Topics in extra-galactic astronomy

Introduction

Astronomy 580: Topics in extra-galactic astronomy

When: Mondays and Thursdays at 2.00-3.30pm.

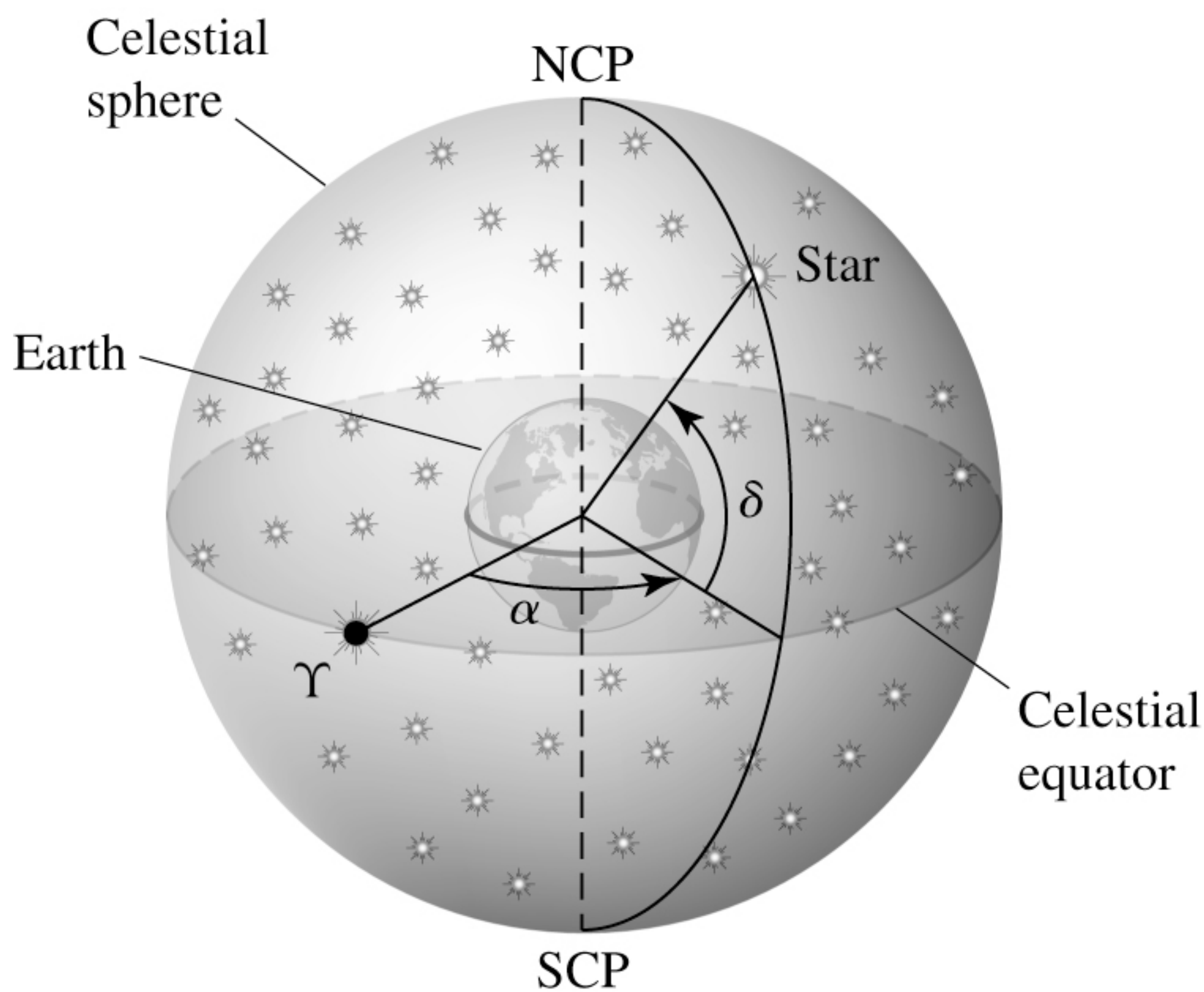
Where: Chart Room.

Lecturers and titles:

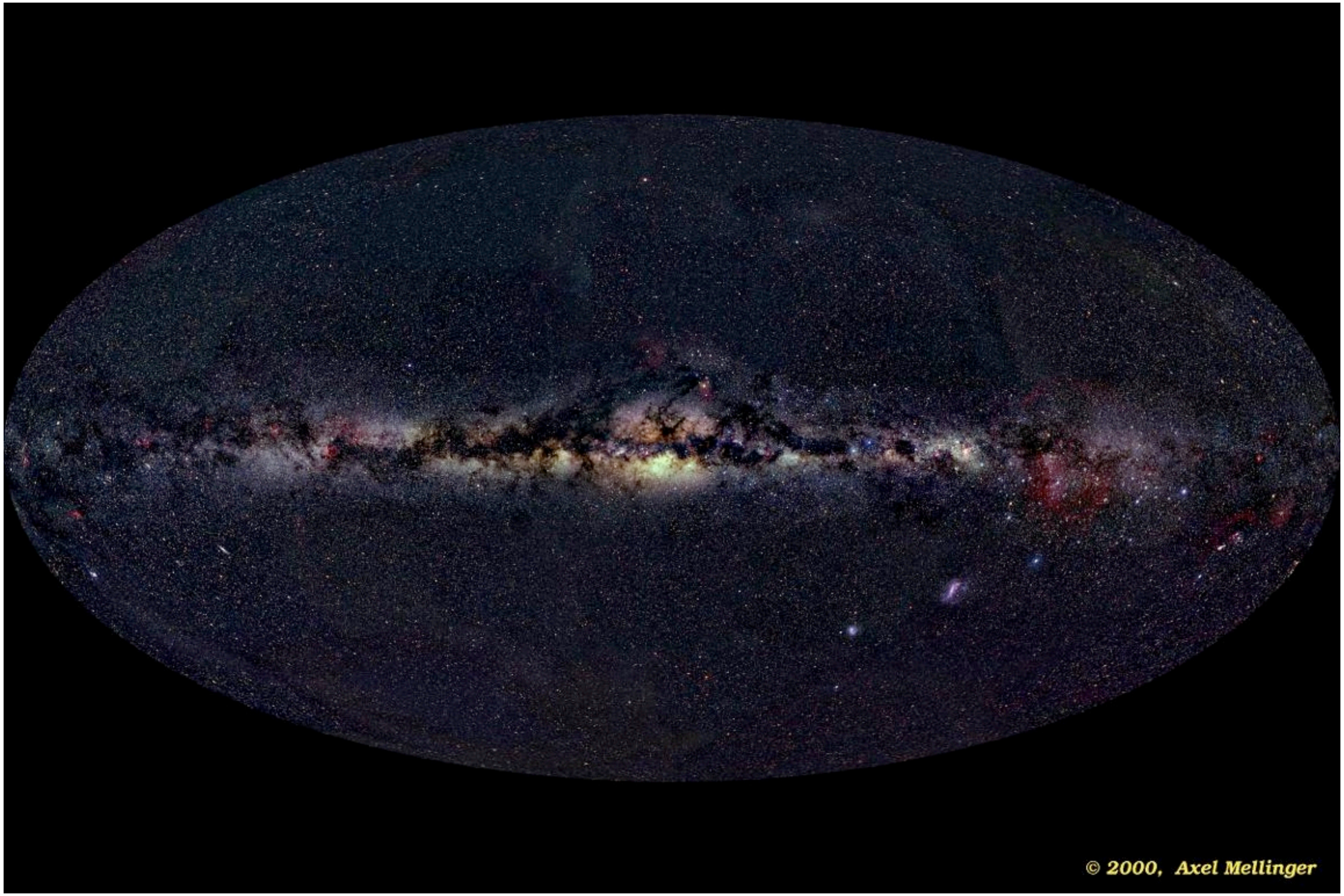
Jon Willis	Introduction	September 25th and 29th
Sara Ellison	Galaxies probed through quasar absorption lines	October 2nd and 6th
Luc Simard	The formation and evolution of galaxy discs	October 9th and 16th
David Schade	Galaxy populations in clusters	October 20th and 23rd
Chris Willott	Reionization	October 27th and 30th
Thomas Puzia	Stellar populations, chemical enrichment and galaxy formation	November 3rd and 6th
John Blakeslee	Structure and motions in the nearby universe	Novermber 13th and 17th
Chris Pritchet	Supernova cosmology	November 20th and 24th

Assessments: TBC October 10th.

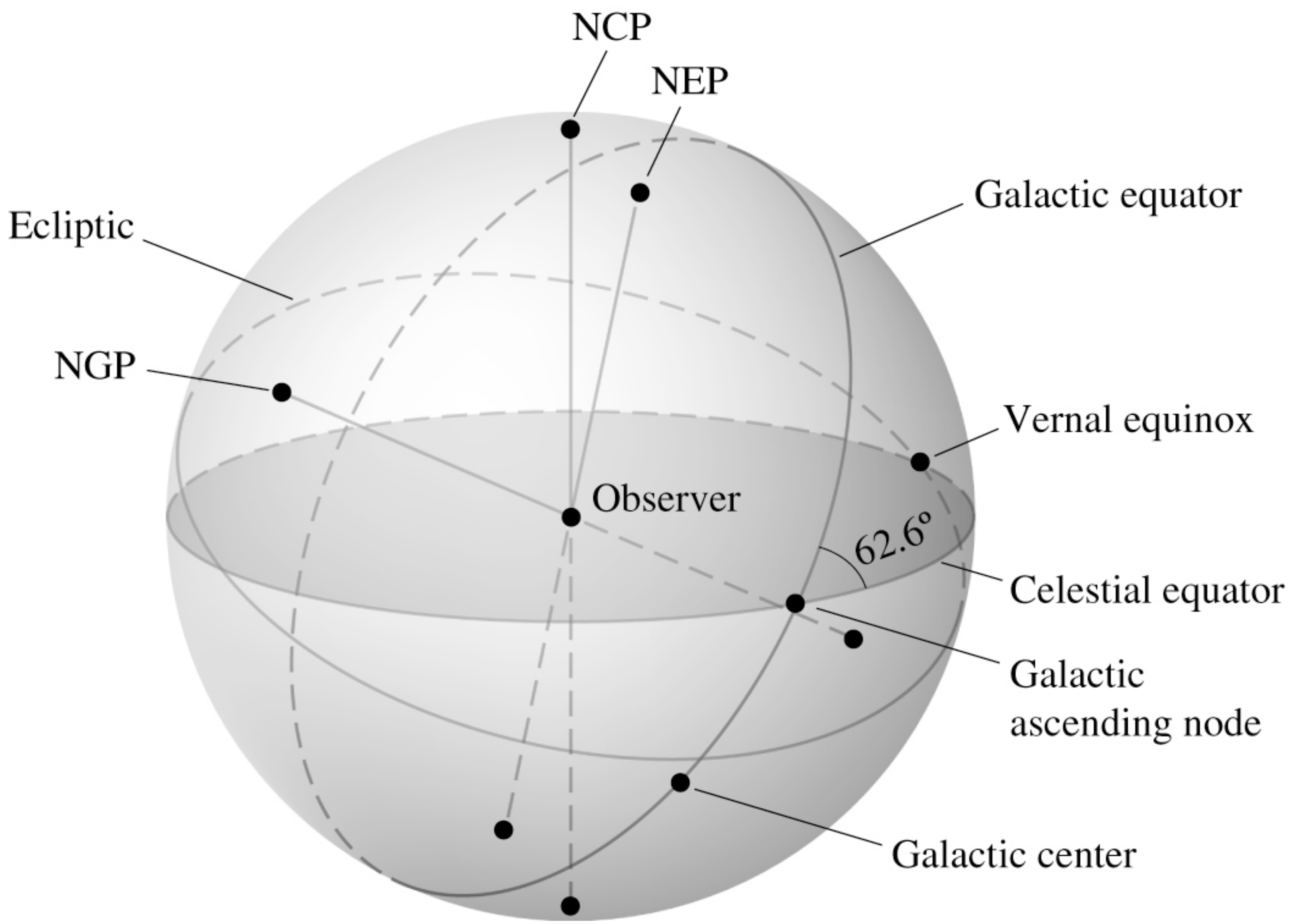
Right ascension and declination



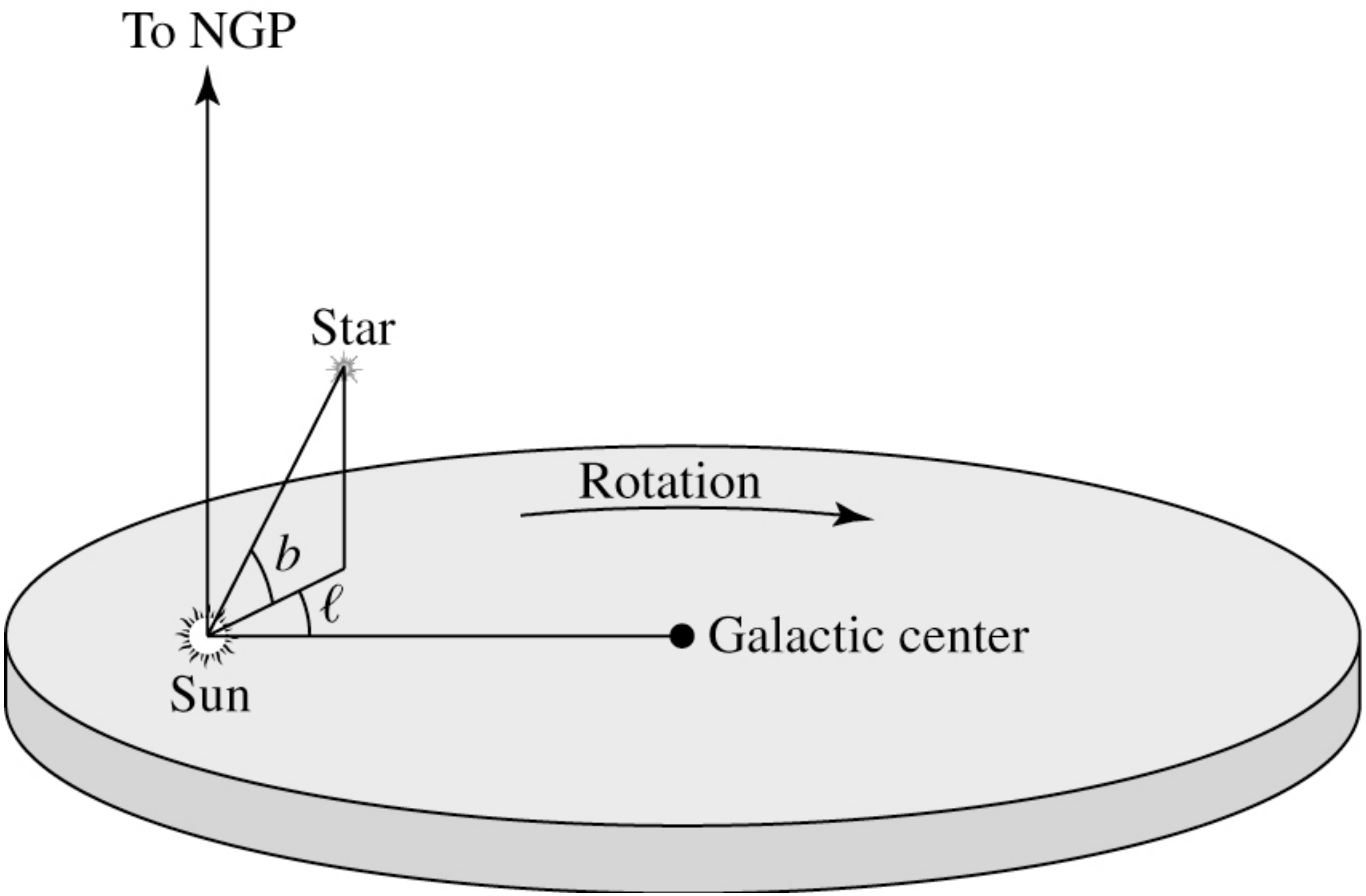
The Galactic view



The orientation of the Galaxy on the celestial sphere

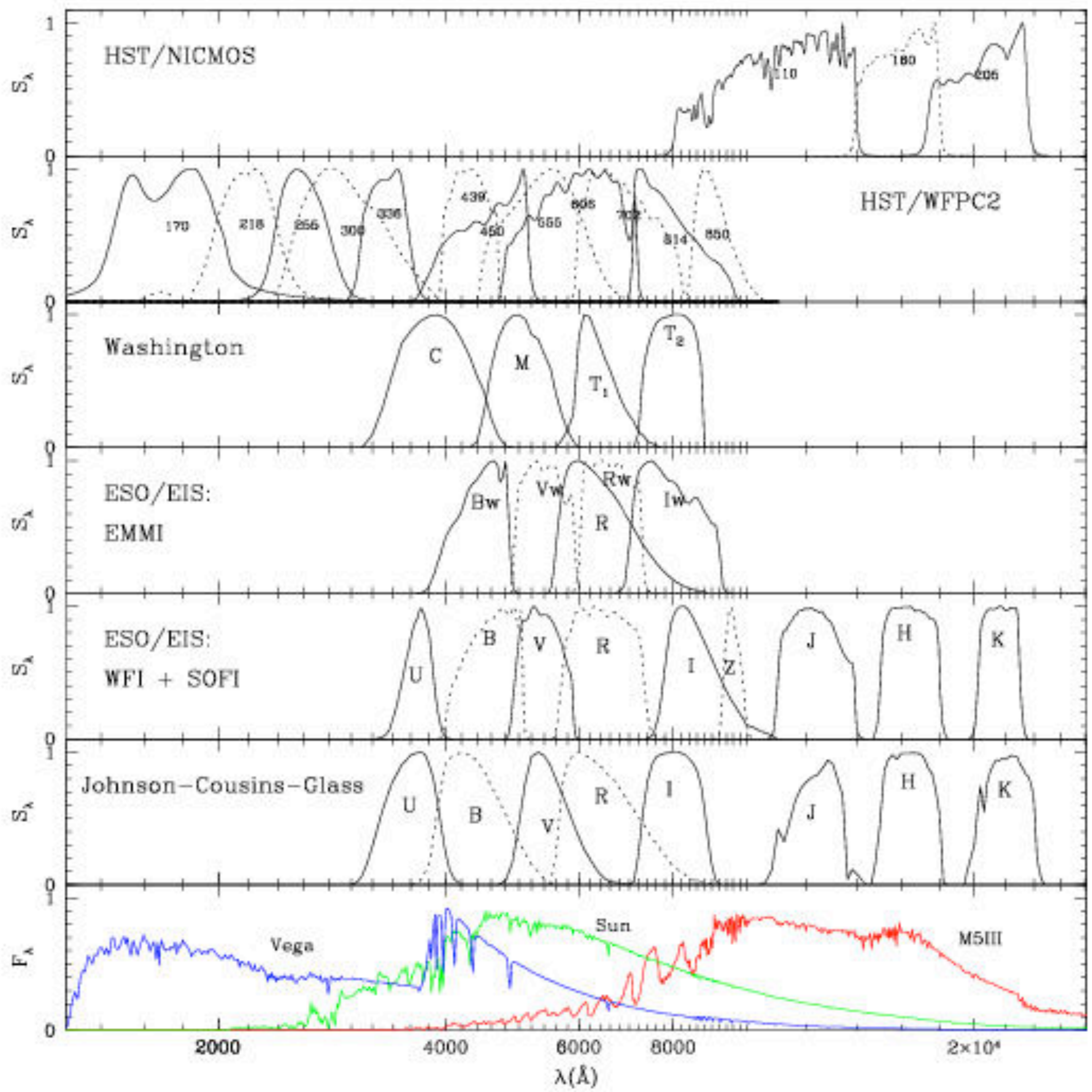


Galactic coordinates



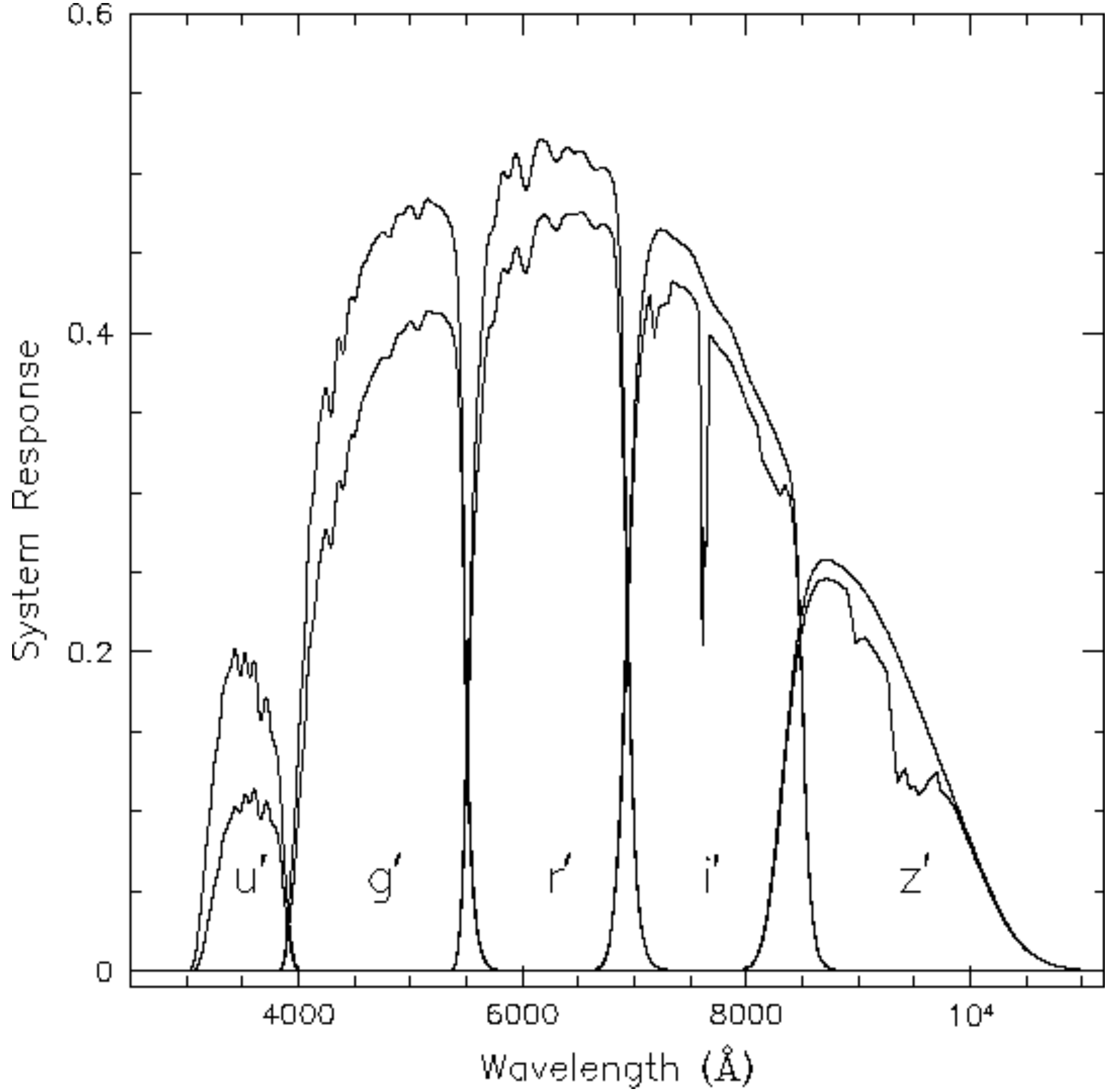
Common filter systems

Response

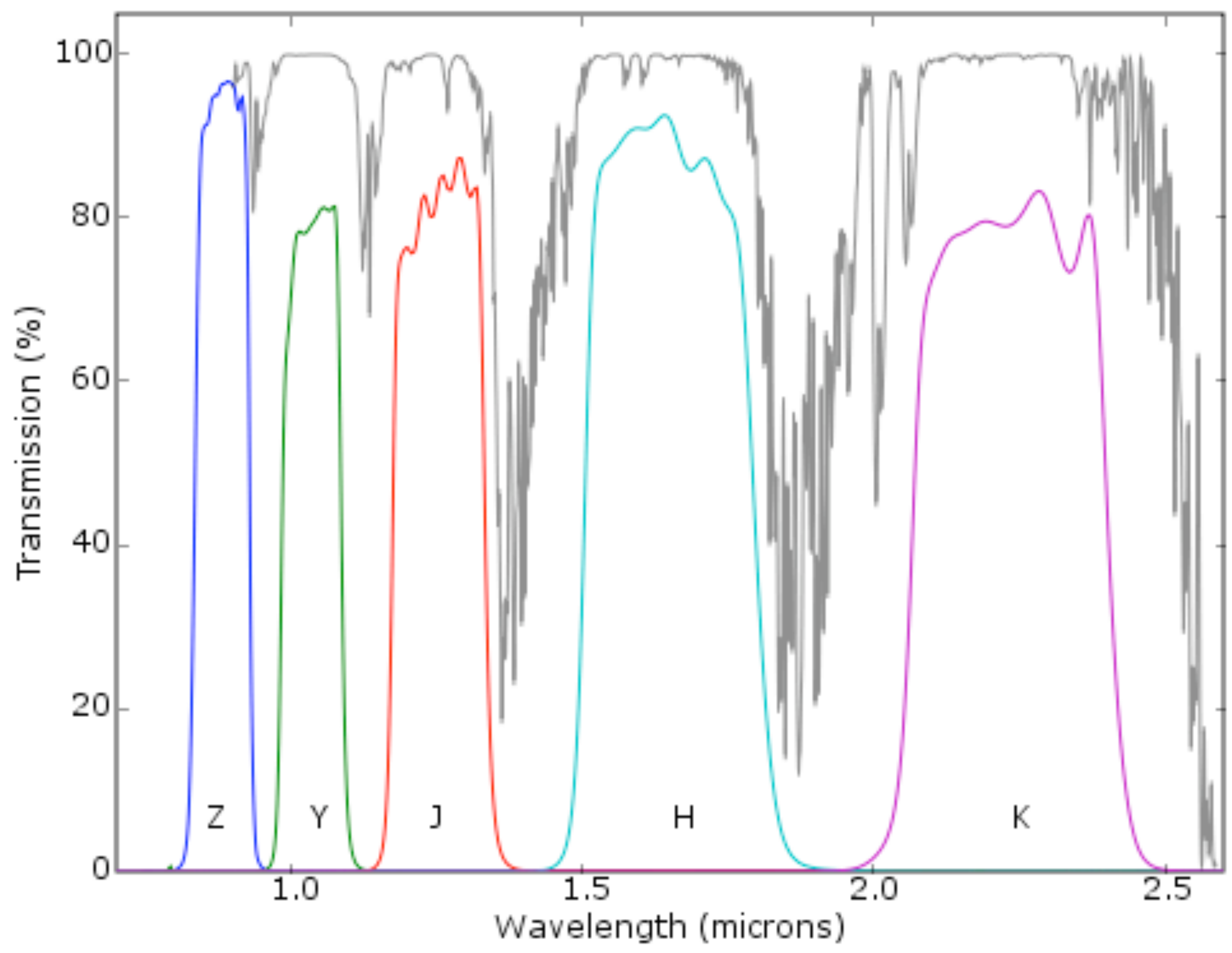


Wavelength

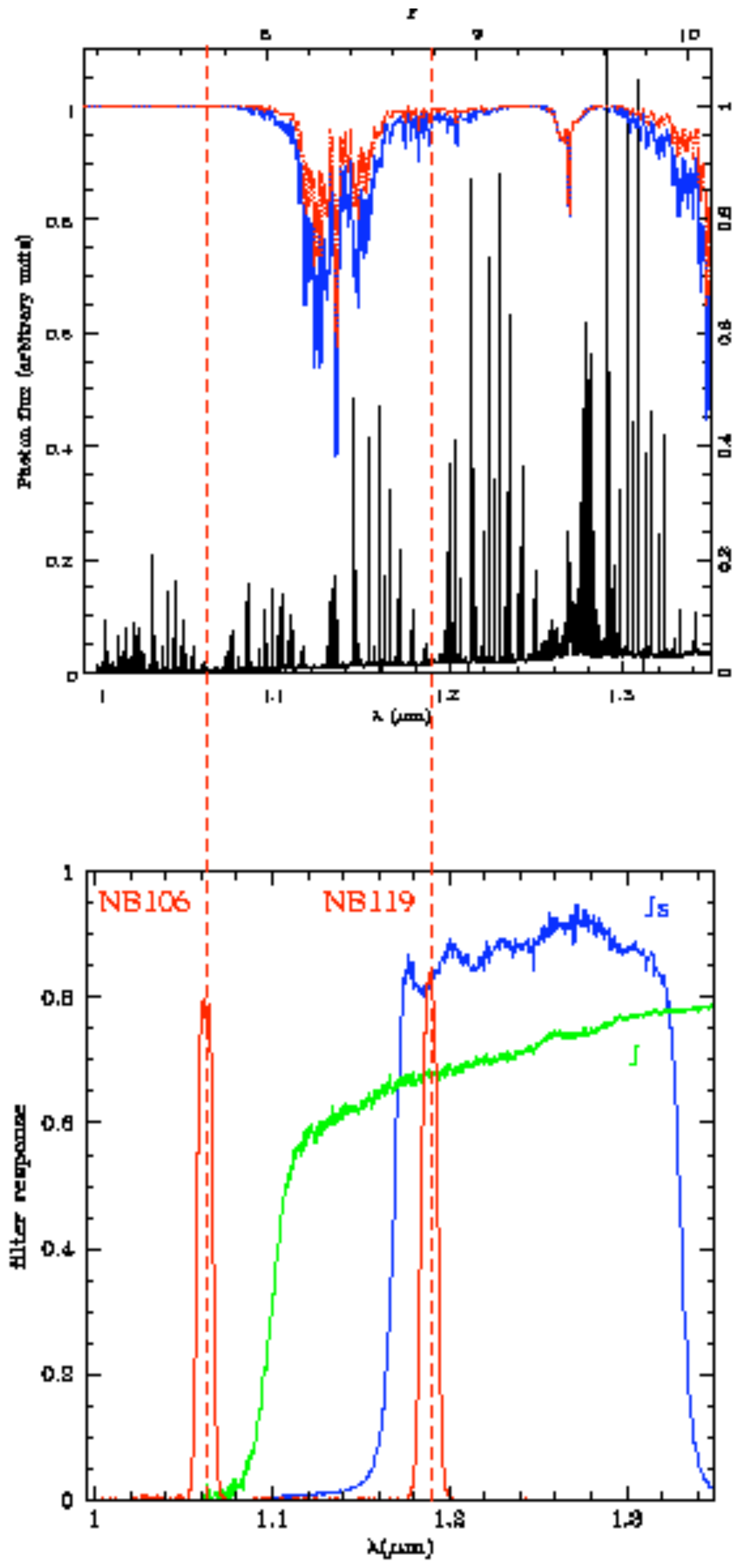
Sloan filters

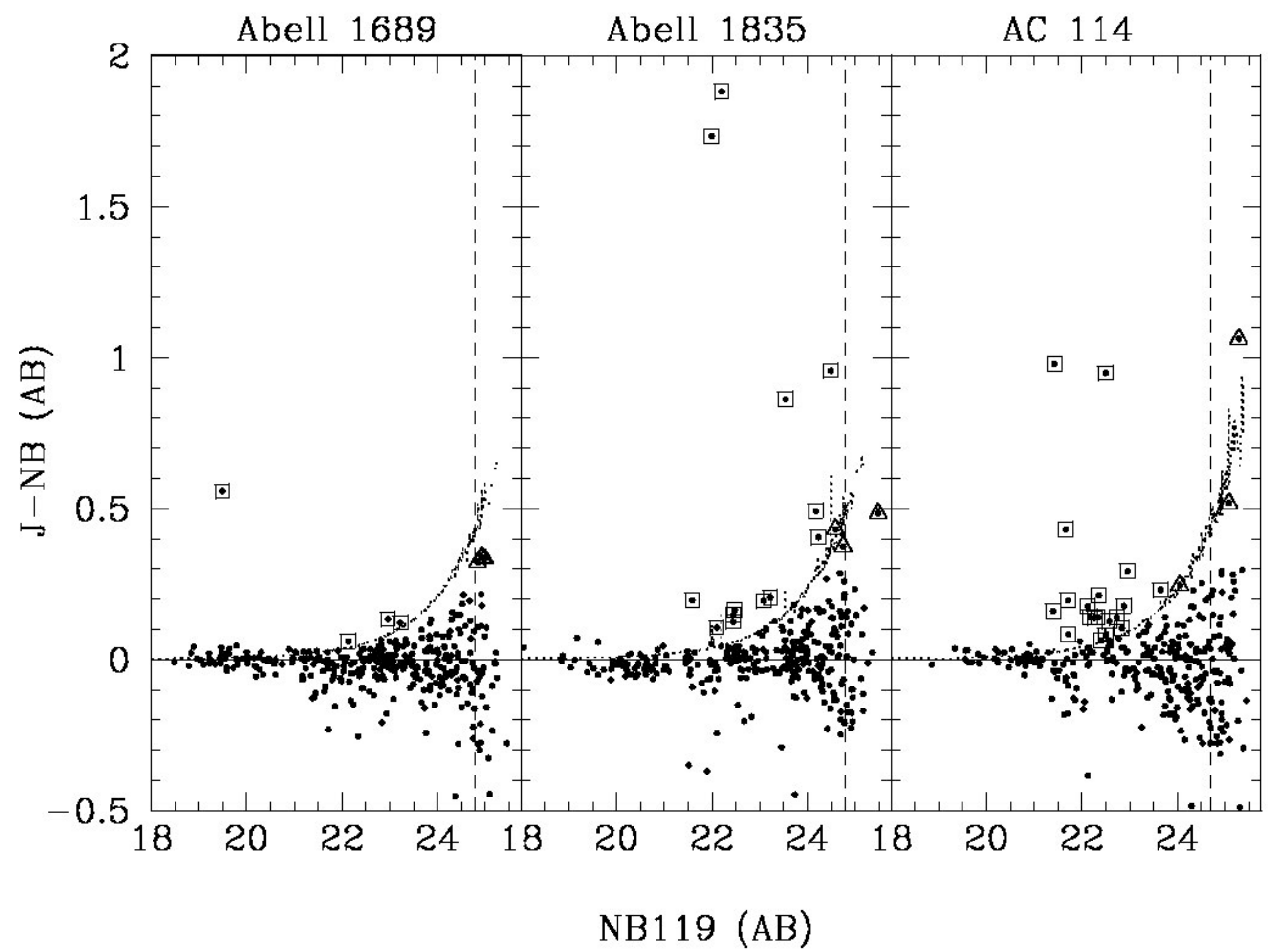


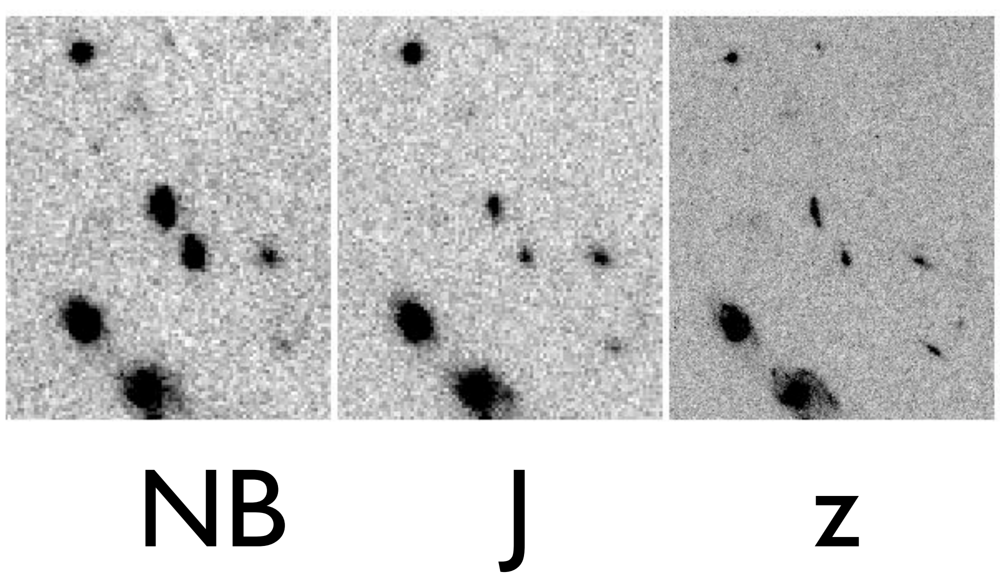
VISTA filters plus atmospheric transmission



Narrow band filters







Hubble's law:

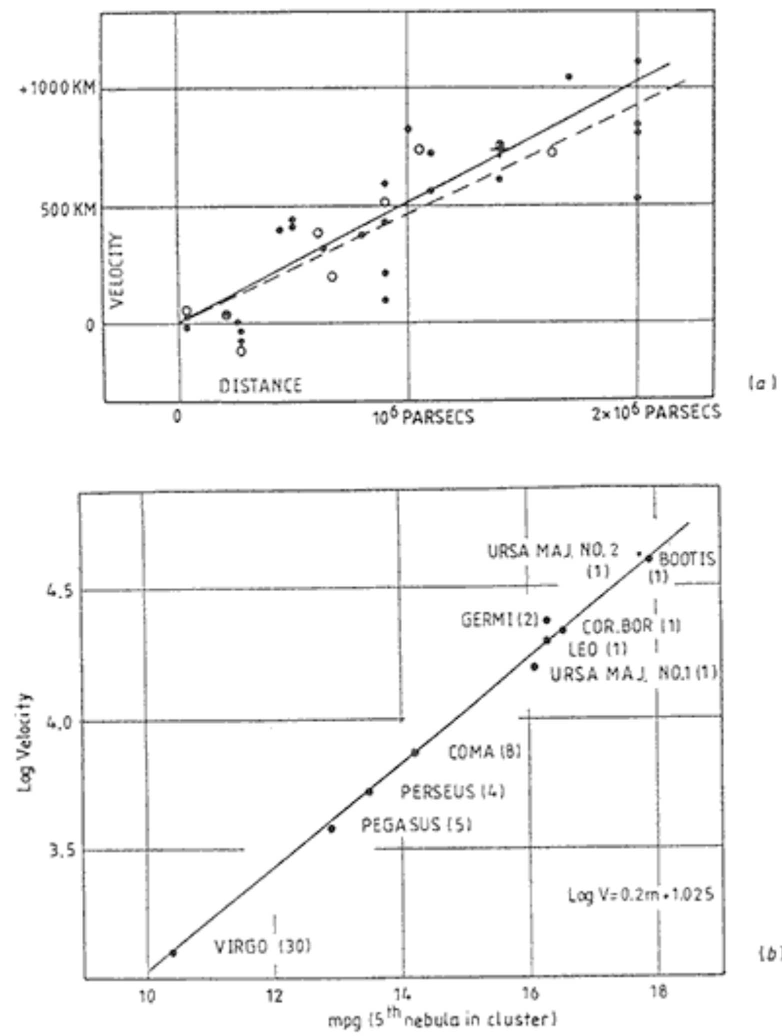
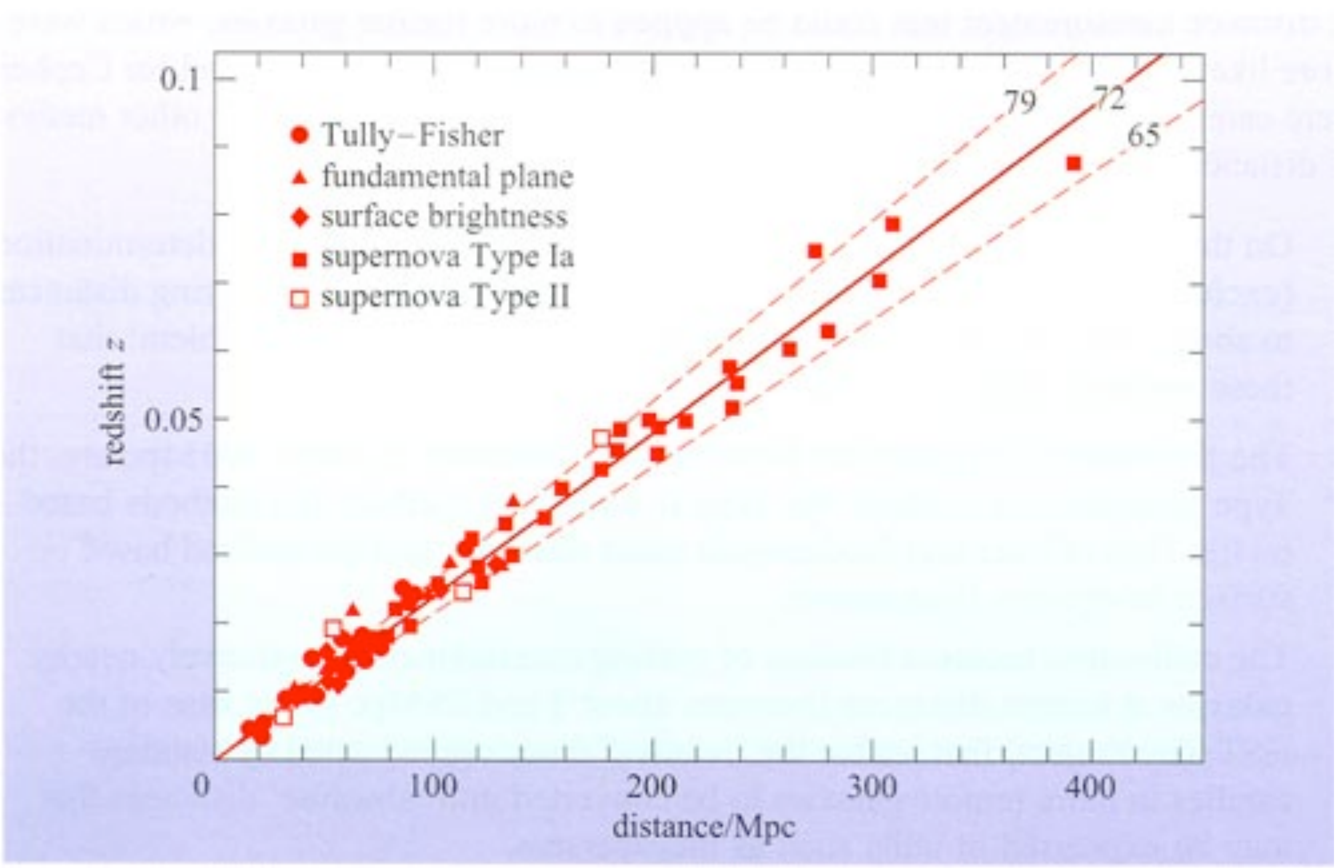
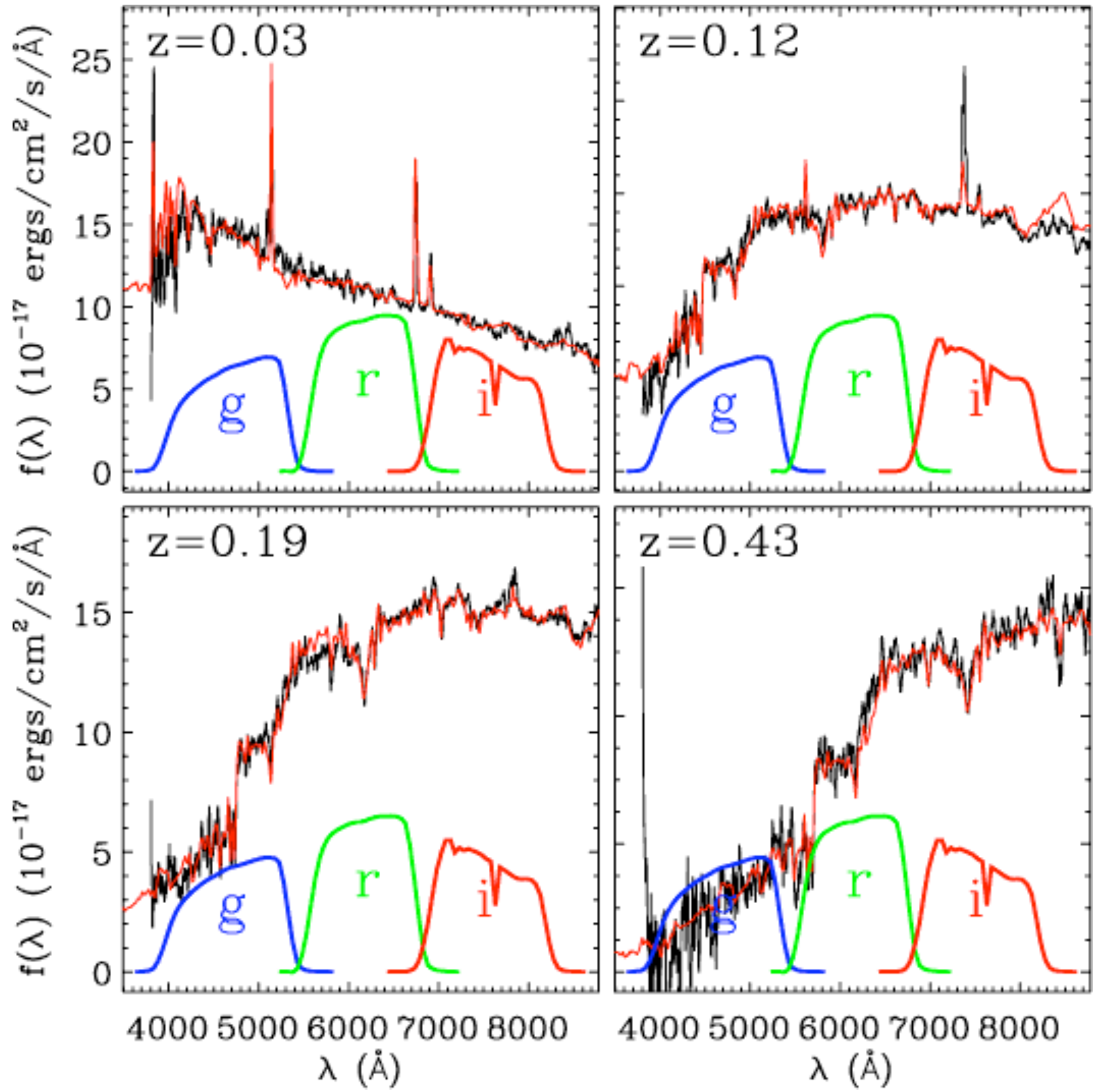


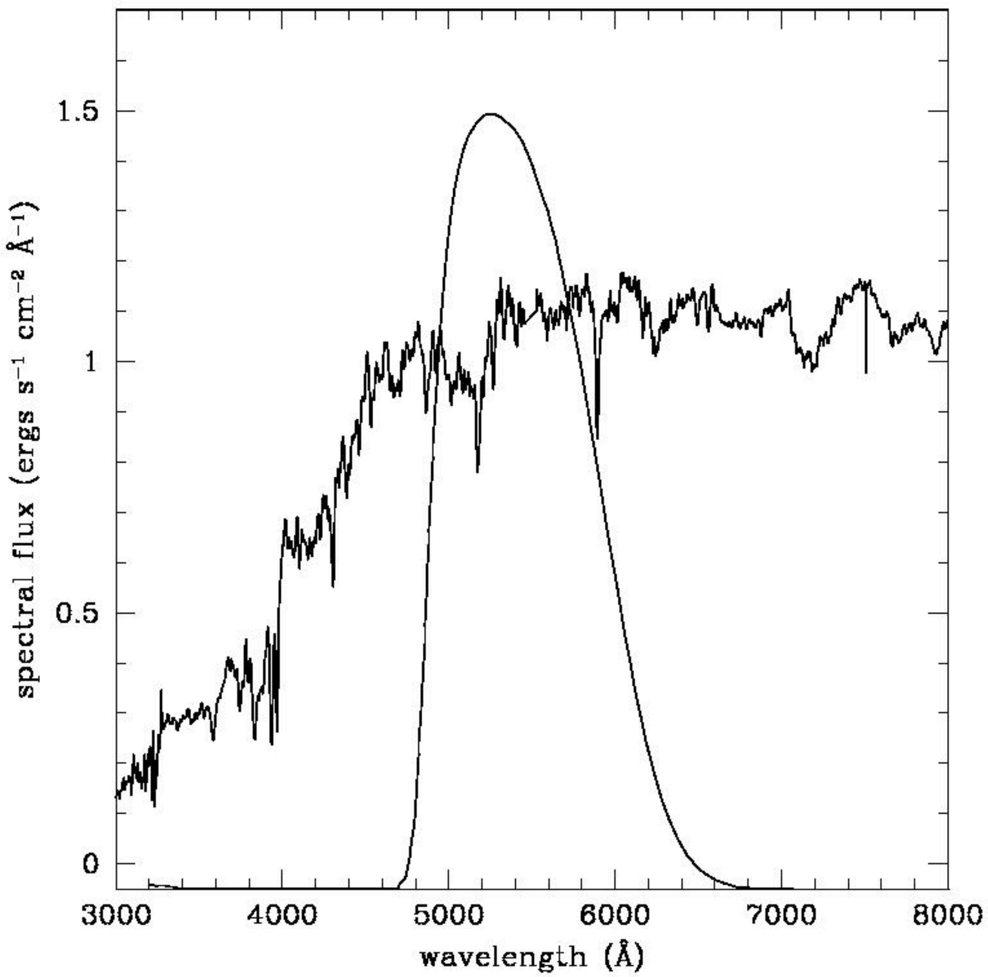
Fig. 1.2. (a) Hubble's first velocity–distance relation for nearby galaxies (Hubble 1929). The filled circles and the full line represent a solution for the solar motion using the nebulae individually; the open circles and the dashed line is a solution combining the nebulae into groups. (b) The velocity–apparent magnitude relation for the fifth brightest members of clusters of galaxies, corrected for galactic obscuration (Hubble and Humanson 1934). Each cluster velocity is the mean of the radial velocities of galaxies in the cluster, the number of galaxies being indicated by the figure in brackets. (See Sect. 2.3 for a discussion of the use of apparent magnitudes to measure distances in this relation.)



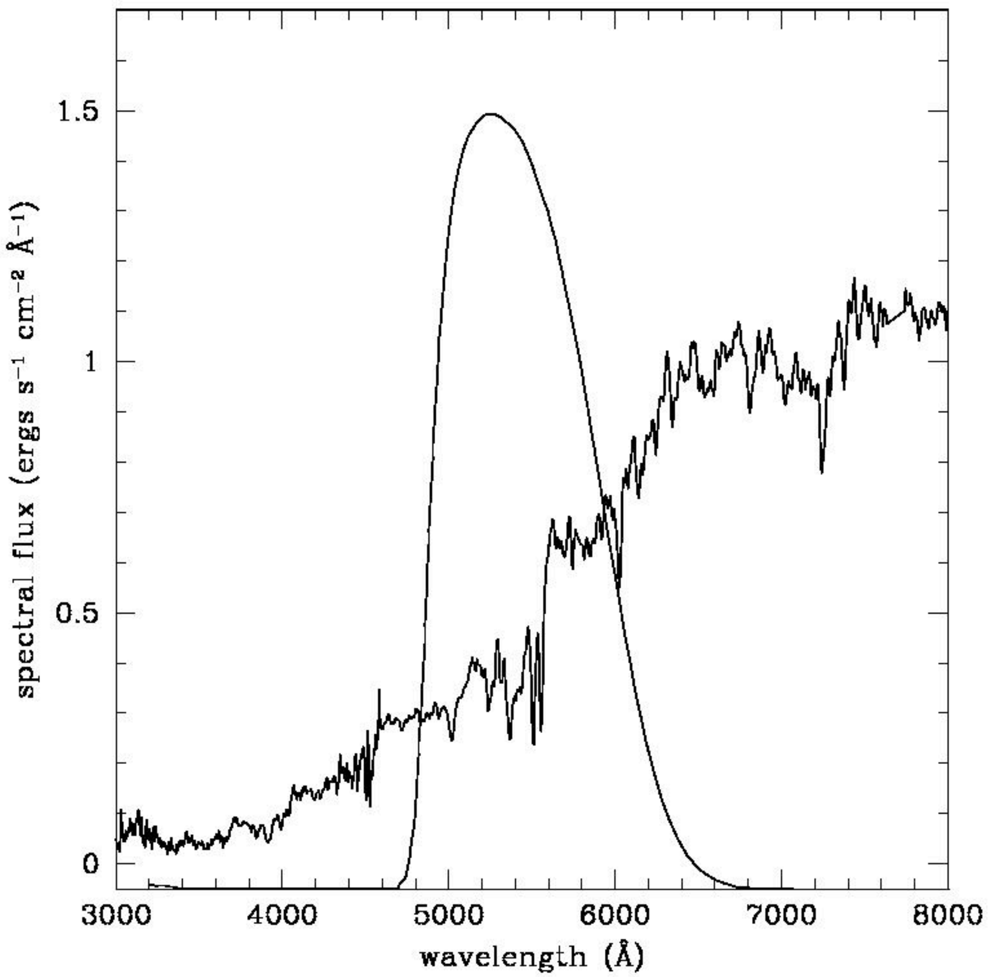
The k-correction

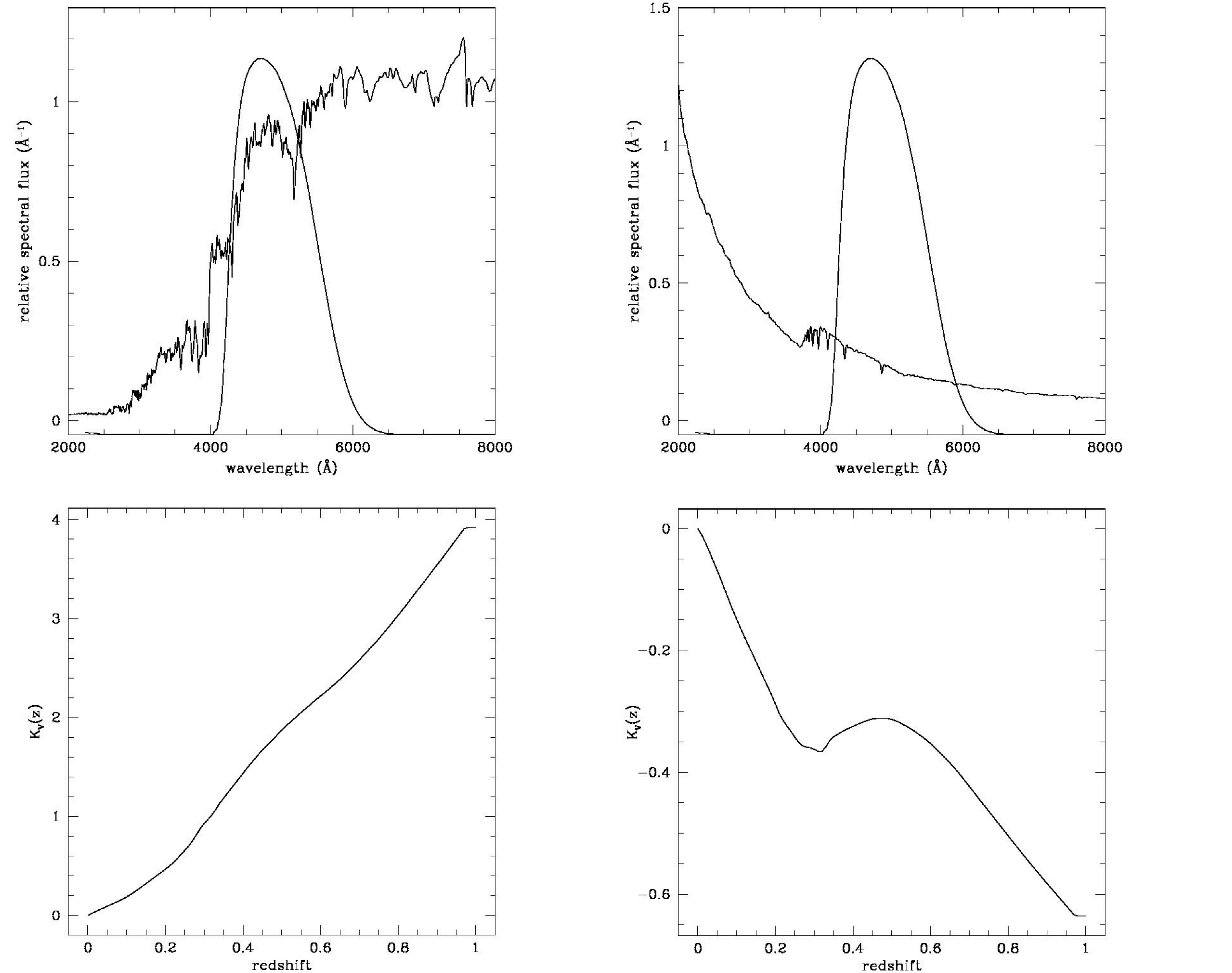


Elliptical at z=0 viewed with R-band filter



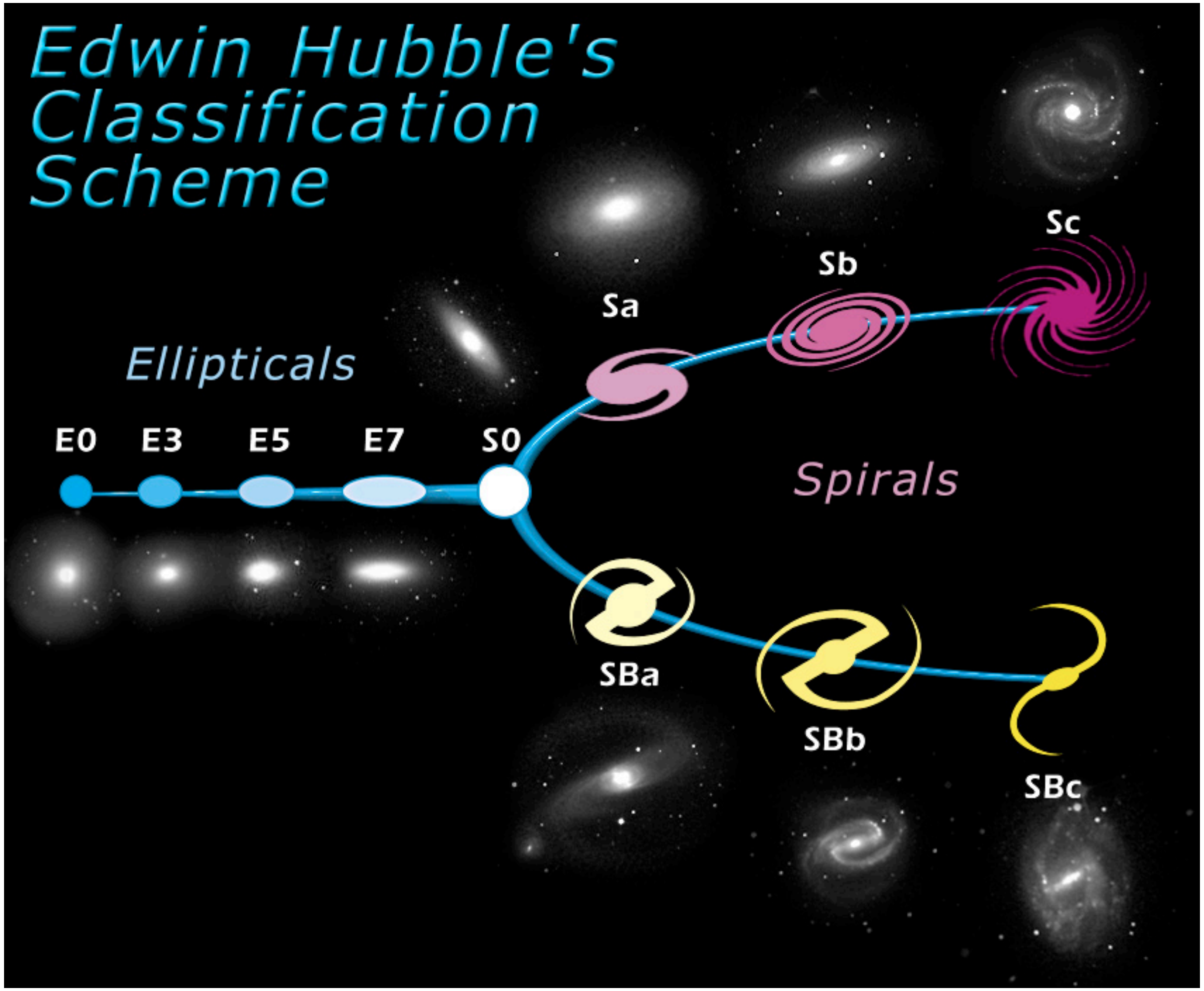
Elliptical at z=0.4 viewed with R-band filter

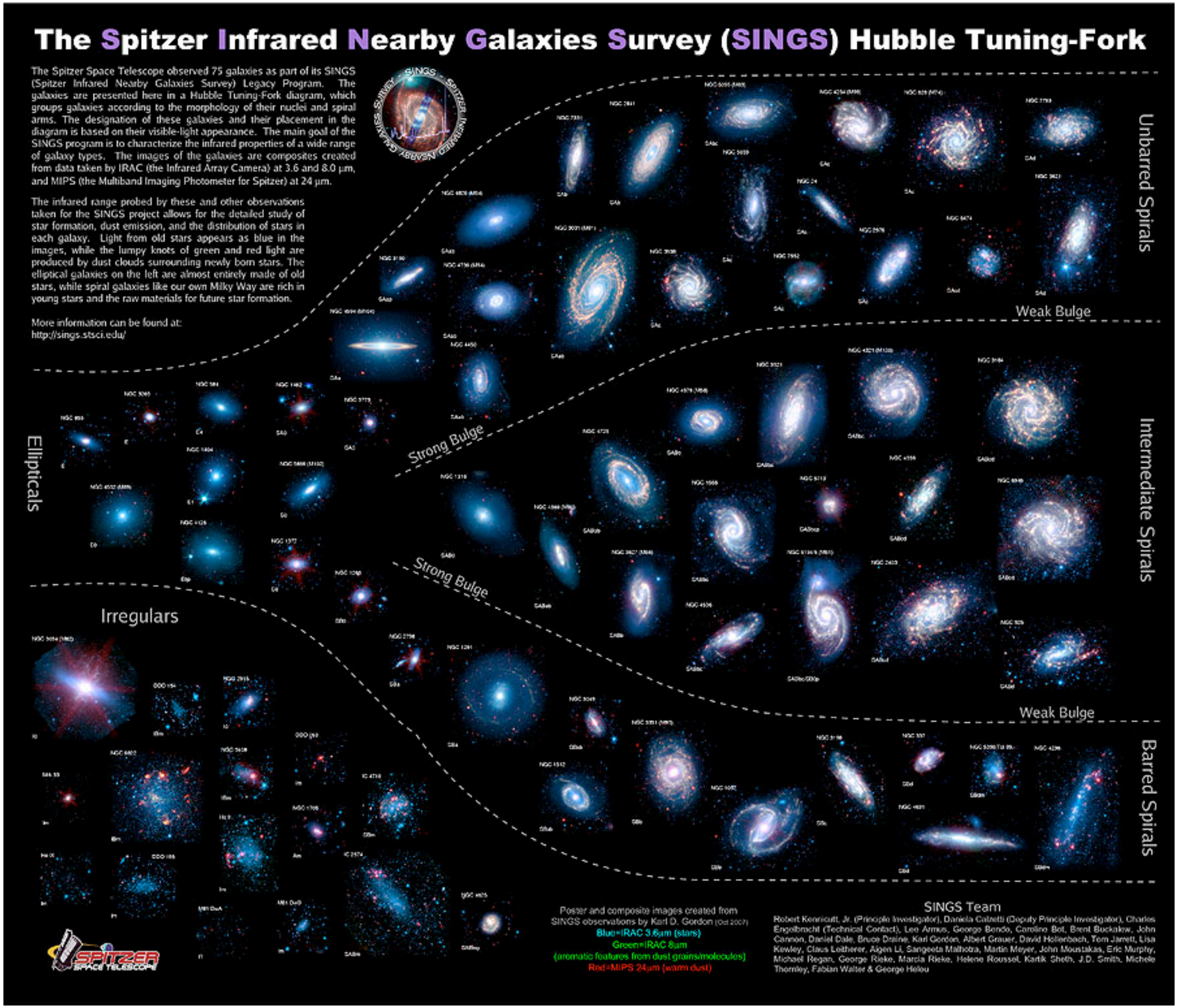




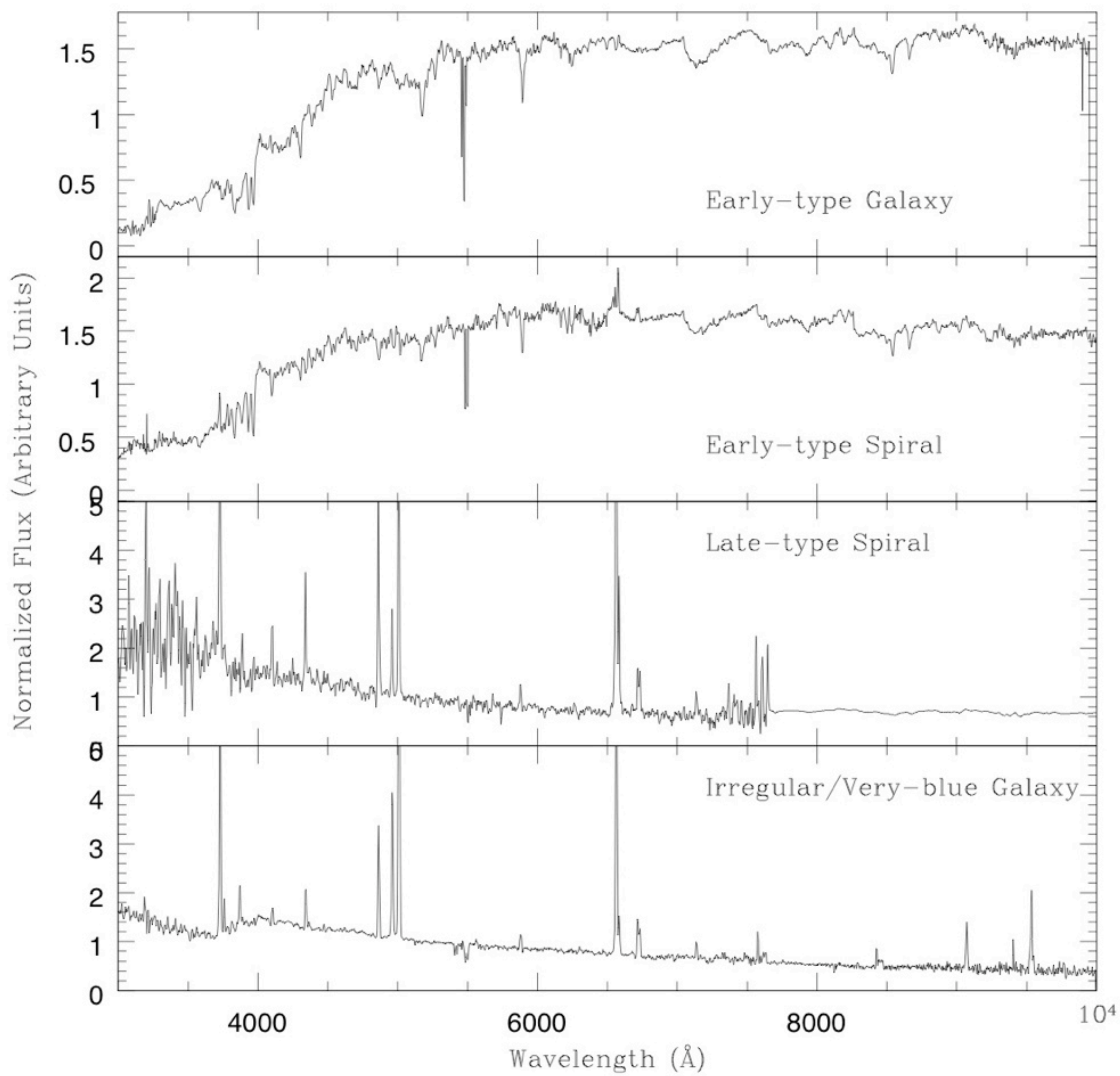
relative spectral flux (Å⁻¹)
wavelength (Å)
2000
4000
6000
8000
0
0.5
1
1.5
K_V(z)
redshift
0
0.2
0.4
0.6
0.8
1
2
3
4
−0.2
−0.4
−0.6

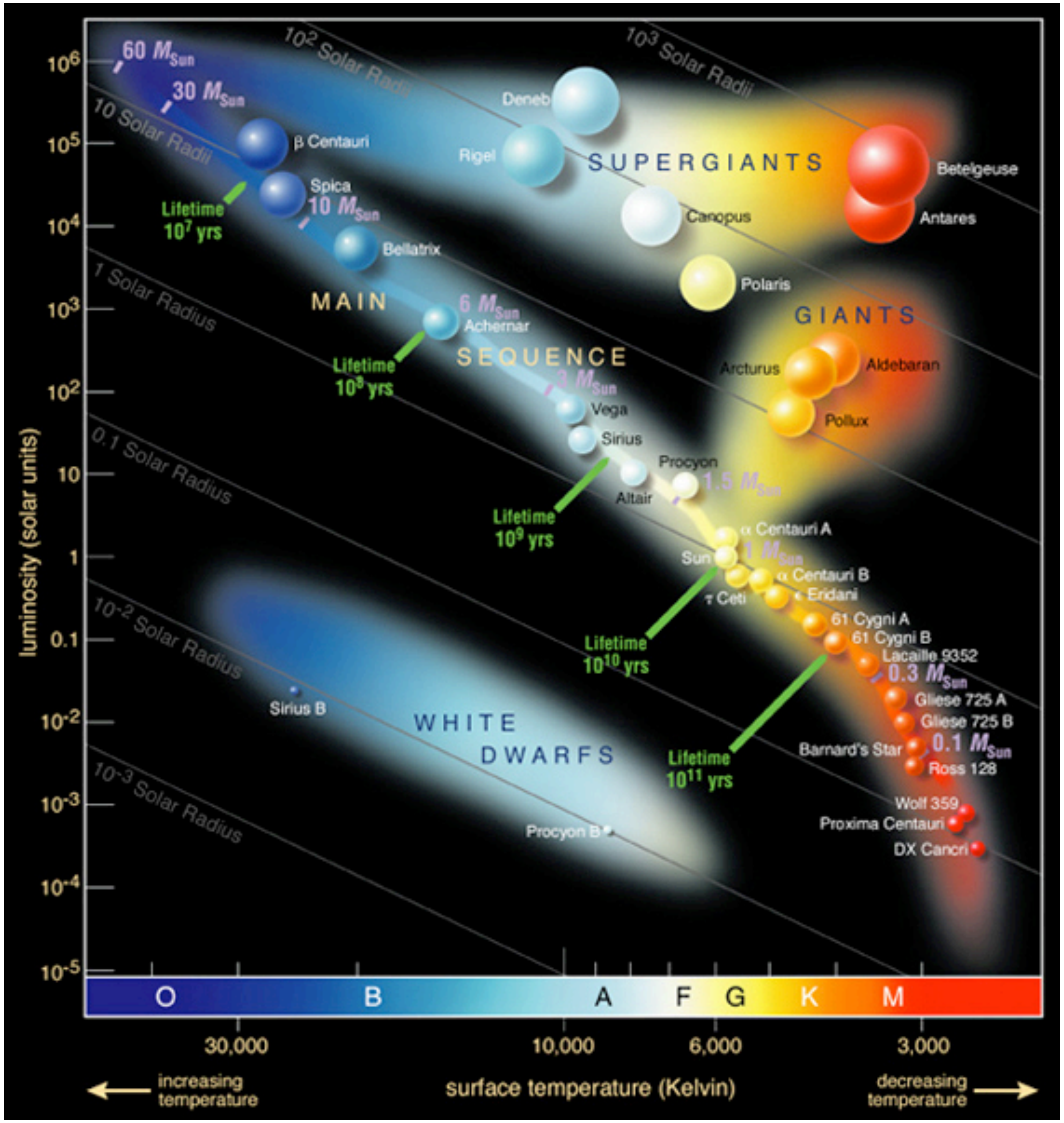
Galaxy morphologies



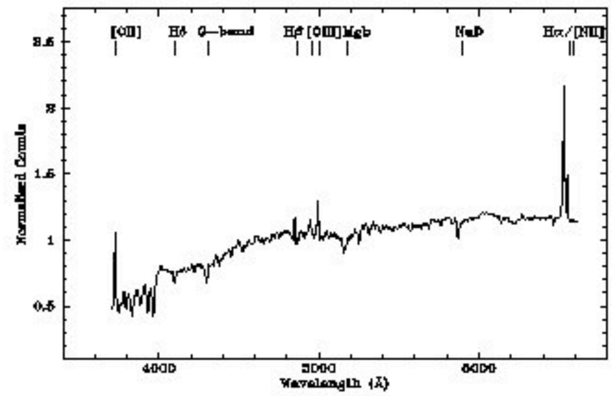

The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork
The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the 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
Ellipticals
Strong Bulge
Weak Bulge
Irregulars
Barred Spirals
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

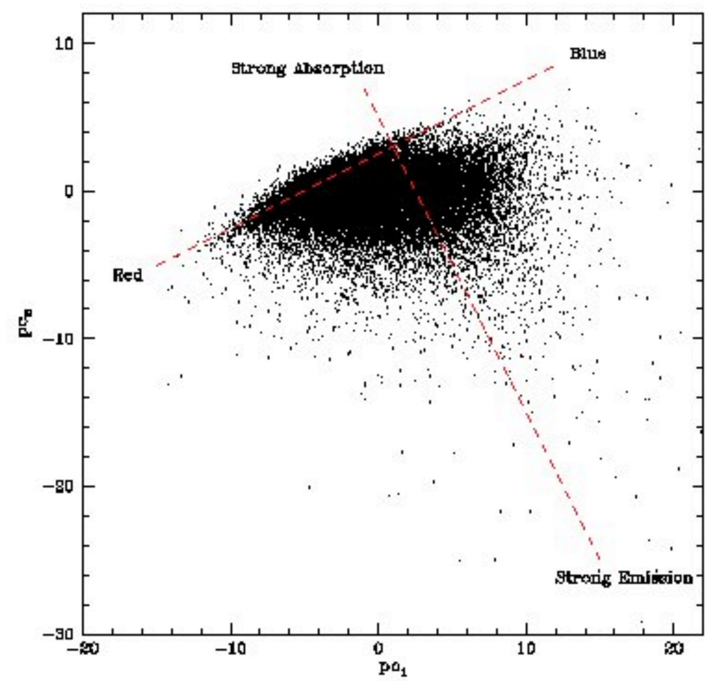
Galaxy spectral types

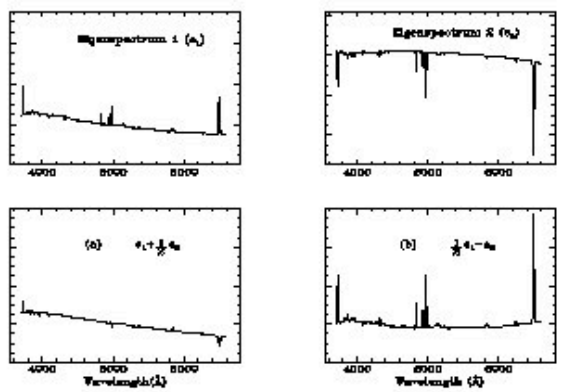


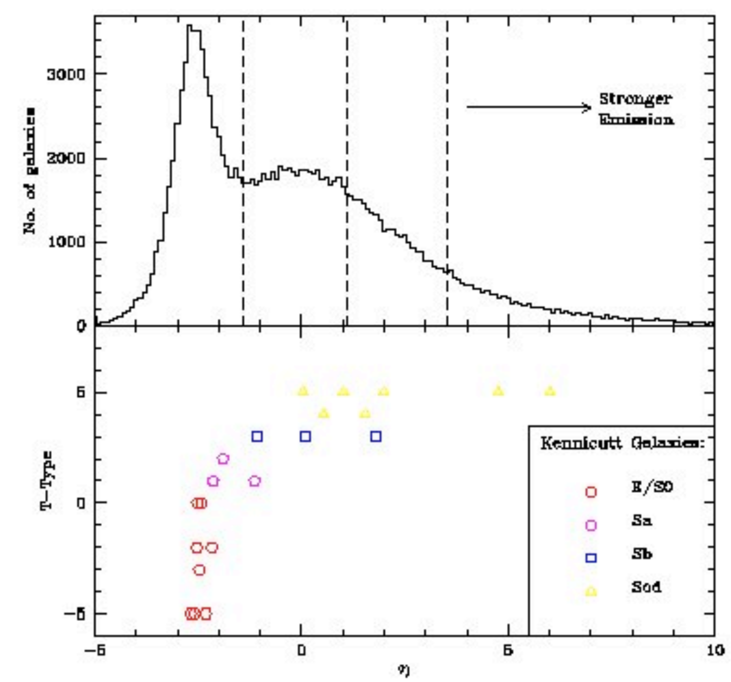


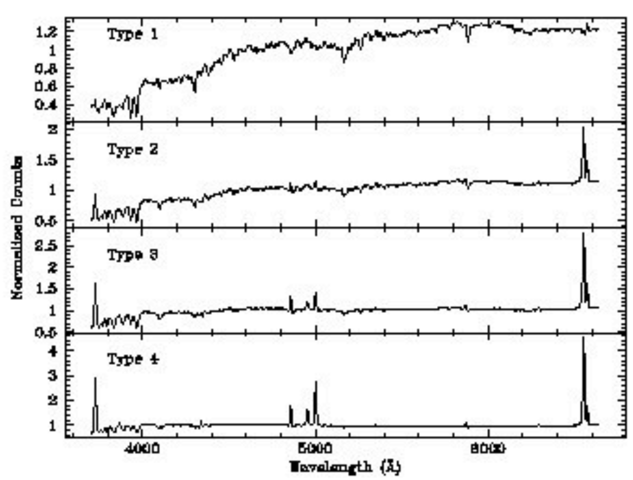
60 M Sun
30 M Sun
10 M Sun
6 M Sun
3 M Sun
1.5 M Sun
1 M Sun
0.3 M Sun
0.1 M Sun
10^2 Solar Radii
10^3 Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^-2 Solar Radius
10^-3 Solar Radius
β Centauri
Spica
Bellatrix
Achernar
Vega
Sirius
Altair
Procyon
α Centauri A
Sun
α Centauri B
τ Ceti
ε Eridani
61 Cygni A
61 Cygni B
Lacaille 9352
Gliese 725 A
Gliese 725 B
Barnard's Star
Ross 128
Wolf 359
Proxima Centauri
DX Cancri
Deneb
Rigel
Canopus
Polaris
Betelgeuse
Antares
Arcturus
Aldebaran
Pollux
Sirius B
Procyon B
SUPERGIANTS
GIANTS
MAIN
SEQUENCE
WHITE
DWARFS
Lifetime 10^7 yrs
Lifetime 10^8 yrs
Lifetime 10^9 yrs
Lifetime 10^10 yrs
Lifetime 10^11 yrs
luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^-2
10^-3
10^-4
10^-5
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
increasing temperature
surface temperature (Kelvin)
decreasing temperature


[OII]
Hδ
G—band
Hβ
[OIII]
Mgb
NaD
Hα/[NII]
Normalized Counts
Wavelength (Å)

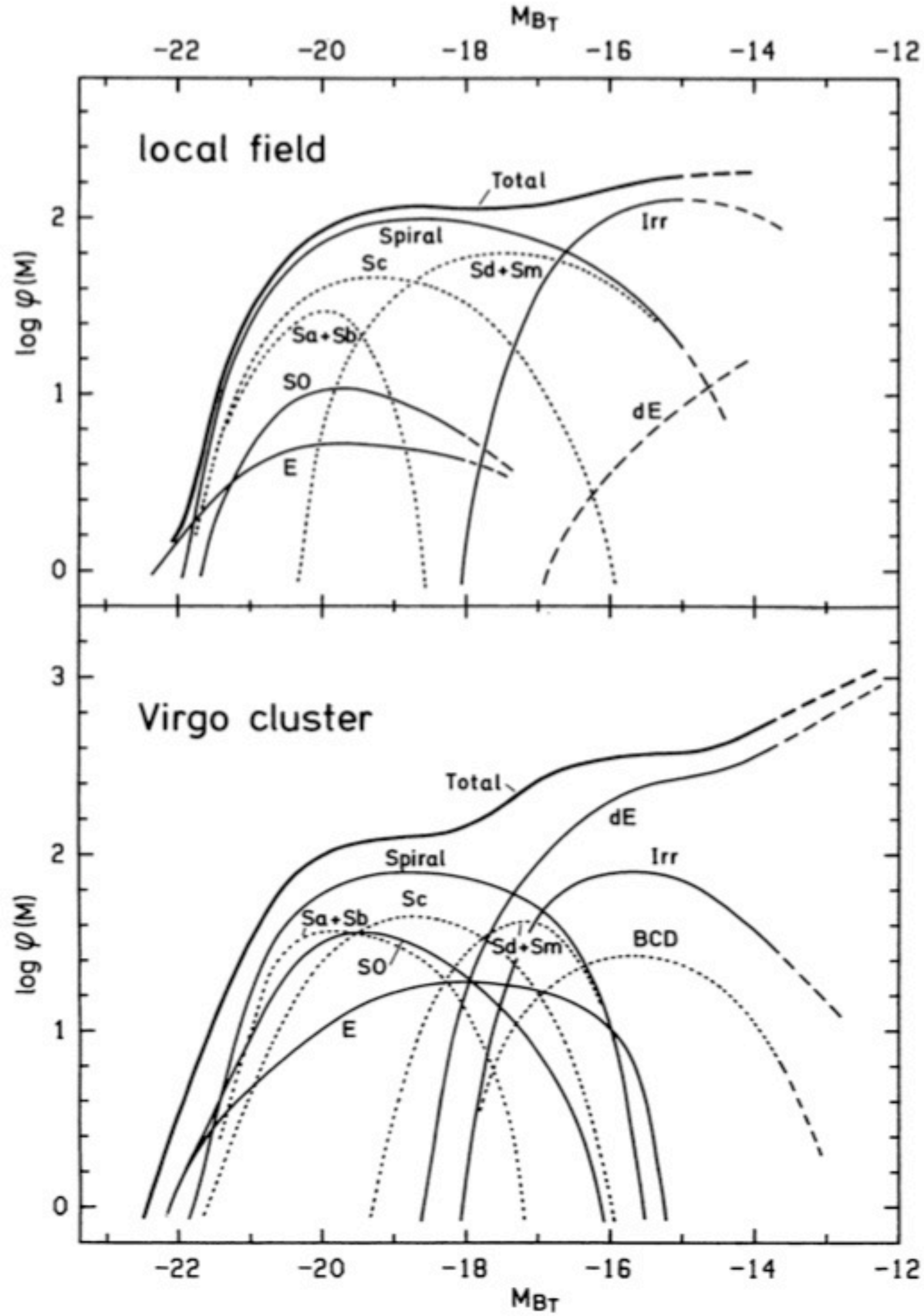

Strong Absorption
Blue
Red
Strong Emission

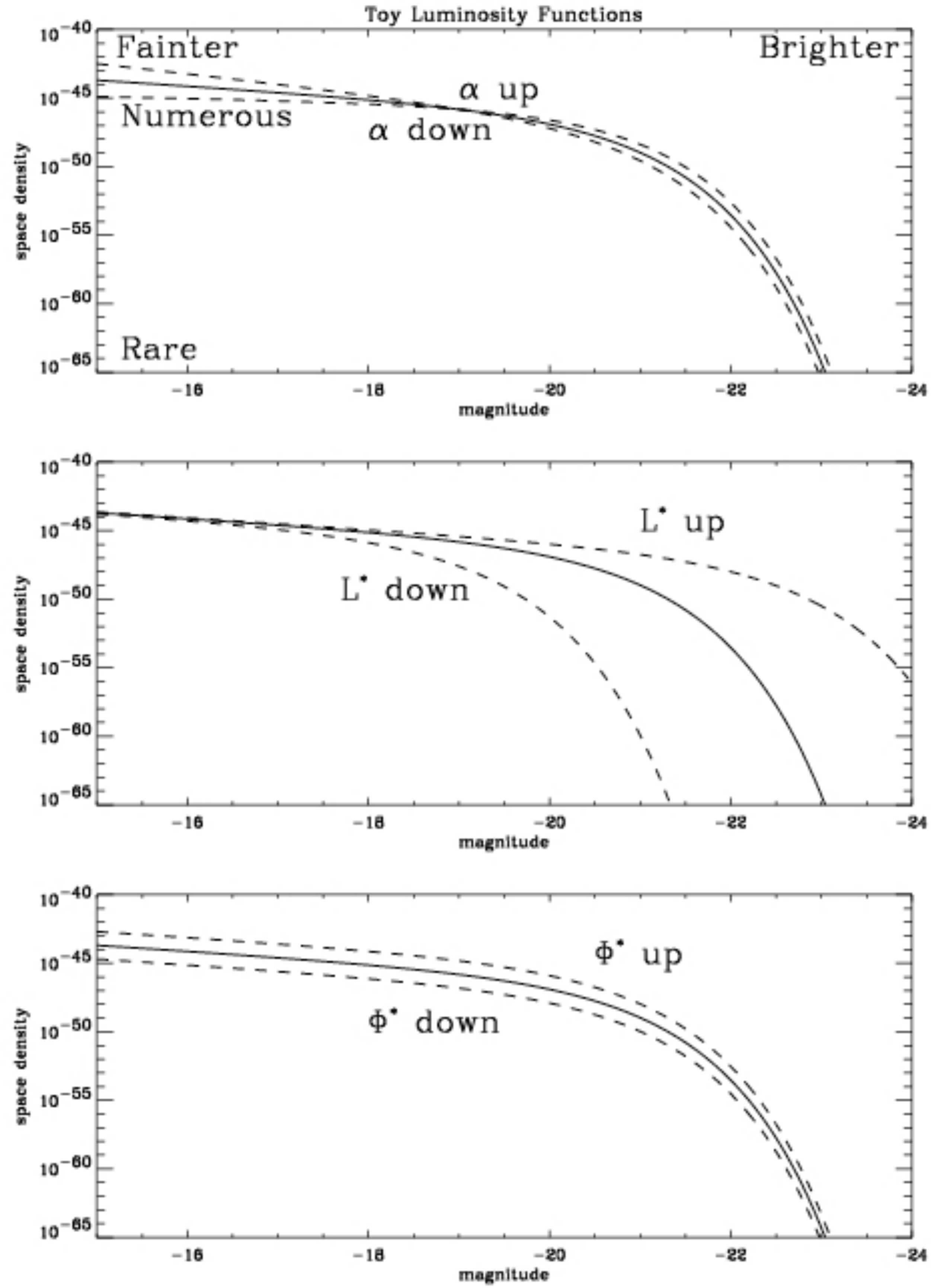

Wavelength(Å)


No. of galaxies
Stronger Emission
T-Type
Kennicutt Galaxies:
E/S0
Sa
Sb
Scd

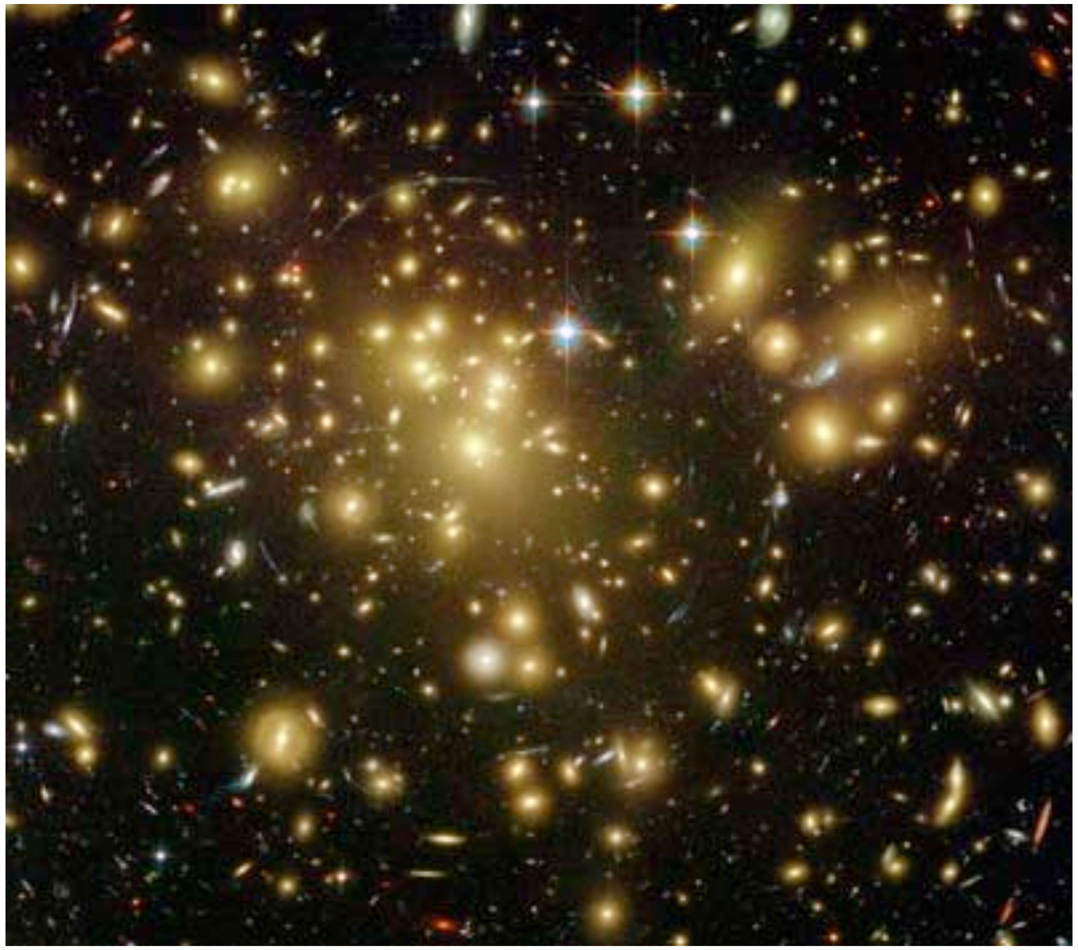

Type 1
Type 2
Type 3
Type 4
Normalized Counts
Wavelength (Å)

The galaxy luminosity function



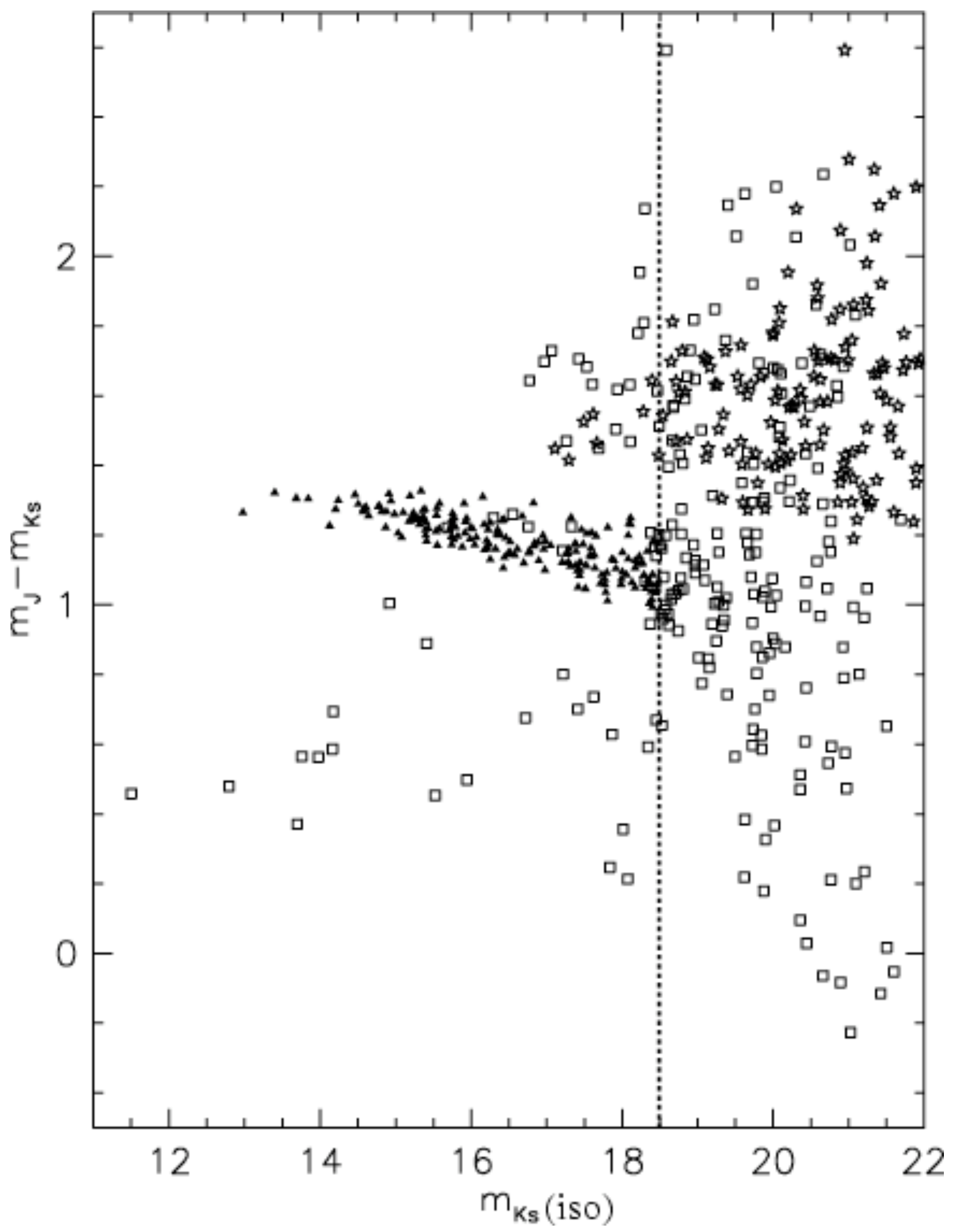

Toy Luminosity Functions
Fainter
Brighter
α up
Numerous
α down
Rare
L* up
L* down
Φ* up
Φ* down
space density
magnitude
10^-40
10^-45
10^-50
10^-55
10^-60
10^-65
-16
-18
-20
-22
-24

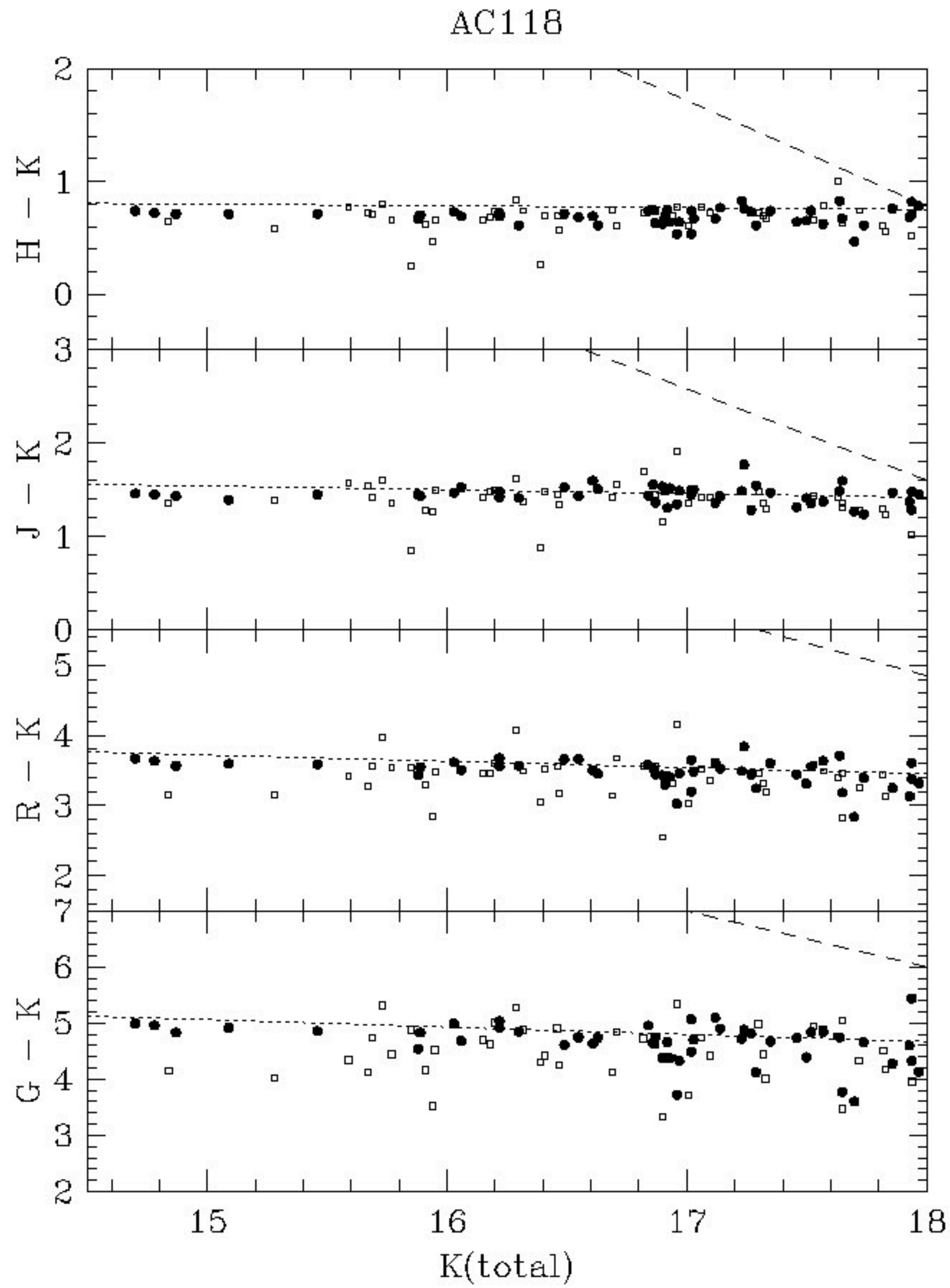
Galaxy populations in clusters:



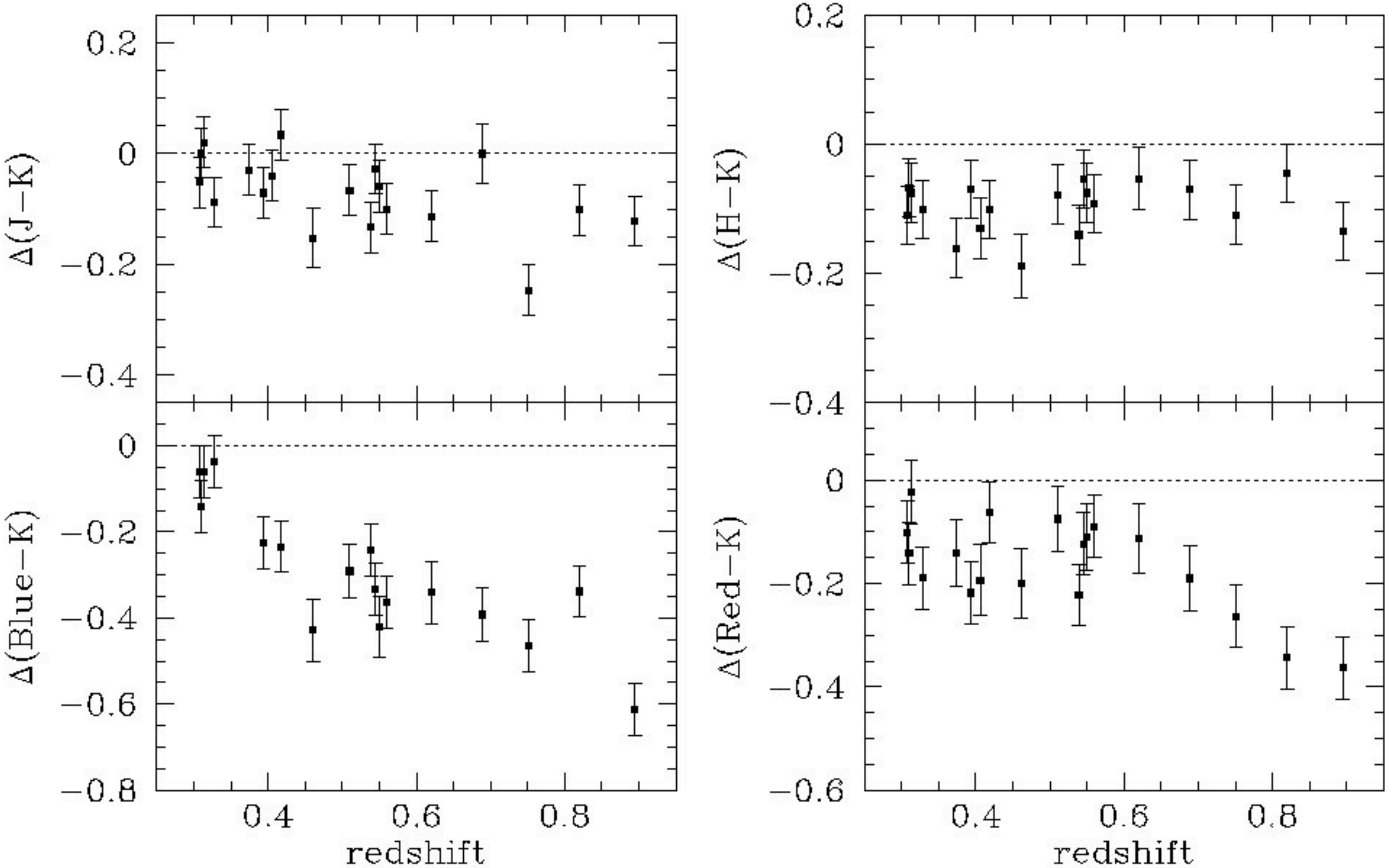
Abell 1689   z = 0.18

The colour magnitude relation

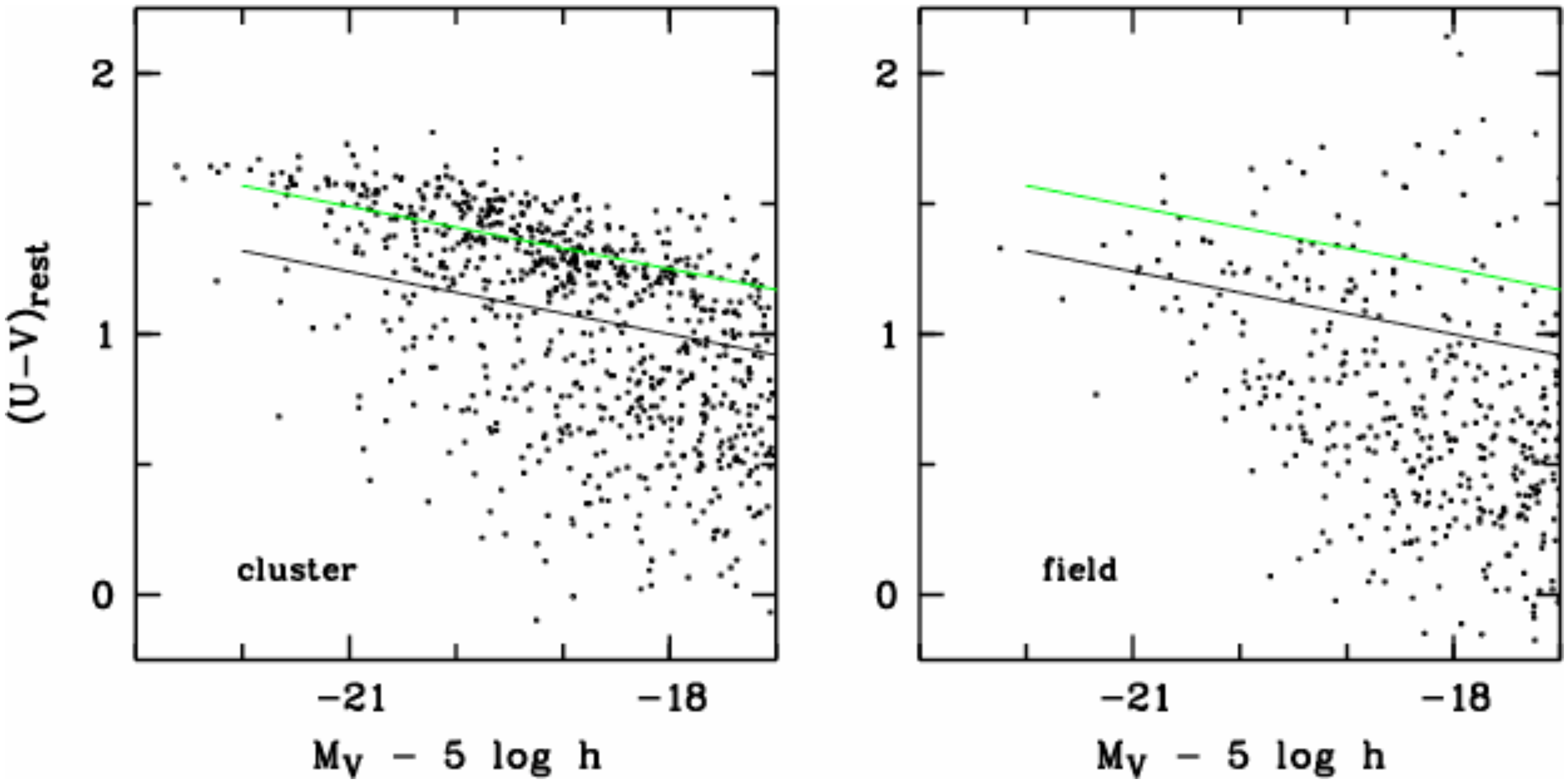


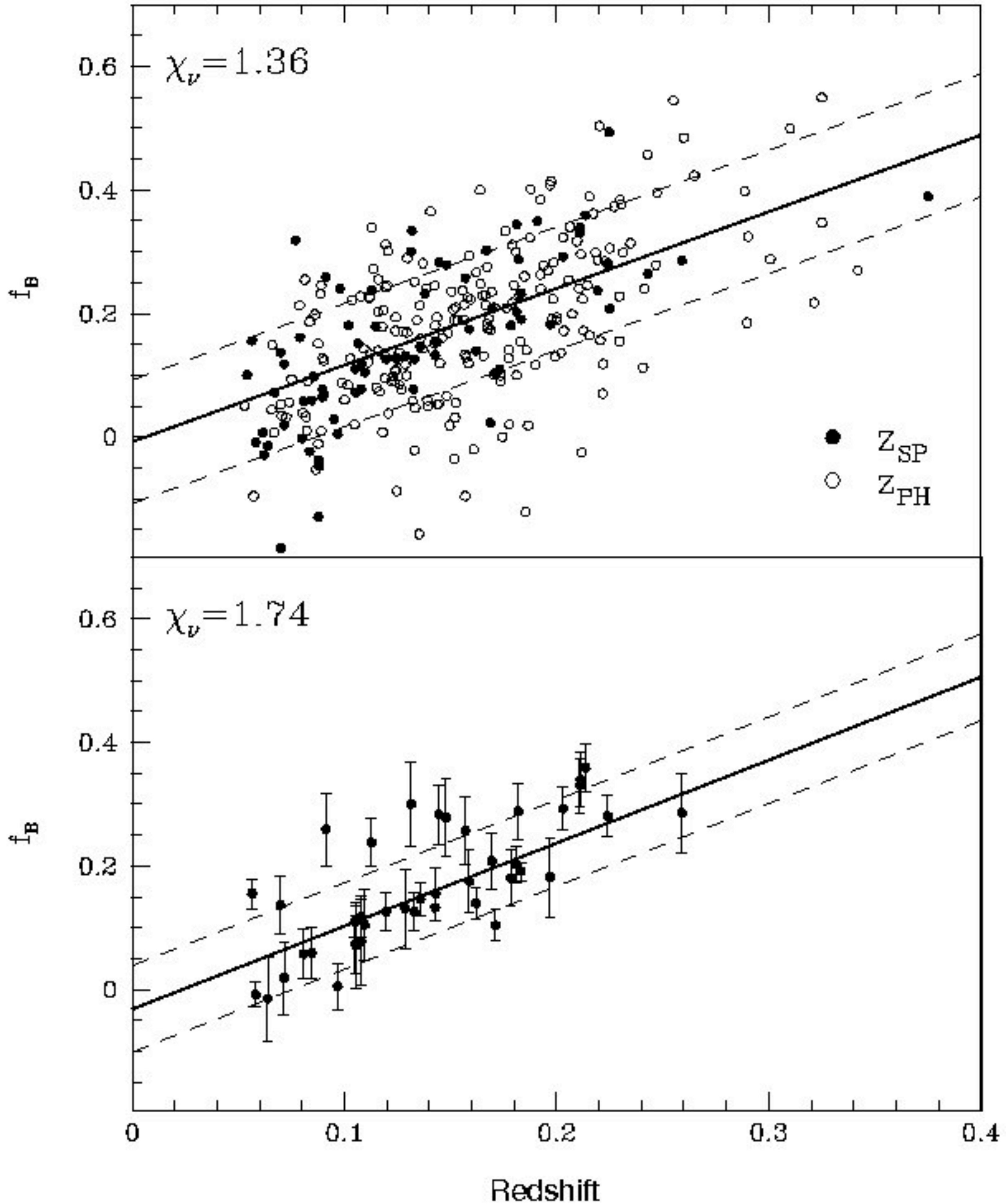

AC118
H − K
J − K
R − K
G − K
K(total)

Younger stellar populations at higher redshift



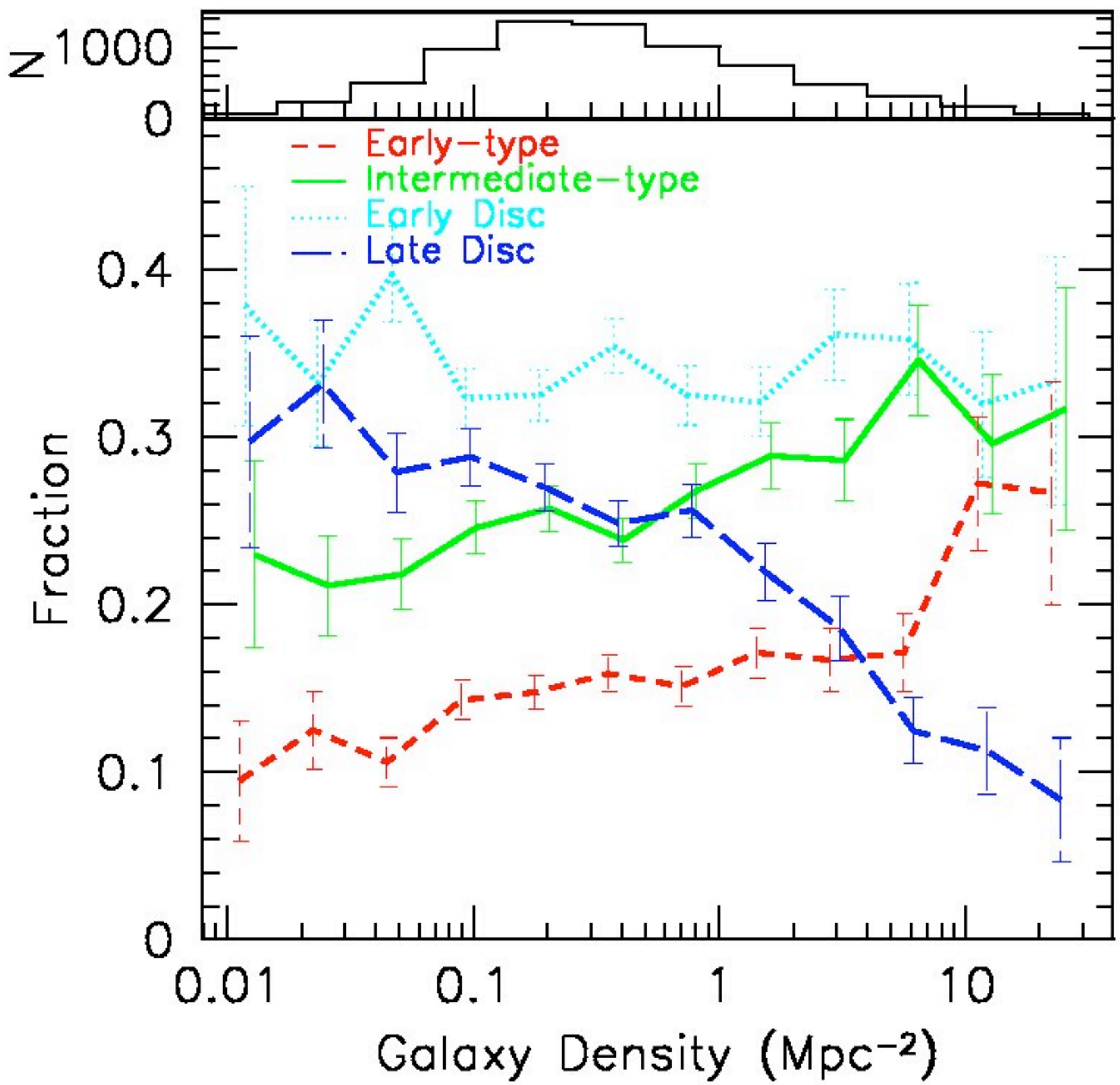
The Butcher-Oemler effect





$\chi_\nu = 1.36$
Z_{SP}
Z_{PH}
$\chi_\nu = 1.74$
f_B
Redshift

The morphology density relation



Galaxy scaling relations

Kormendy relation

Faber-Jackson relation

What is this?

Fundamental plane

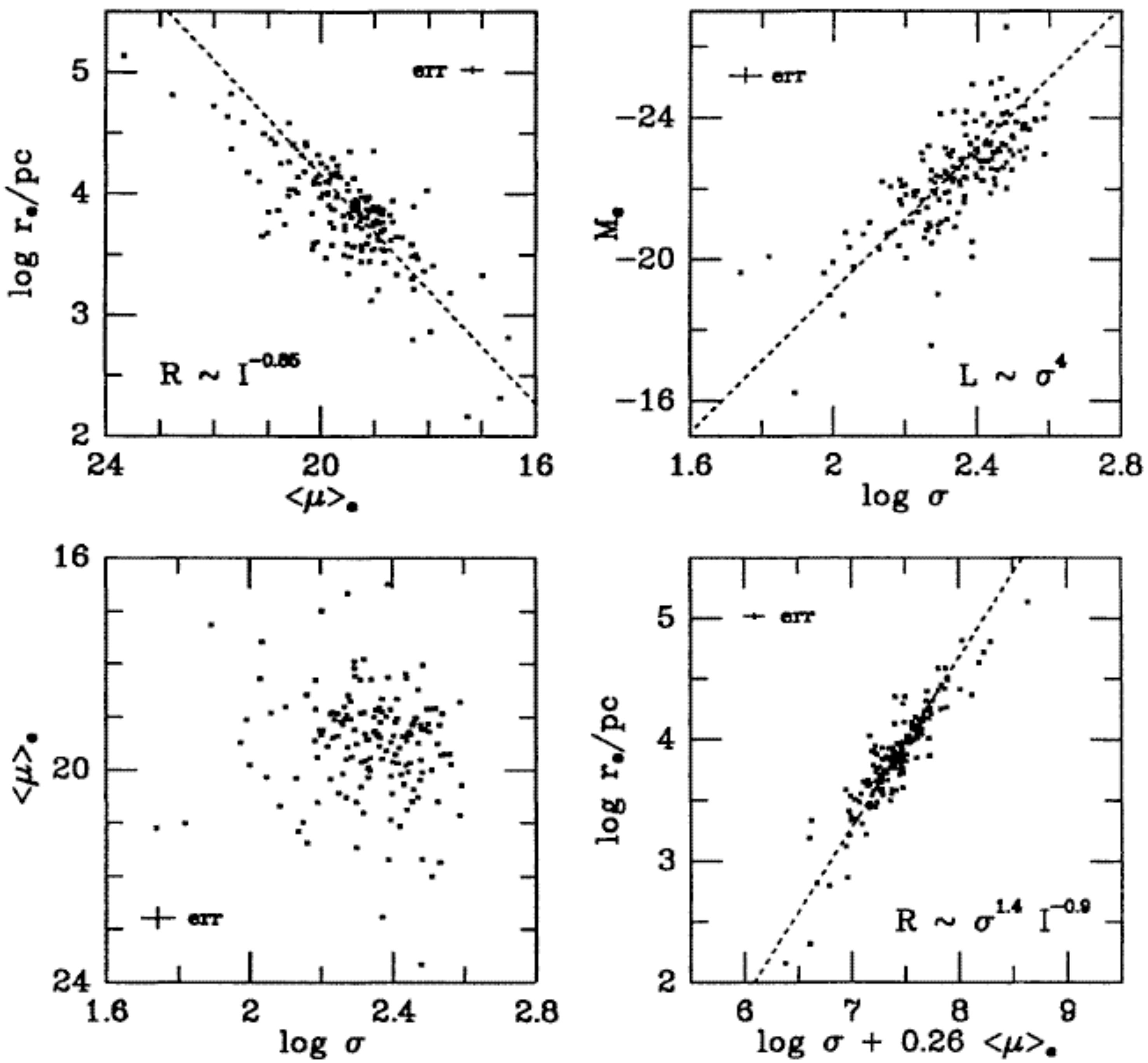
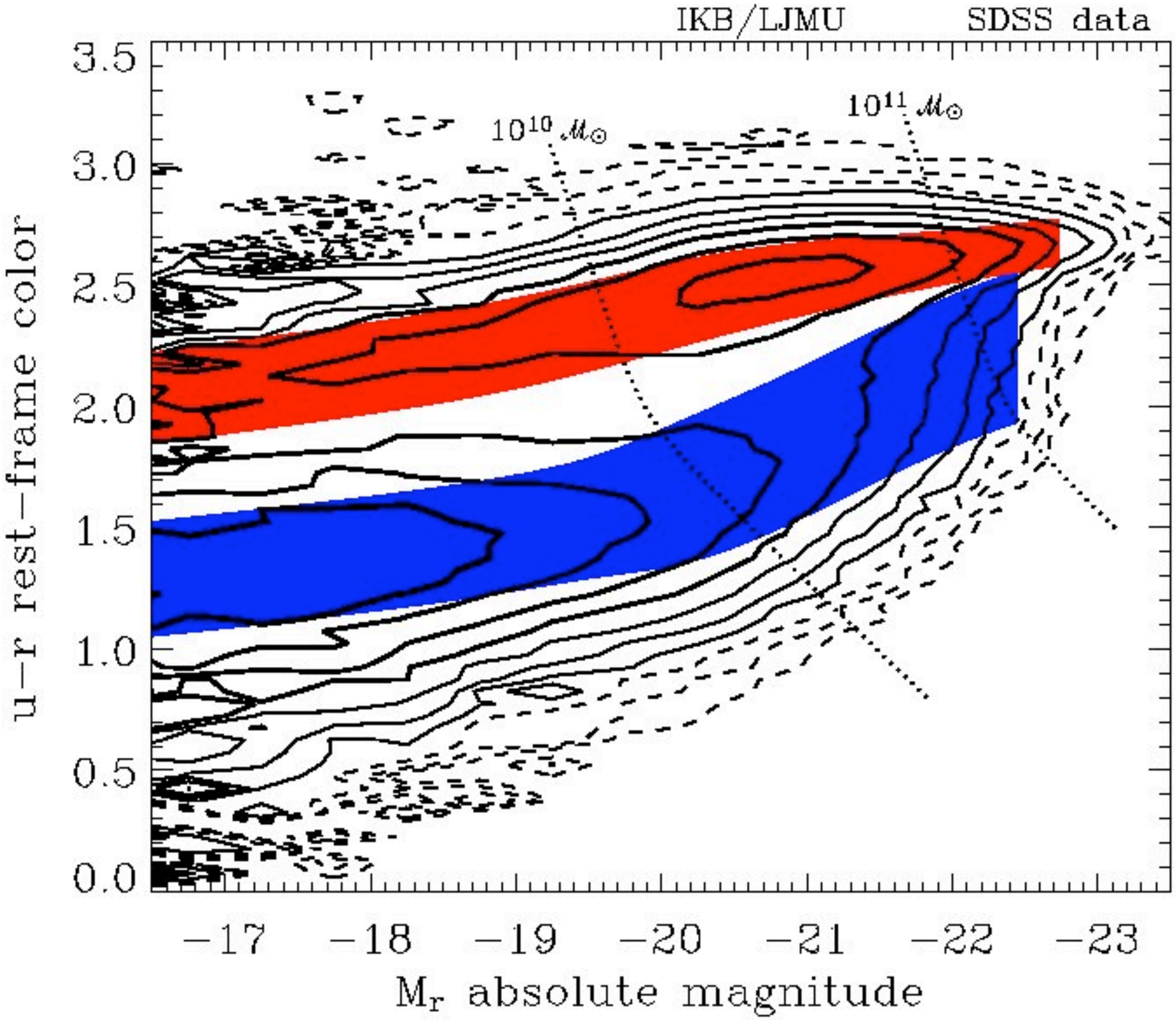
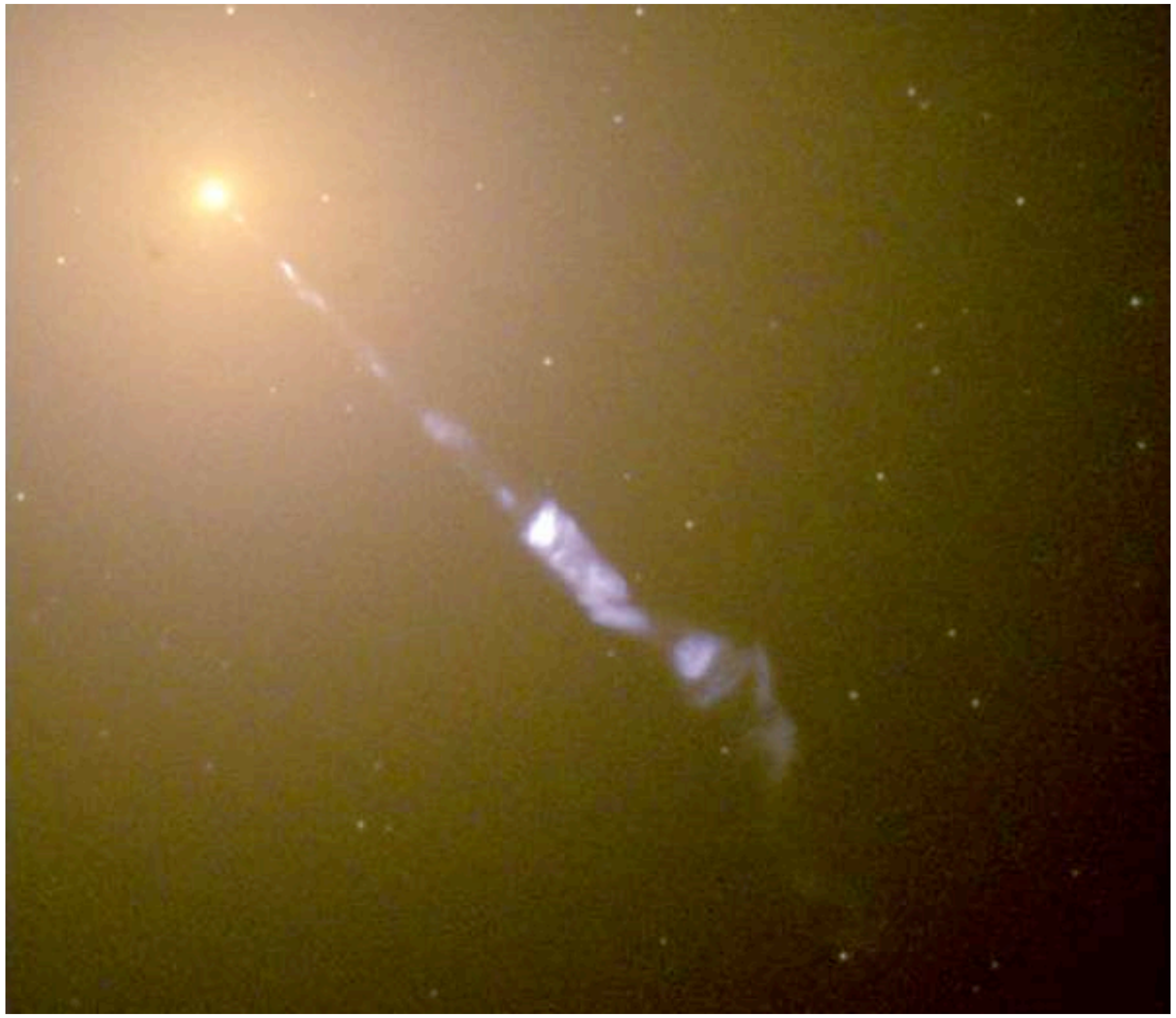


Figure 2 Projections of the fundamental parameter plane of elliptical galaxies. *Top panels*:

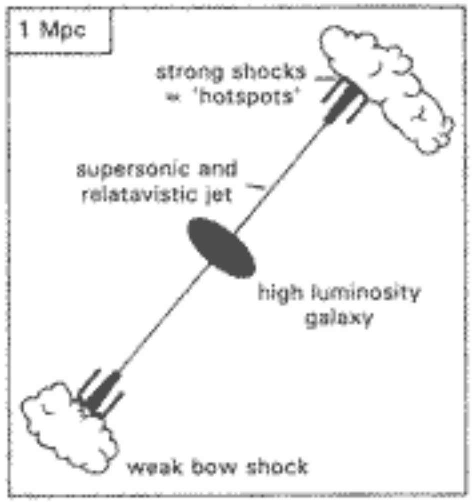
Colour bimodality



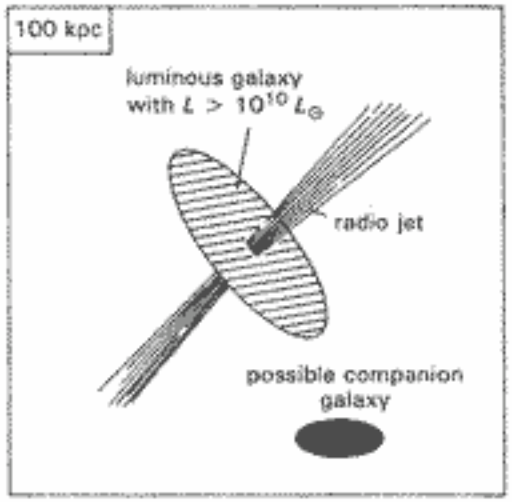
Active galaxies



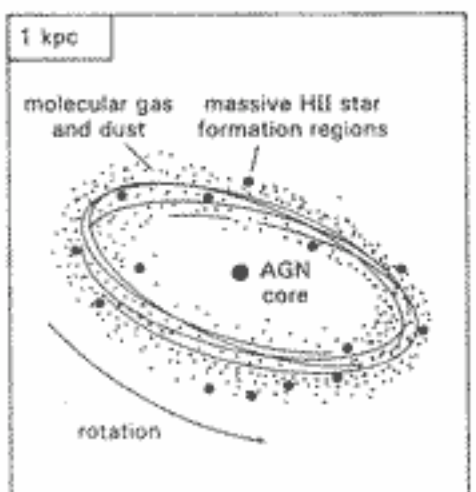
HST view of M87 in the Virgo cluster



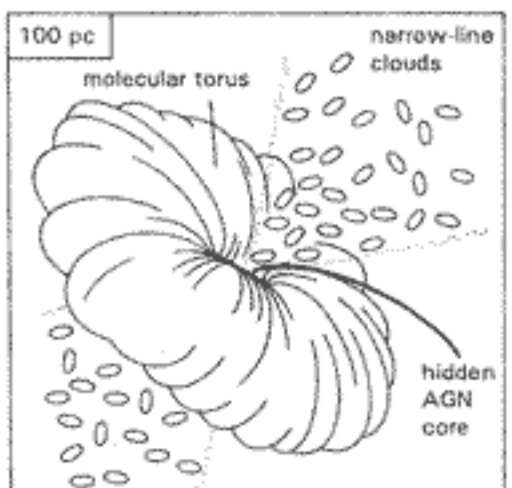
Extended radio sources — shown is an FRII source with an edge-brightened structure. The FRIs have lower jet velocities and fade-out to the ends.



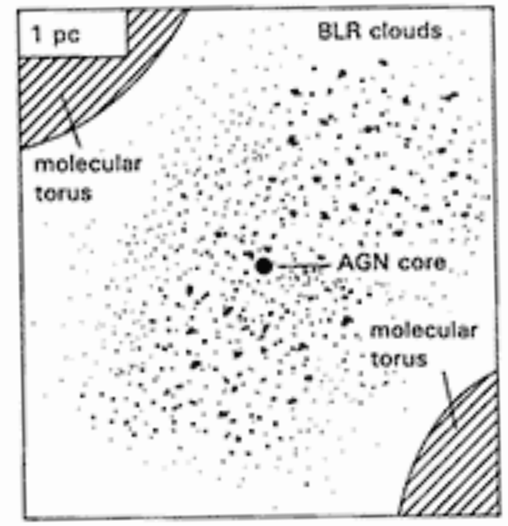
The host galaxy. Although shown as an early type galaxy with a smooth profile, it could also be highly irregular with multiple nuclei as a result of merging.



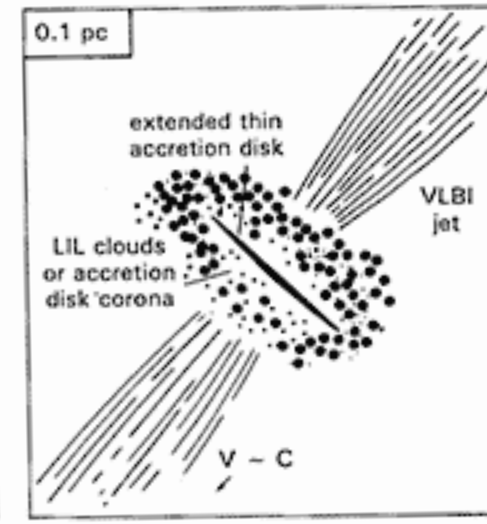
The central kpc star formation disk. This strong far infrared emitting zone might be fed by a bar structure, as seems to be the case for NGC1068.



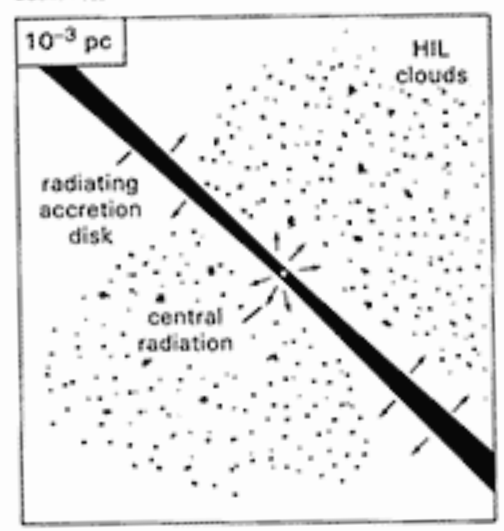
The narrow-line region comprising small but numerous clouds of the interstellar medium ionized by the central AGN core.



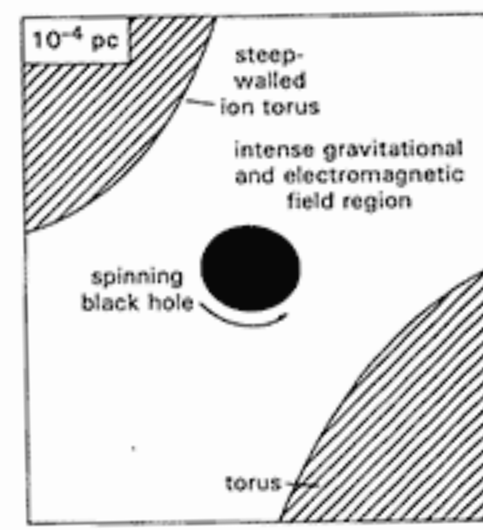
The outer extent of the broad-line region and the deep-walled molecular torus which can provide an effective shield of the central AGN, depending on the relative orientation of the observer.



Inside the molecular torus — the VLBI jet becomes self-absorbed closer in, and the low ionization lines of the BLR, which might be the corona of the accretion disk.



The accretion disk which radiates strongly at UV and optical wavelengths. The high ionization clouds of the BLR are excited by the central continuum radiation field.



The black hole. The Schwarzschild radius for a $10^8\ M_{\odot}$ black hole is 2 AU (10^{-5} pc). The spin will introduce twisted magnetic field lines and particle acceleration.

Name	Radio	Observational Characteristics
Seyfert 1	RQ	moderate luminosity ($M_B > -23$); strong/visible blue optical continuum; host galaxy clearly visible; broad + narrow lines; narrow lines have high ionization; radio quiet
Seyfert 2	RQ	as for Seyfert 1, but weaker/no blue optical continuum & only narrow lines visible
QSO	RQ	Radio quiet quasar; optically luminous ($M_B < -23$); host galaxy barely/not visible; strong optical continuum; broad + narrow lines of high ionization
QSO-2	RQ	same as QSO but missing broad lines; not many currently known (some are IRAS-QSOs)
LINER	RQ/L	Low Ionization Nuclear Emission Line Region; weak/no continuum; narrow lines of low ionization & moderate strength; sometimes weak broad Hα visible; can be either radio quiet or loud
BLRG	RL	Broad Line Radio Galaxy; similar to Seyfert 1 but radio loud
NLRG	RL	Narrow Line Radio Galaxy; similar to Seyfert 2 but radio loud
PRG-II	RL	Powerful Radio Galaxy of Fanaroff-Riley class II (edge brightened, powerful jet); unspecified optical spectrum (could be BLRG/NLRG/LINER)
RG-I	RL	Similar to PRG-II except lower radio luminosity & Fanaroff-Riley class I (edge darkened, lower power jet)
LD-QSR	RL	Lobe Dominated (steep spectrum) Radio Loud Quasar; usually FR-II radio morphology; optically similar to QSO
CD-QSR	RL	Core Dominated (flat spectrum) Radio Loud Quasar; optically similar to QSO
BL-Lac	RL	Strong featureless continuum, no/weak lines, little starlight; highly variable; high polarization; radio loud flat spectrum core
OVV-QSR	RL	Optically Violently Variable Quasar; similar to BL Lac but normal QSO spectrum

- Over the years, many different categories of AGN have been identified, each with its own name. In hindsight, this apparent diversity has three distinct components:
    - **Genuine** variation in one or more **key properties** of AGN
    - **Apparent** variation arising from our particular **viewing angle**
    - Variation which arises from observing the object at a **particular stage in its evolution**.

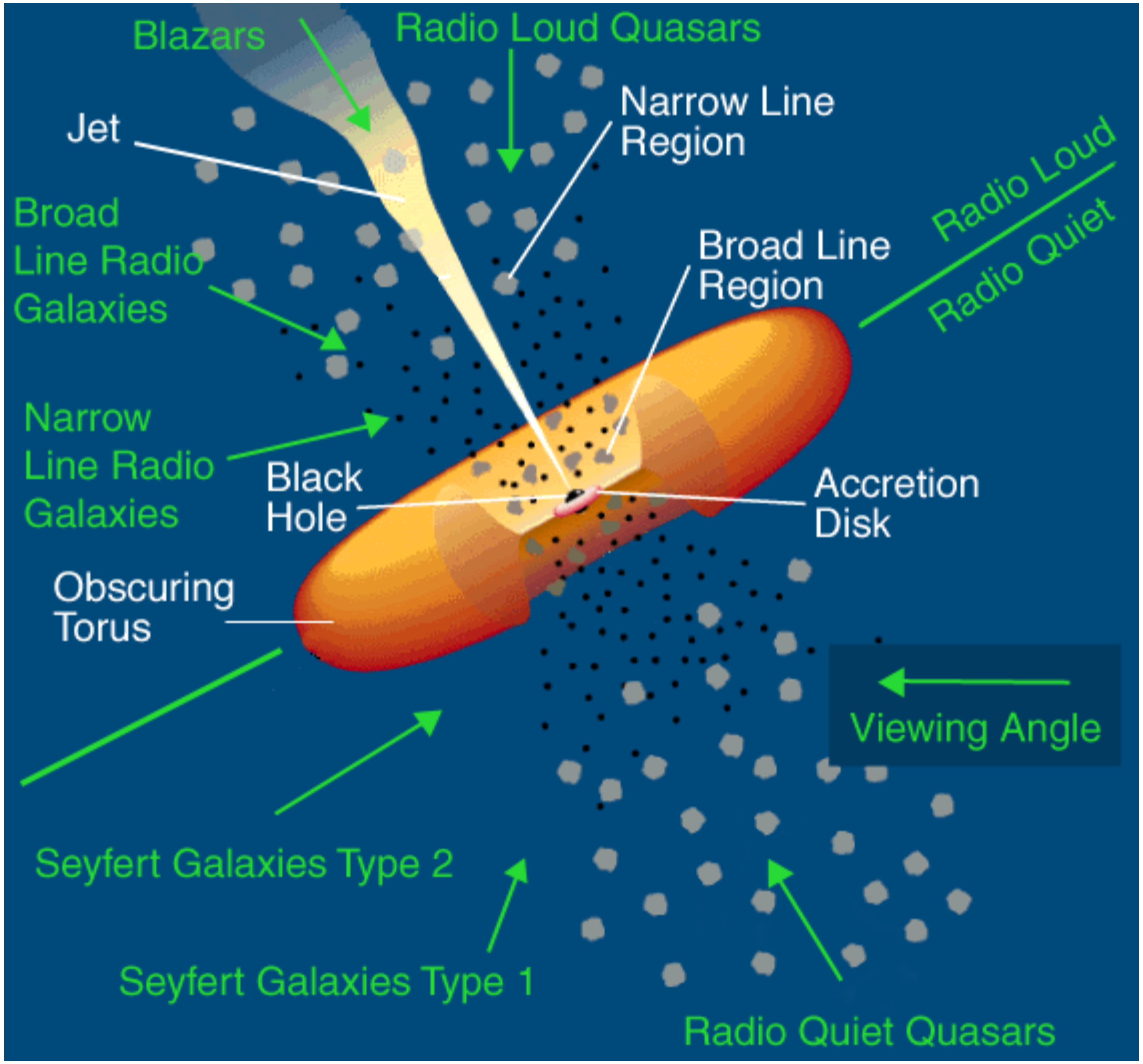
- There are (at least) **two** genuine ways in which AGN differ from each other:
    1. UV/opt/IR luminosity: This probably tracks the accretion rate and black hole mass.
       Three categories:
       Quasars (L_{nuc} L_{gal});
       Strong AGN (L_{nuc} L_{gal});
       Weak AGN ($L_{nuc} << L_{gal}$).

    2. Radio Luminosity: determined mainly by the jet power
       The cause of jet power isn't known : possibly black hole spin and/or disk temperature?
       Two categories:
       Radio Quiet (L_R 10^{-4} L_{opt})
       Radio Loud (L_R 10^{-2} L_{opt})

- There are (at least) **two** differences which seem to depend on viewing angle
    1. Emission Line Shapes: do we get a clear view to the inner (BLR) region, or not.
       Two categories:
       Broad + Narrow lines (**can** see the BLR)
       Narrow lines only (**can't** see the BLR).

    2. High variability & high polarization: this depends whether we look directly down a fast jet.
       Two categories:
       a. High variability & polarization (look down jet);
       b. Low variability & polarization (look at some other angle).

A unified model?



Major astronomical surveys:

- SDSS and 2dF: large local redshift surveys
  - 250,000 to 1,000,000 galaxies + AGN with spectra
  - r_spec < 19, r_phot < 22, z < 0.3
- Deep2 and VVDS: large, distant galaxy surveys
  - 10,000s of galaxies with spectra
  - i_spec < 24, 0.8 < z < 1.2
- HDF N&S and UDF: ultradeep HST fields
  - i ~ 29 over 9 arcmin^2
- RASS: all-sky X-ray imaging survey
- XMM-LSS: 10 deg2 X-ray imaging survey
- FIRST: all sky radio survey