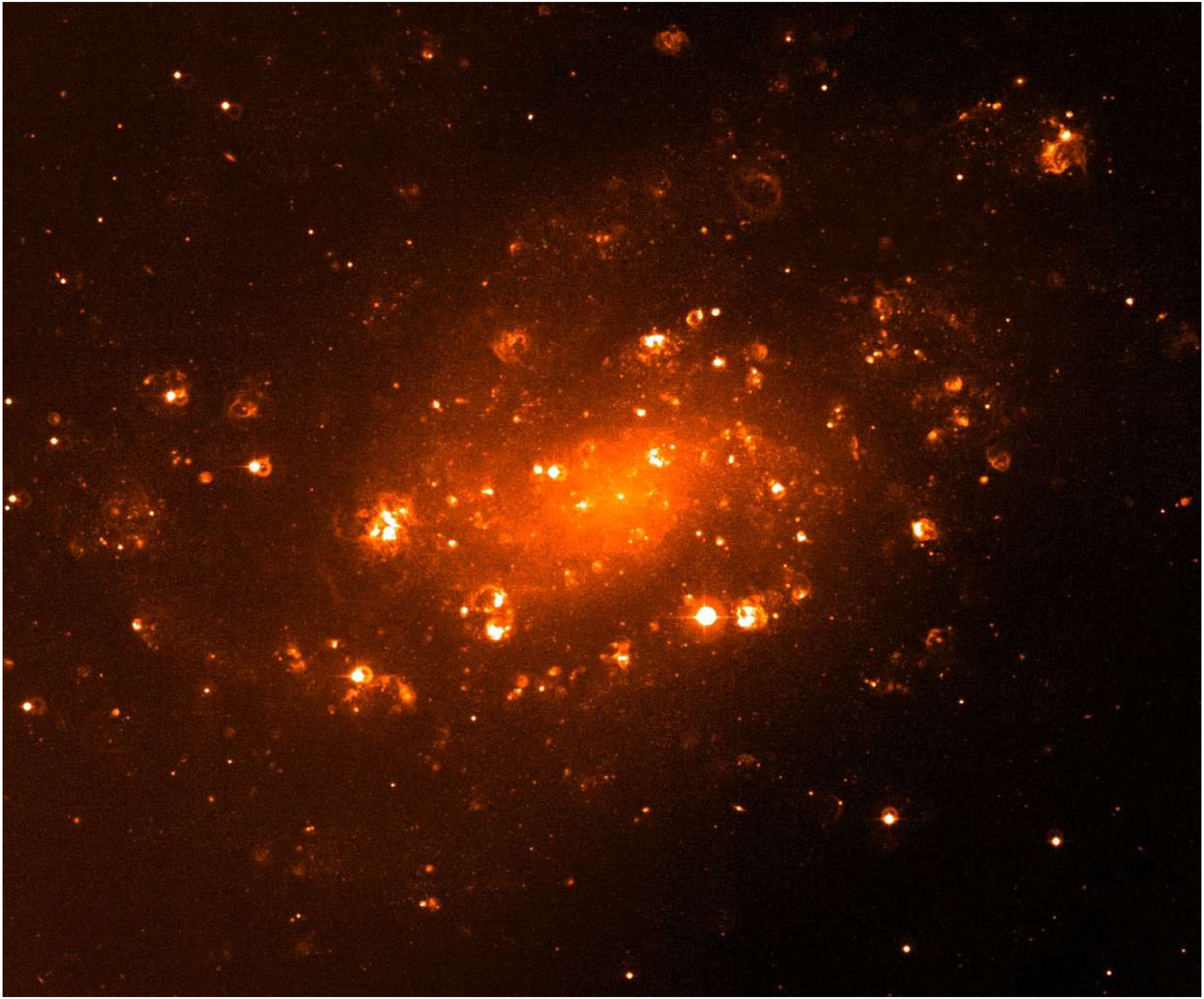
STAR FORMATION

Hydrogen recombination lines (especially Hα in the optical part of the spectrum) are produced in HII regions, zones of ionized gas around young star clusters. Young OB stars are hot enough to produce significant fluxes of ionizing radiation shortwards of the Lyman limit.

In equilibrium, there will be a balance between the photo-ionization and recombination rates, which allows us to measure the ionizing luminosity from a star solely from the intensity of line radiation from the surrounding ionized gas.

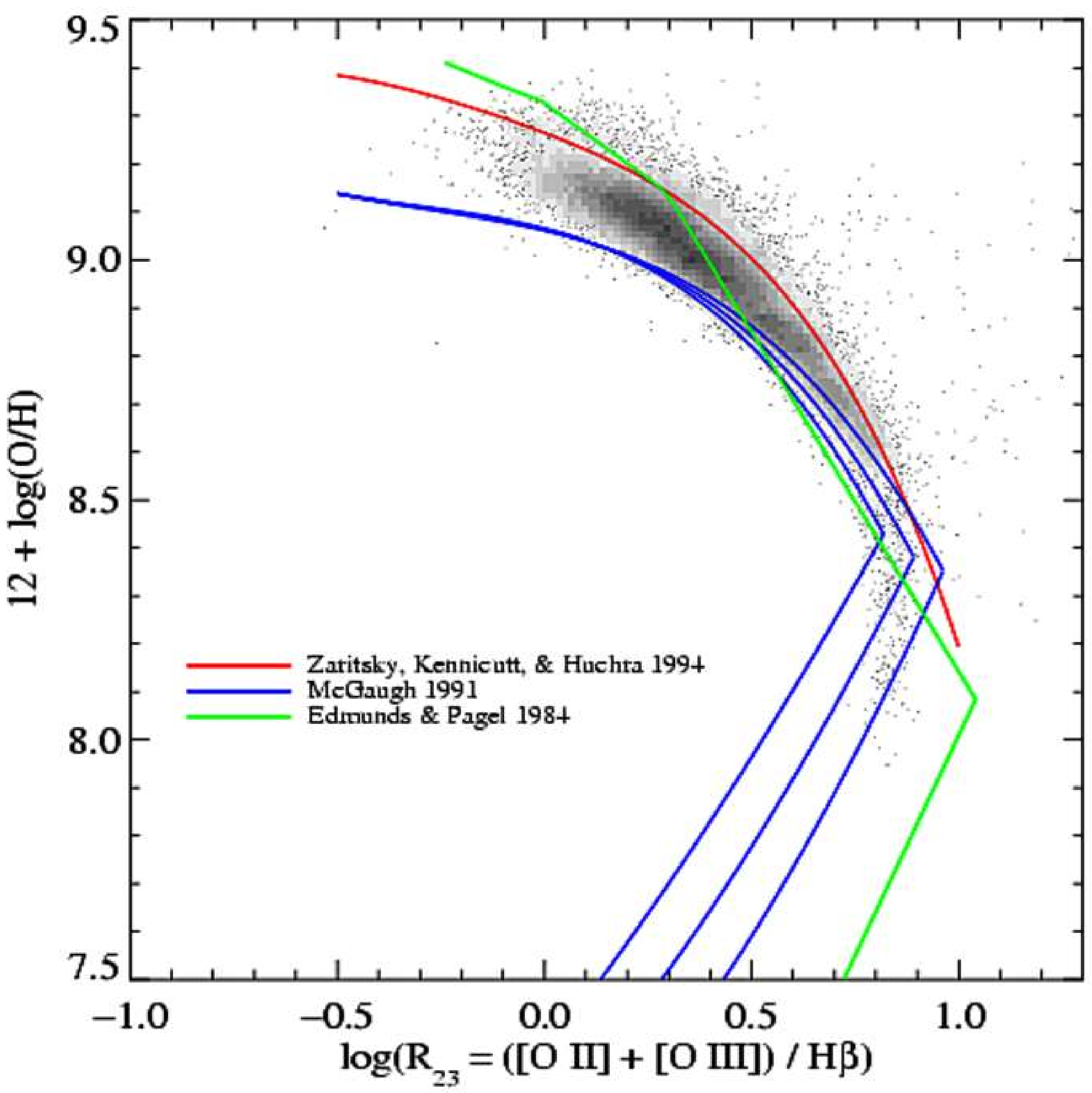
The theory of stellar atmospheres predicts the number of ionizing photons as a function of the temperature of the star and its evolutionary stage.
If we know the mass distribution of the stars that are "born", then we can infer the **STAR FORMATION RATE** from L(Hα).

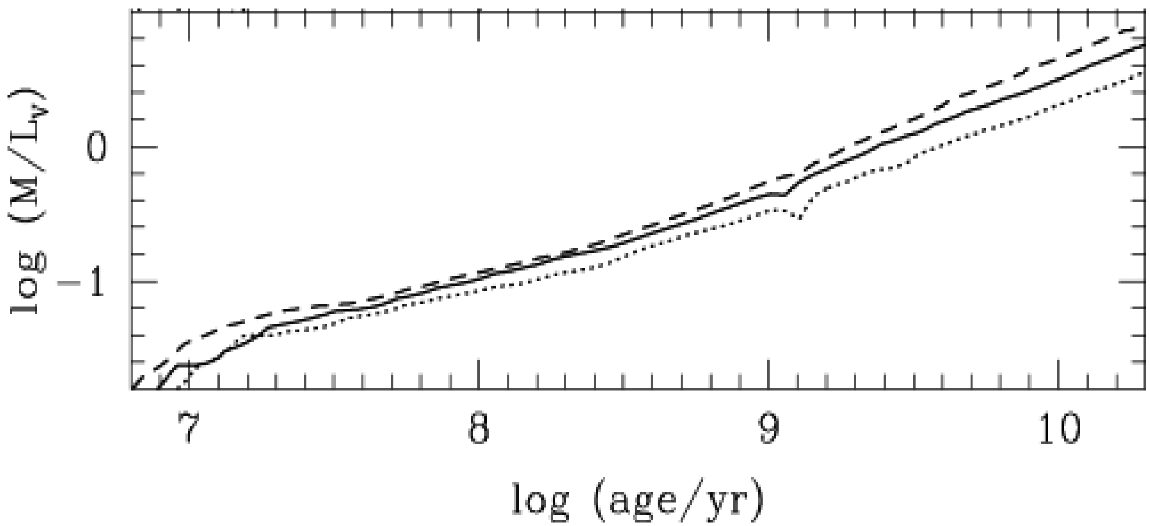
Kennicutt (1983) gives
SFR = L(Hα)/ 1.12 x 10^{41} erg/sec

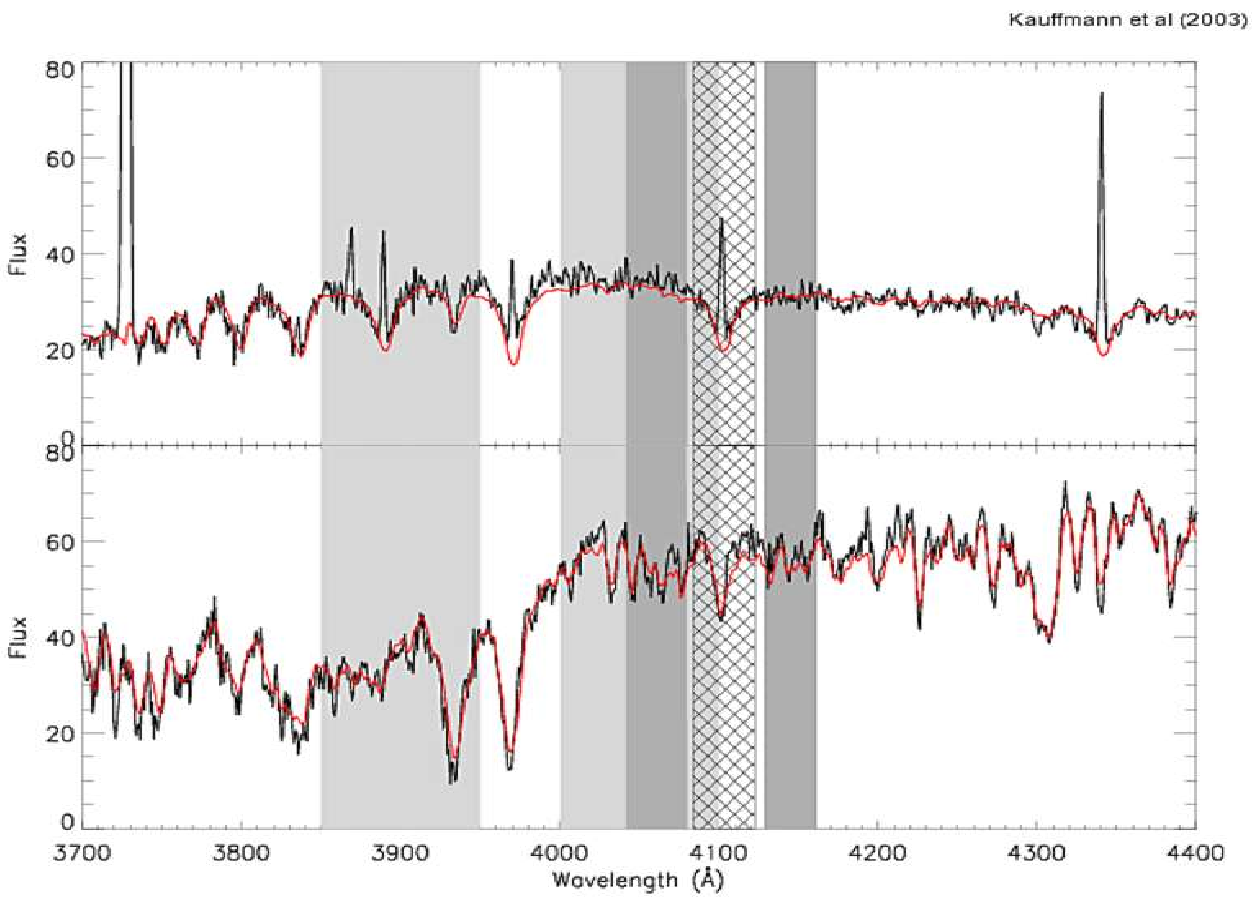


The strengths of other emission lines are sensitive to the METALLICITY of the gas in the HII regions

Tremonti et al (2004)







To transform from luminosity to **STELLAR MASS**, we need to correct for the fact the young galaxies of fixed mass are brighter than old galaxies of the same mass.

Key stellar absorption features in the spectra provide us with an accurate measurement of stellar age.

How do astronomers characterize galaxy properties in a survey?

1) Luminosity function

2) Two point correlation function

3) Galaxy properties as a function of "environment"

4) Relations/correlations between galaxy properties

NEXT TIME: How do these measurements constrain the theory of galaxy formation?

Luminosity Functions of Galaxies

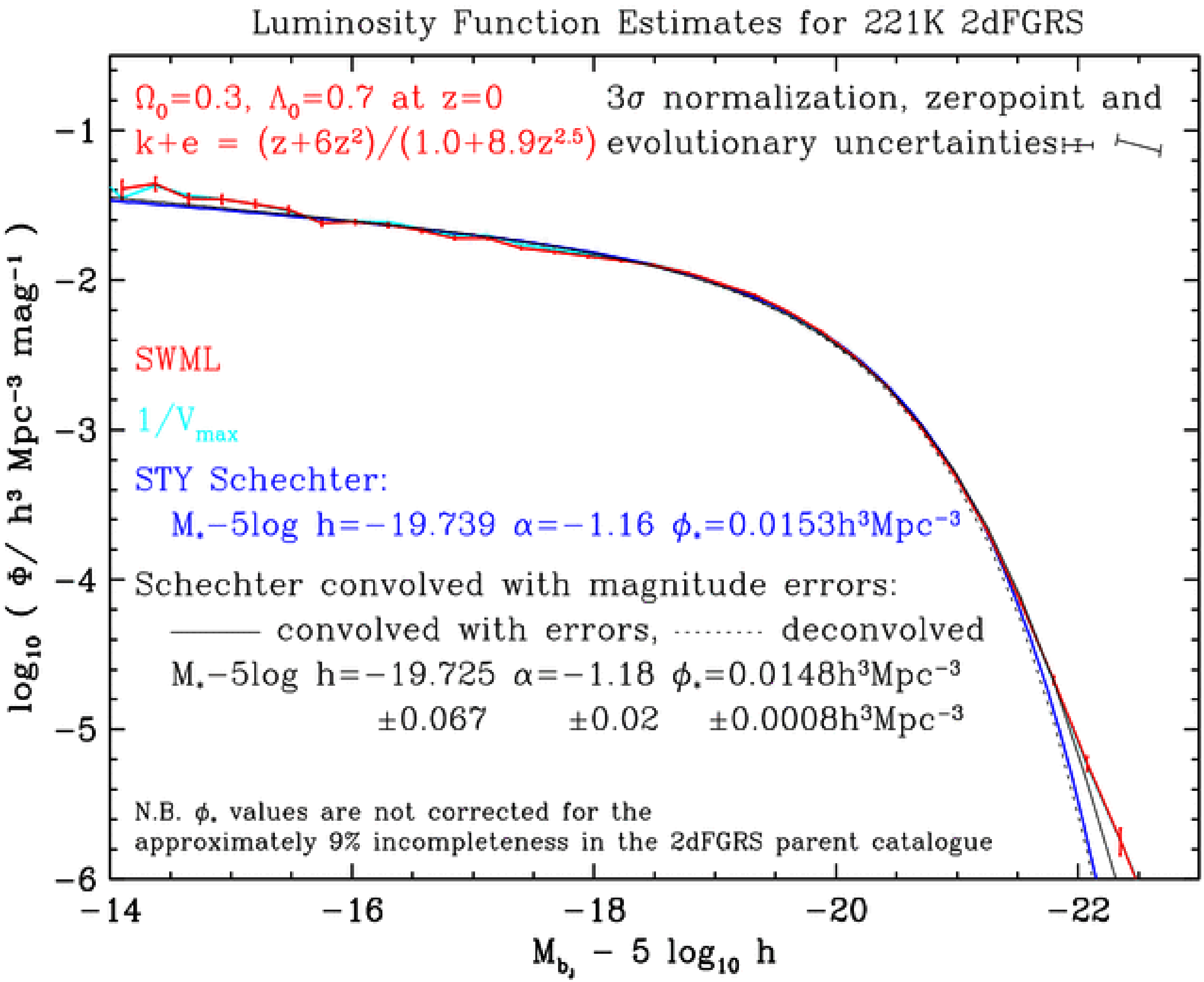
- Schechter (ApJ 203, p297, 1976) proposed a global fitting function for all galaxies (individual types do not follow the Schechter-function)

$$\Phi\left(\frac{L}{L_*}\right) = \Phi_*\left(\frac{L}{L_*}\right)^{\alpha}\exp\left(\frac{-L}{L_*}\right)$$

- typical values (averaged over large volumes)

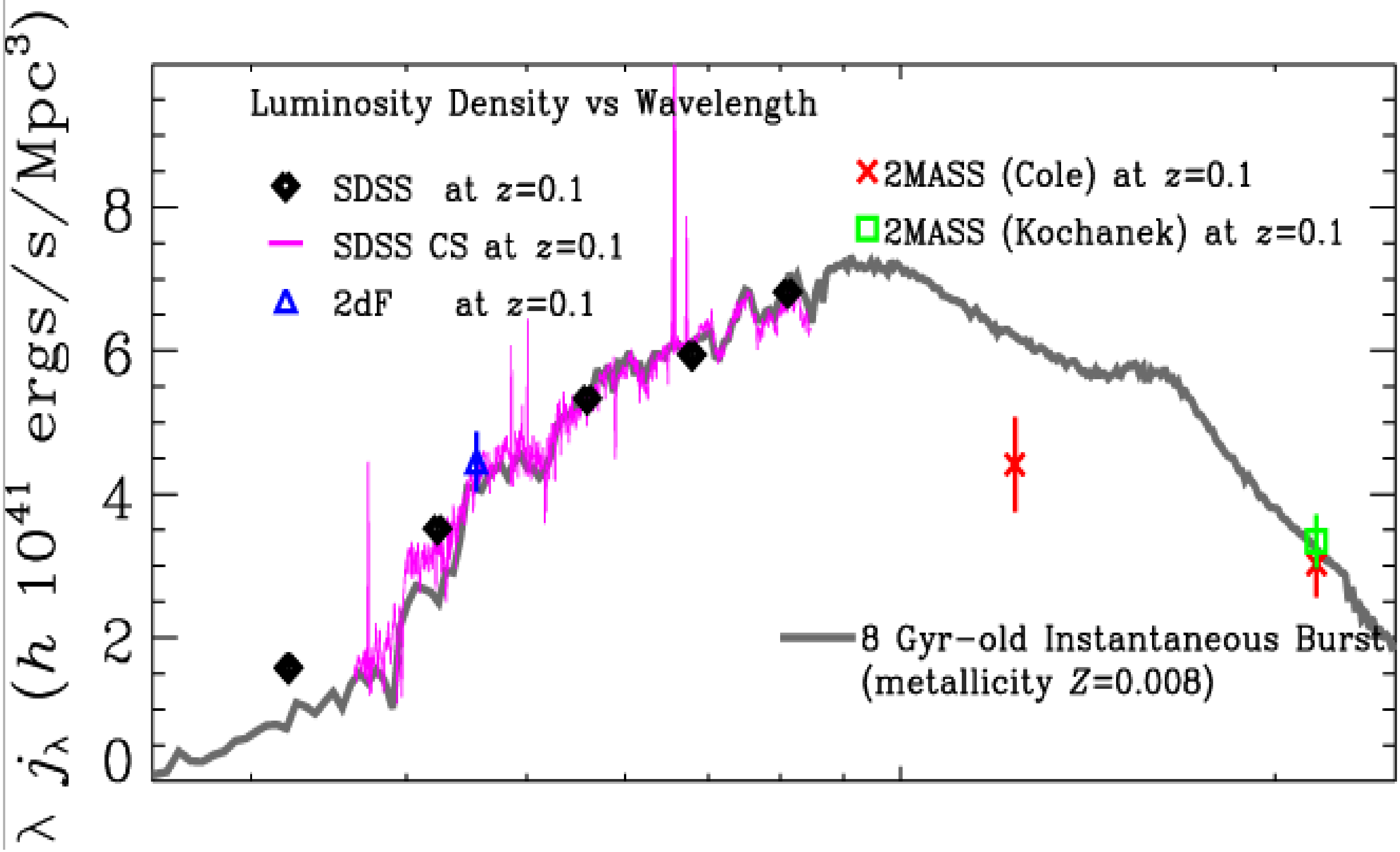
$$\begin{aligned} L_{B,*} &\simeq 10^{10} L_{B,\odot} h^{-2} \\ \text{or: } M_{B,*} &\simeq -19.5 + 5\log h \\ \Phi_* &\simeq 0.01 Mpc^{-3} h^3 \\ \alpha &\simeq -1 \cdots -1.3 \quad \text{(see Peebles 1993)} \end{aligned}$$

with: $h = \frac{H_0}{100\frac{km/s}{Mpc}}$ and $M_B = -2.5\log\frac{L}{L_{B,\odot}} + 5.48$

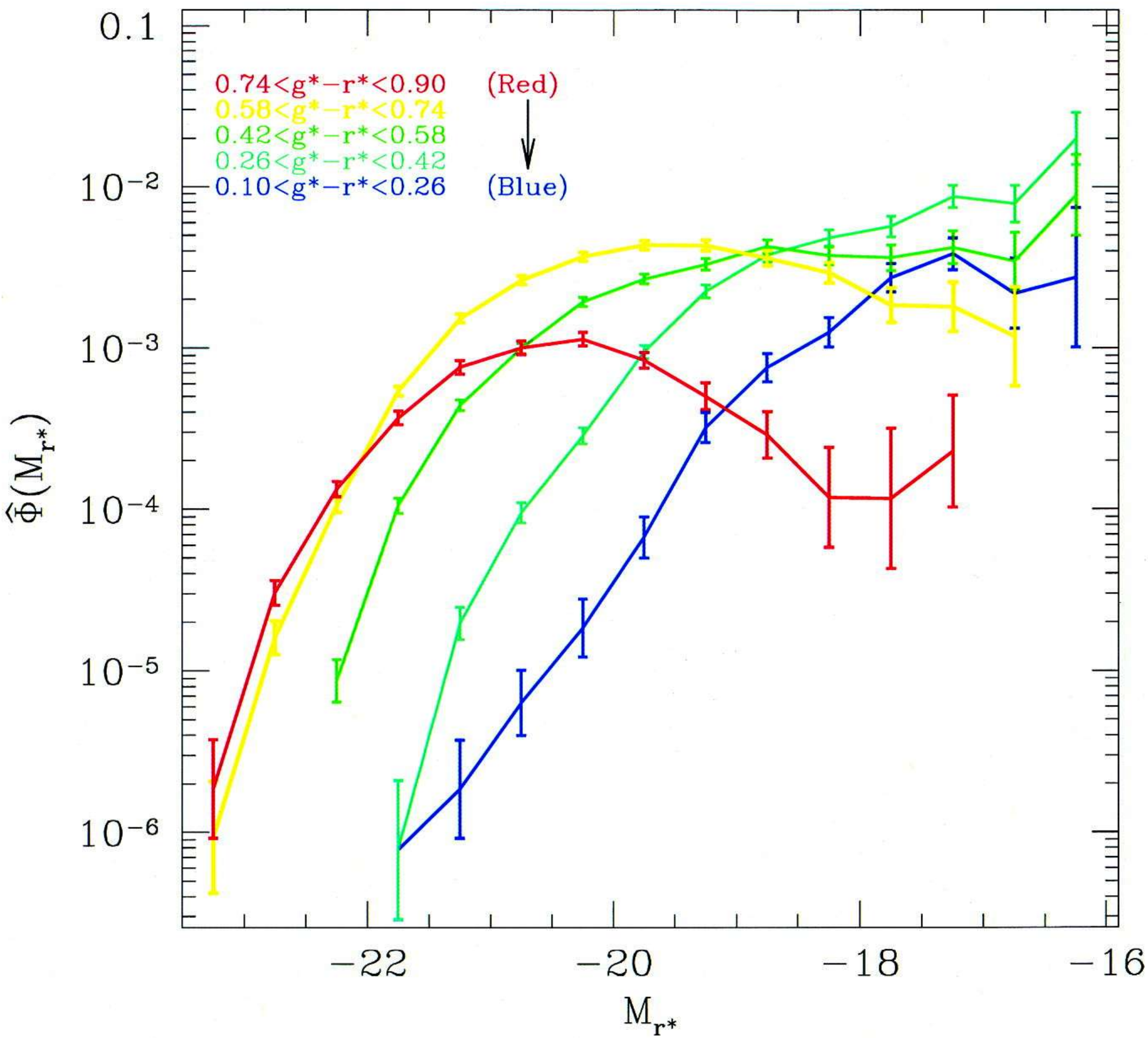


Luminosity Function Estimates for 221K 2dFGRS
Ω_0=0.3, Λ_0=0.7 at z=0
k+e = (z+6z²)/(1.0+8.9z^2.5)
3σ normalization, zeropoint and evolutionary uncertainties
SWML
1/V max
STY Schechter:
M*−5log h=−19.739 α=−1.16 φ*=0.0153h³Mpc⁻³
Schechter convolved with magnitude errors:
convolved with errors, deconvolved
M*−5log h=−19.725 α=−1.18 φ*=0.0148h³Mpc⁻³
±0.067 ±0.02 ±0.0008h³Mpc⁻³
N.B. φ* values are not corrected for the approximately 9% incompleteness in the 2dFGRS parent catalogue
log10 (Φ / h³ Mpc⁻³ mag⁻¹)
M bJ − 5 log10 h
−1
−2
−3
−4
−5
−6
−14
−16
−18
−20
−22

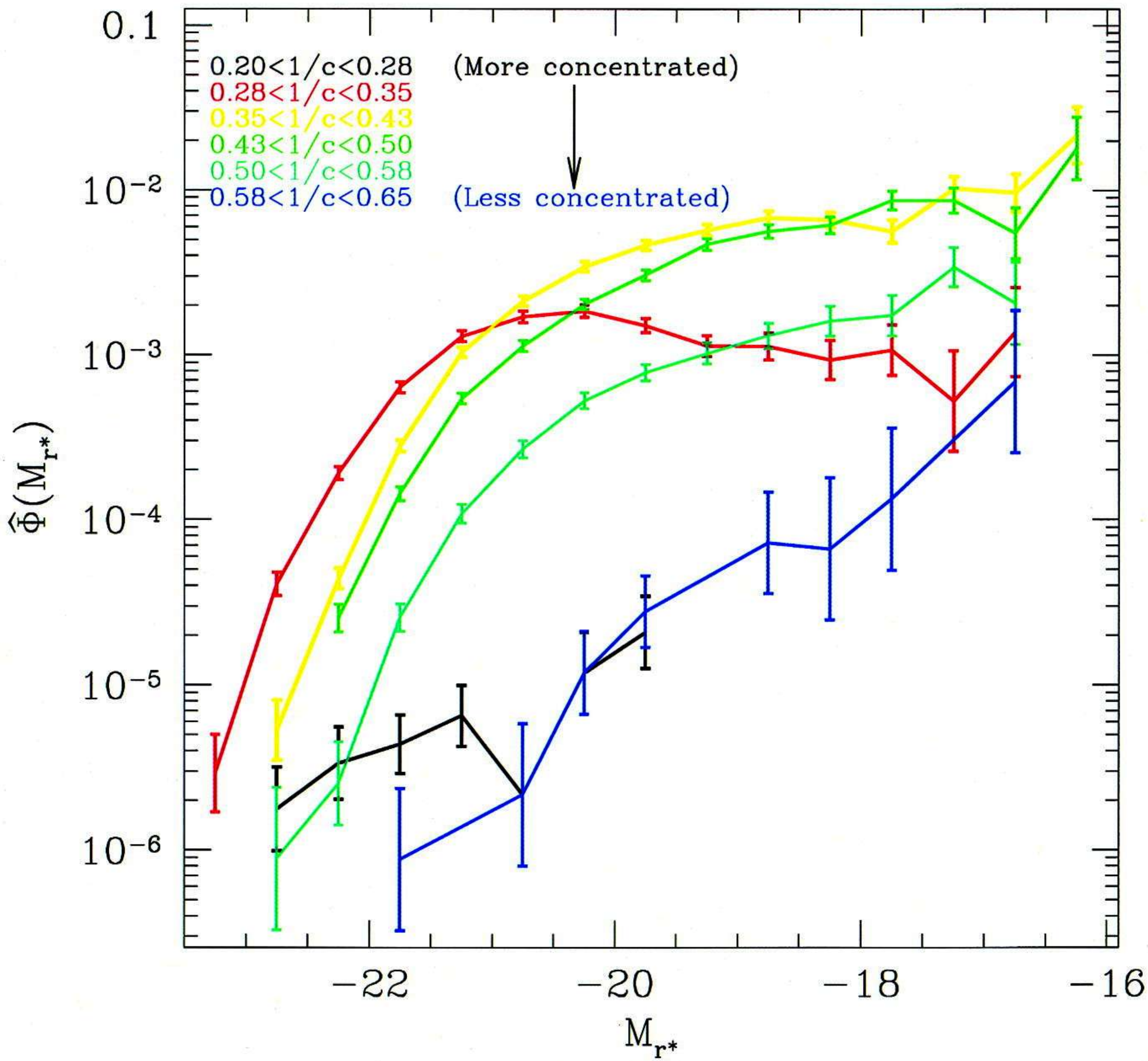
Blanton et al. (2003) (astro-ph/0210215)



The Luminosity Function Split by Galaxy Colour



The Luminosity Function Split by Galaxy Concentration



13.2 The two-point correlation function of galaxies

The two-point correlation function $\xi(r)$ is a quantitative measure of galaxy clustering and is defined via the probability to find pairs of galaxies at a distance r:

$$dN_{pair} = N_o^2(1+\xi(r))dV_1 dV_2$$

where N_o is the mean background density and dV_1 and dV_2 are volume elements around the two positions under consideration.

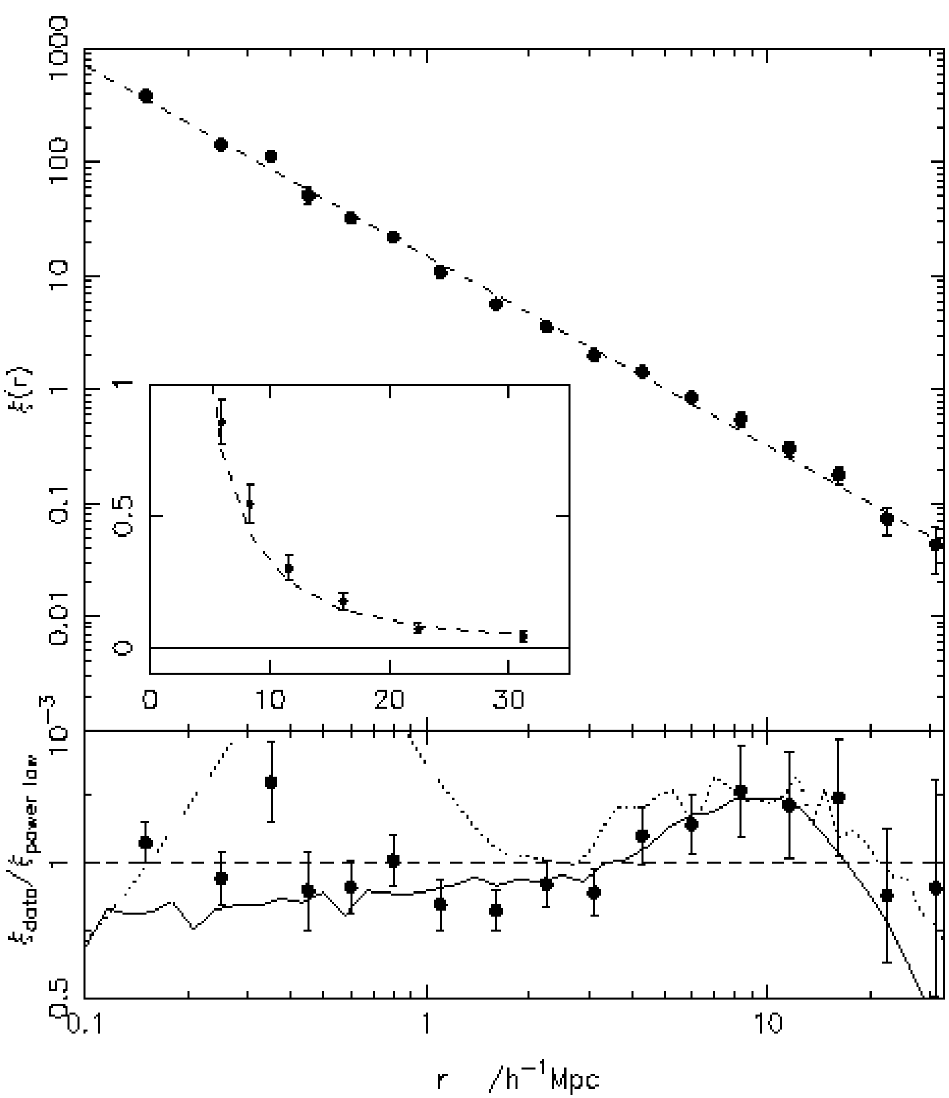
Observationally one obtains averaged over all galaxy types:

$$\xi(r) = \left(\frac{r}{r_o}\right)^{-\gamma}$$

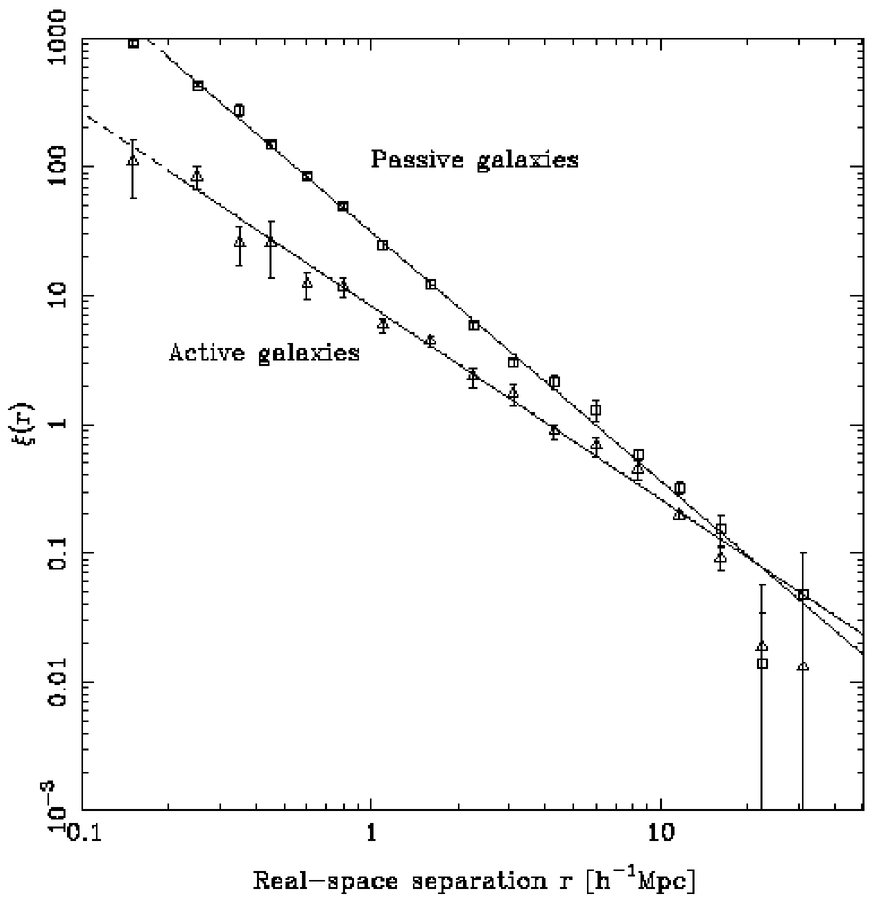
with: $\gamma = 1.8$ and $r_o = 5/h$Mpc ($h = H_o/100$km/s/Mpc) which is valid for scales from 100kpc to 10Mpc. Beyond 10Mpc the correlation function falls more rapidly.

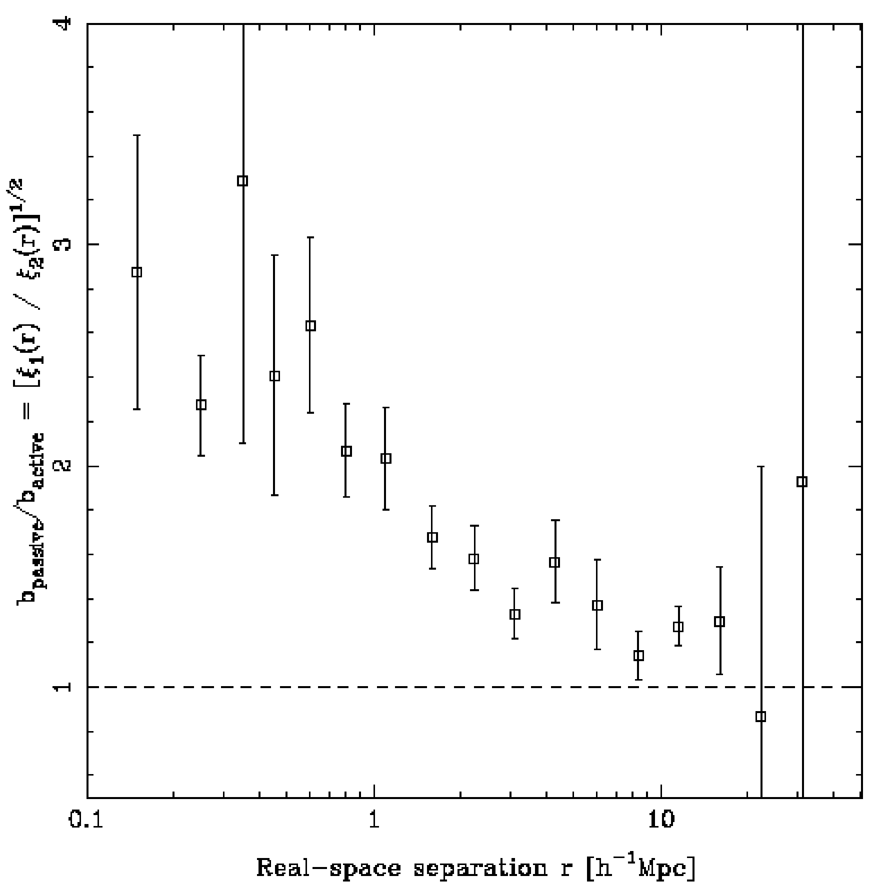
Recent determinations of the 2-point correlation function

Survey	r_0 (h^{-1} Mpc)	γ_r
2dFGRS (P)	4.95 ± 0.25	1.72 ± 0.04
2dFGRS (I)	5.05 ± 0.26	1.67 ± 0.03
SAPM	5.1 ± 0.3	1.71 ± 0.05
ESP	4.15 ± 0.2	$1.67^{+0.07}_{-0.09}$
Durham UKST	5.1 ± 0.3	1.6 ± 0.1
LCRS	5.06 ± 0.12	1.86 ± 0.03
SDSS	6.14 ± 0.18	1.75 ± 0.03



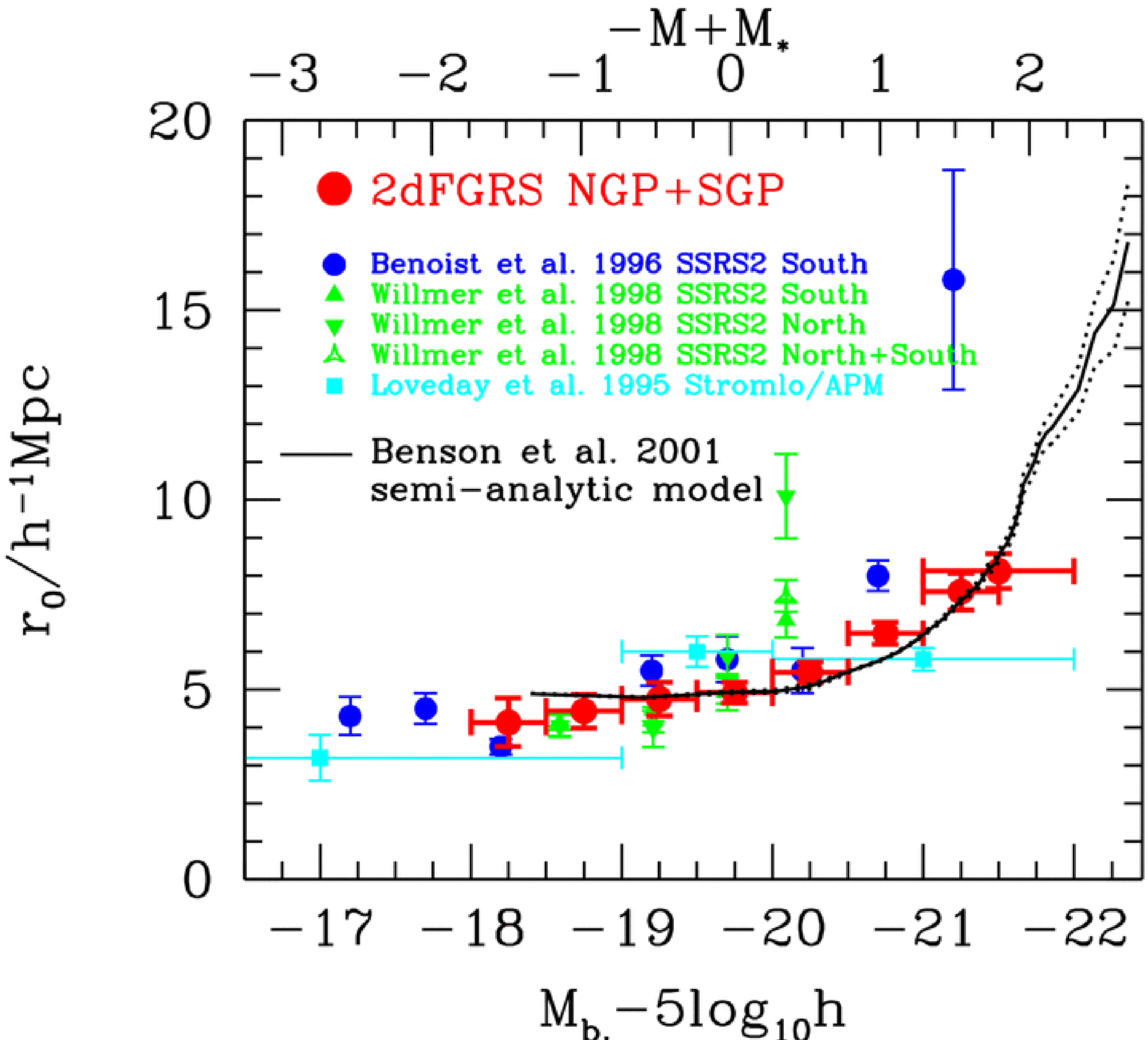
The correlation function depends on colour/spectral type





Madgwick et al
2001

The 2dF Galaxy Redshift Survey
Luminosity dependence of galaxy clustering



Norberg et al. (the 2dFGRS team) 2001, astro-ph/0105500

The Effect of Environment on the Properties of Galaxies

Different ways to define "evironment":

1) Distance to the n'th nearest neighbour, with n =3 to 10.

2) Counts of galaxies with a given aperture.

3) Distance from the centers of clusters (where the center is usually given by the position of the brightest cluster galaxy).

4) The velocity dispersion/mass of the group or cluster where the galaxy is found.

Distance to n'th nearest neighbour:

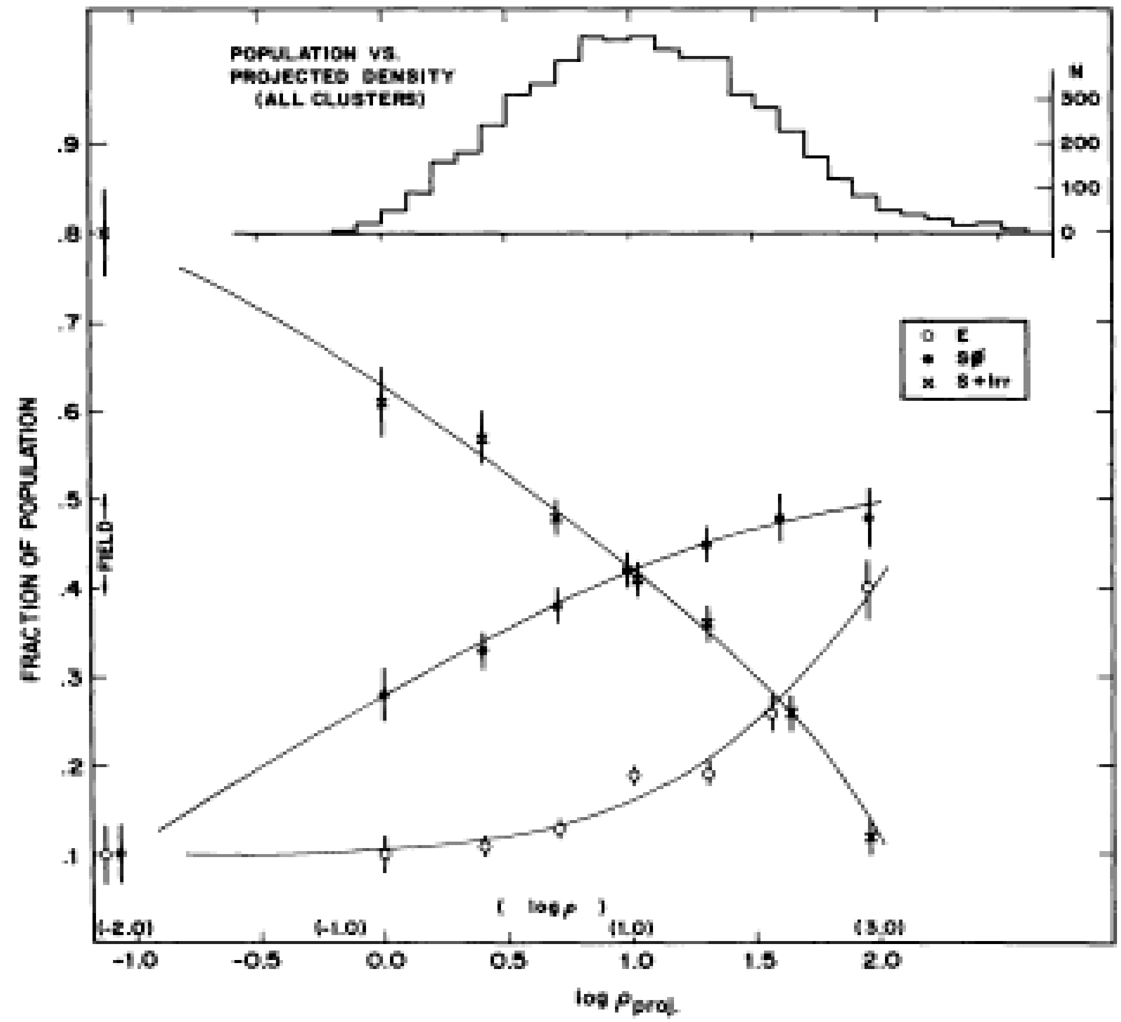
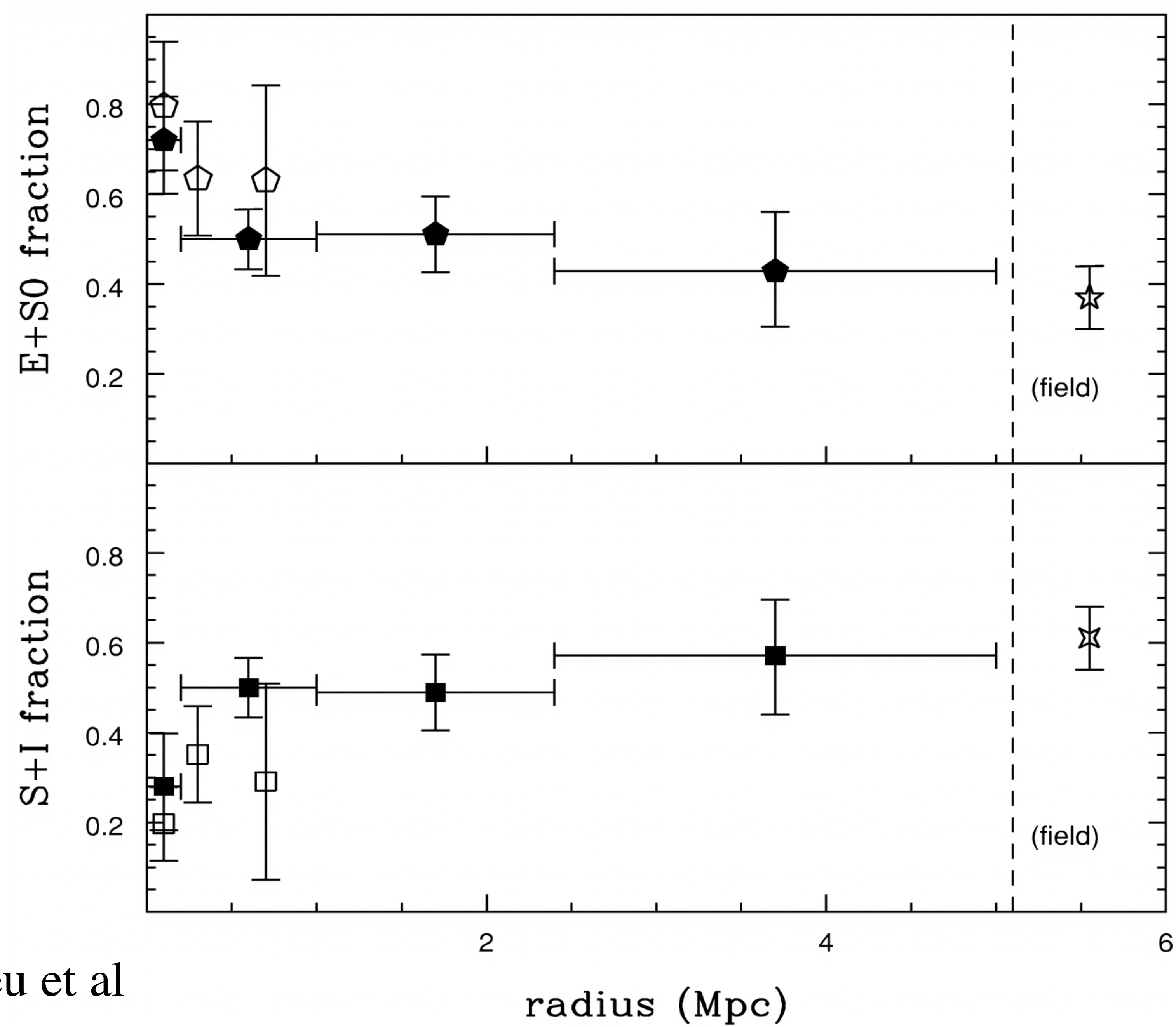


FIG. 4.—The fraction of E, S0, and S+I galaxies as a function of the log of the projected density, in galaxies Mpc^{-2}. The data shown are for all cluster galaxies in the sample and for the field. Also shown is an estimated scale of true space density in galaxies Mpc^{-3}. The upper histogram shows the number distribution of the galaxies over the bins of projected density.

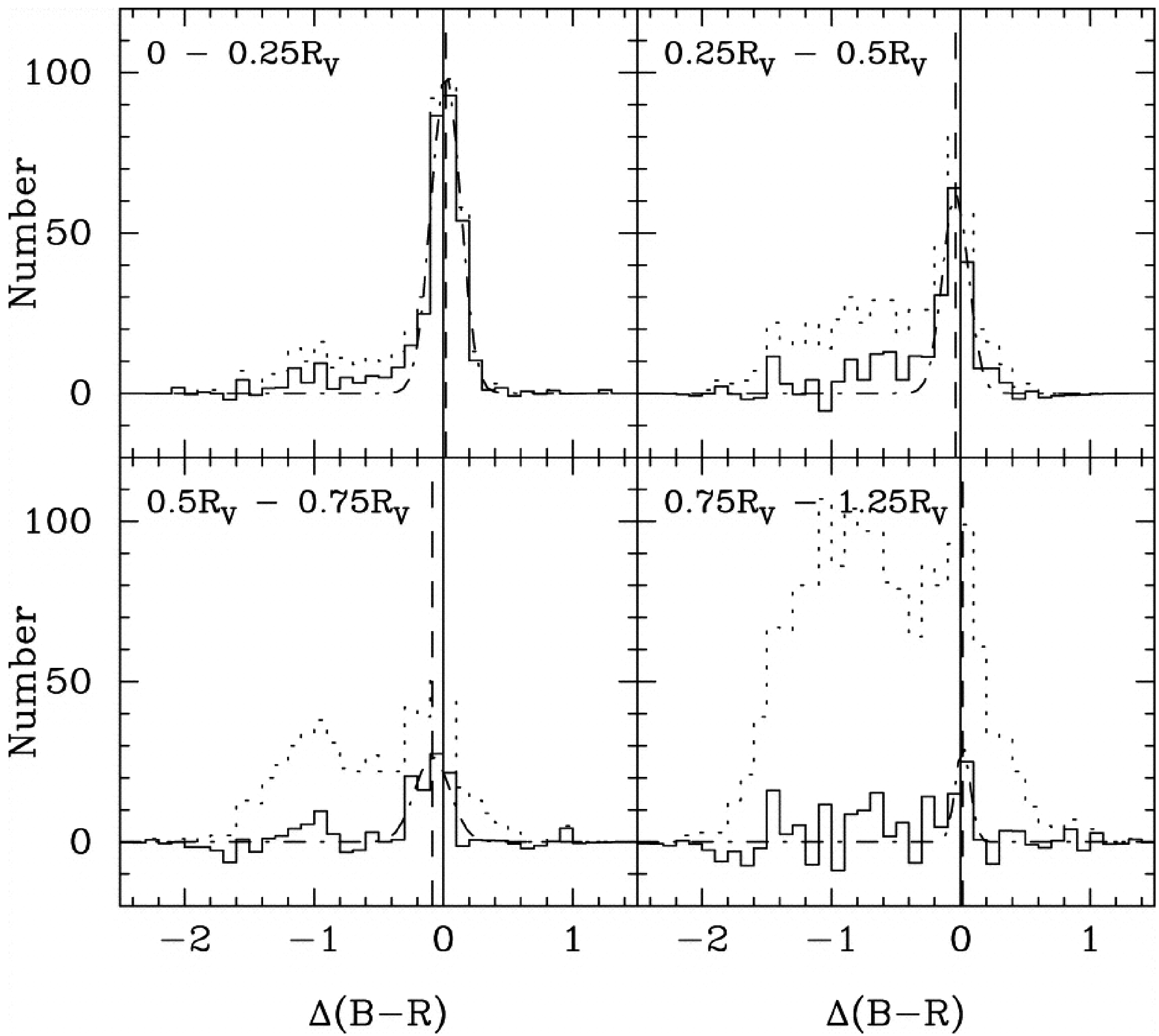
Morphology-density relation (Dressler 1980)

Distance as a function of clustercentric radius....

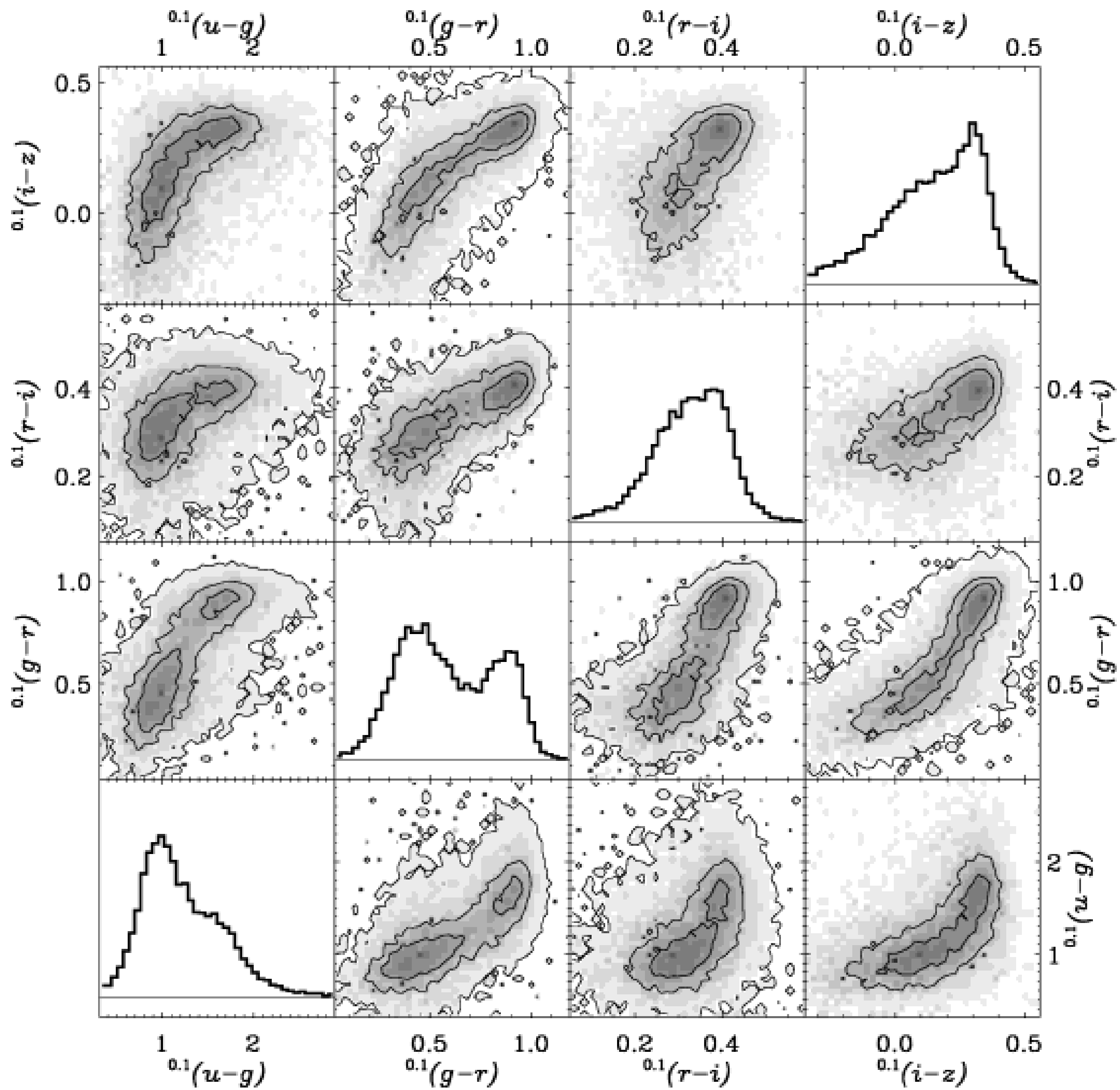


Treu et al

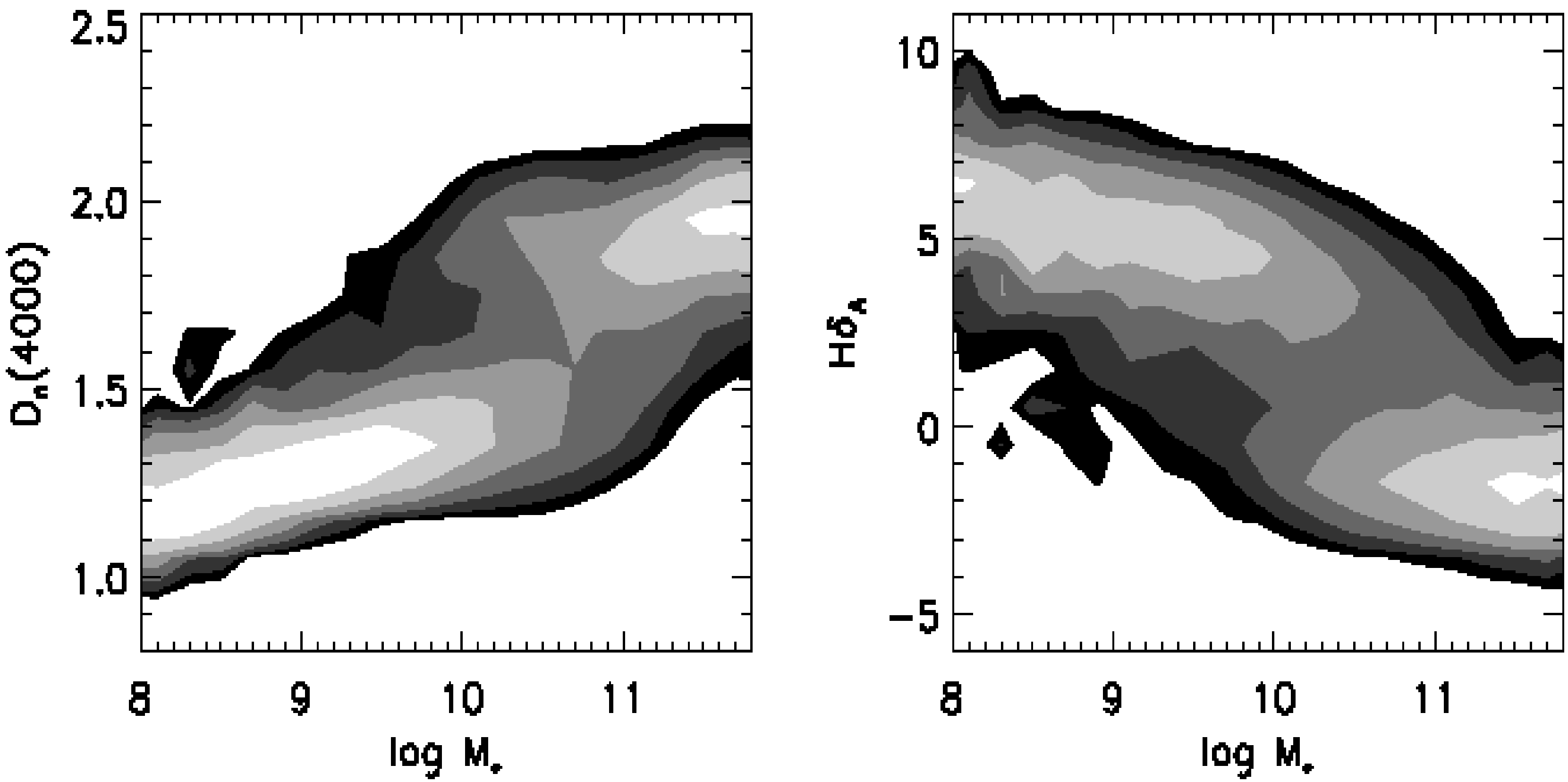
Colour distributions as a function of clustercentric radius



Bimodality in colour-colour space



Stellar age indicators as a function of stellar mass

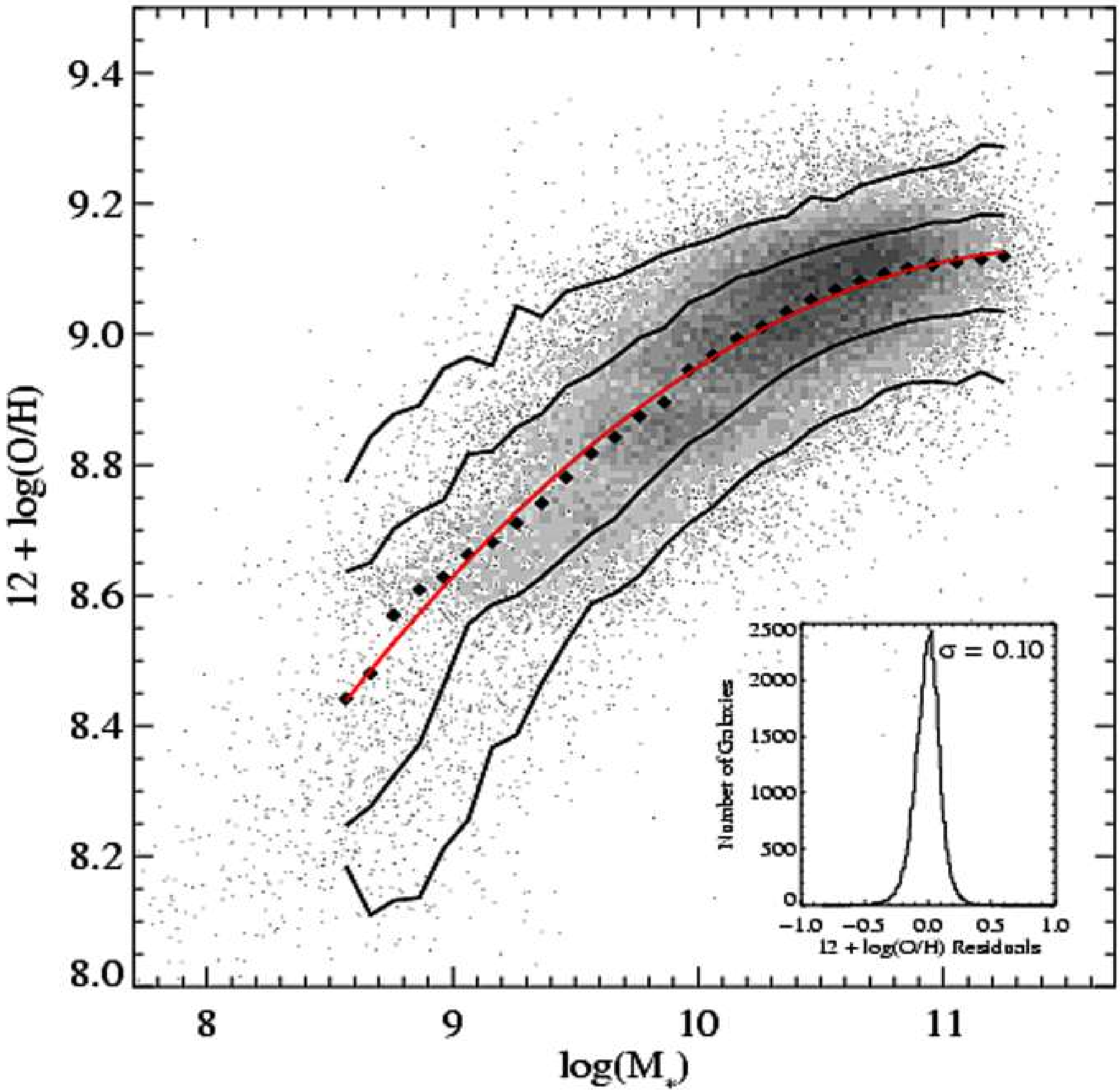


Kauffmann et al 2003

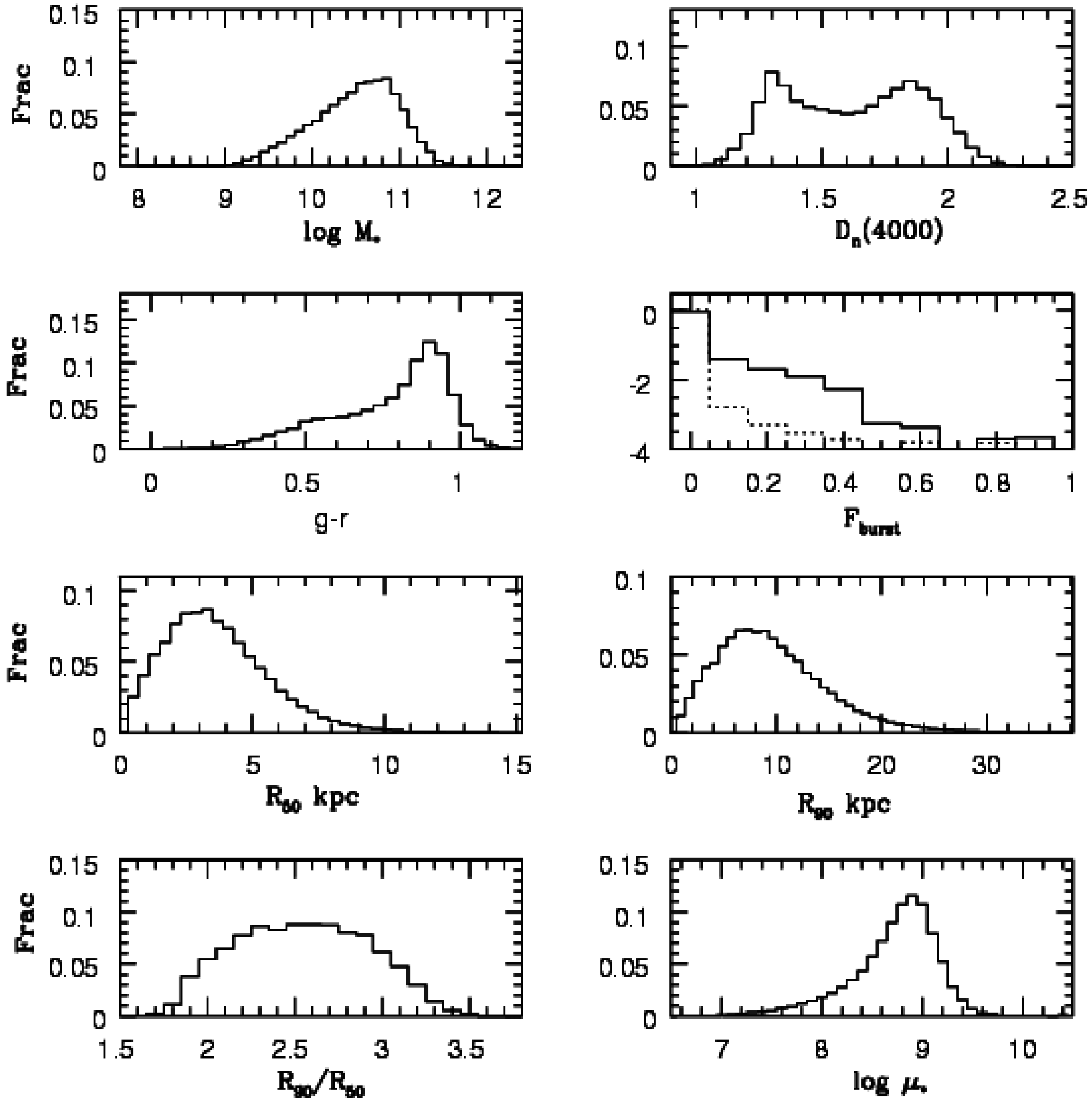
There is a strong transition from young to old at a stellar mass of 3×10^{10} M_sun

Relation between Metallicity and Stellar Mass

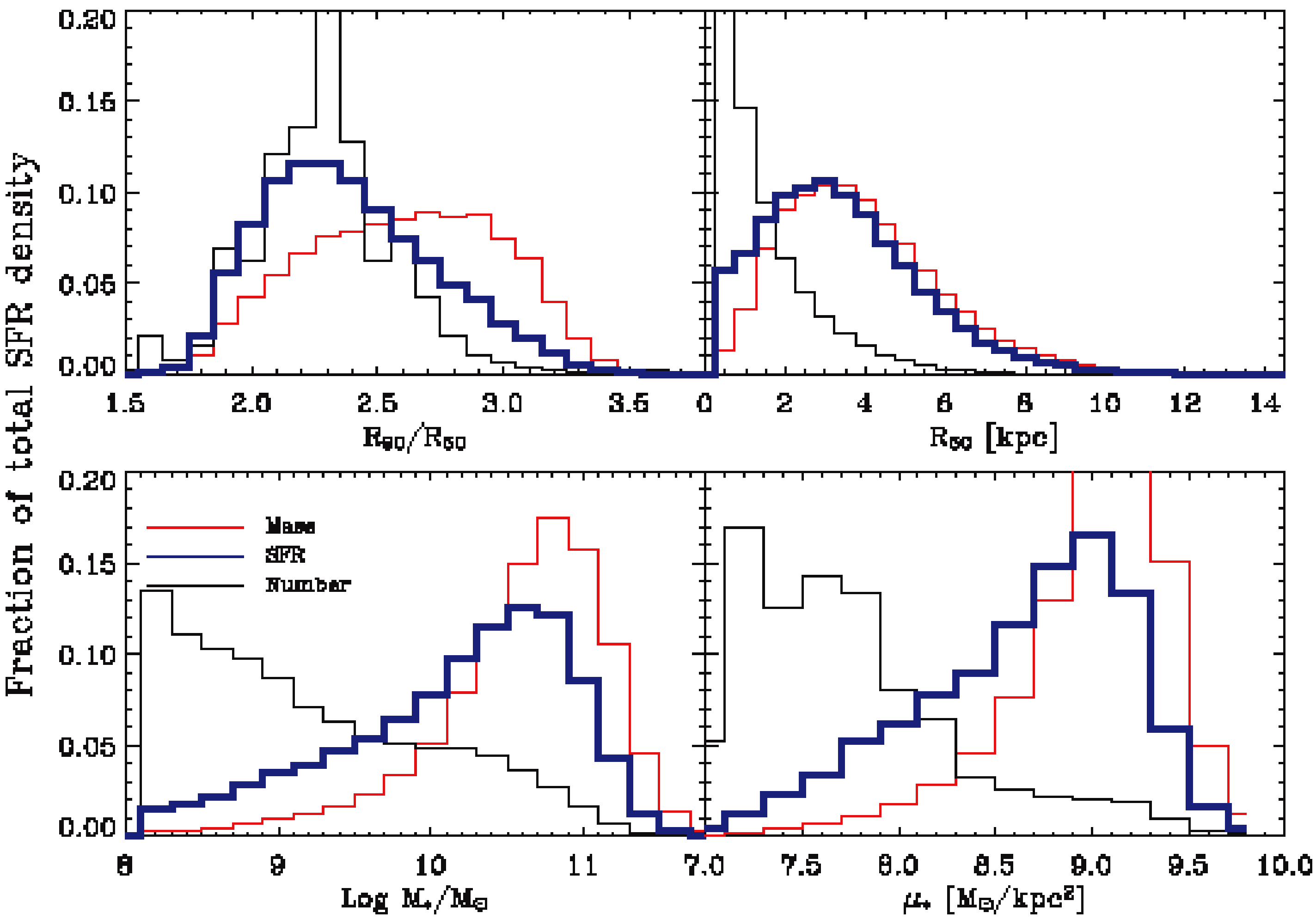
Tremonti et al (2004)



Inventory of the Stellar Mass in the Local Universe



Where is the Star Formation Occurring?



Brinchmann et al