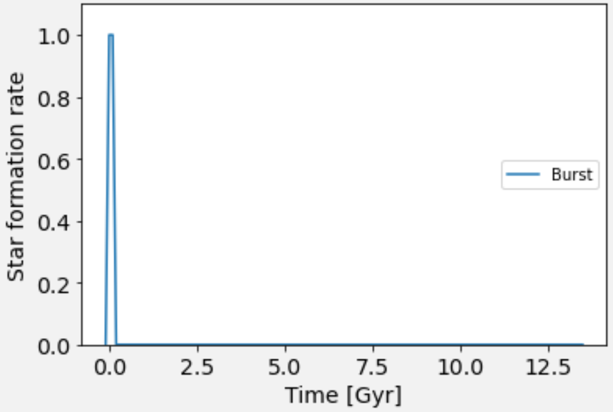
Spectral Evolution of different stellar populations

SFR(t): single burst at t=0

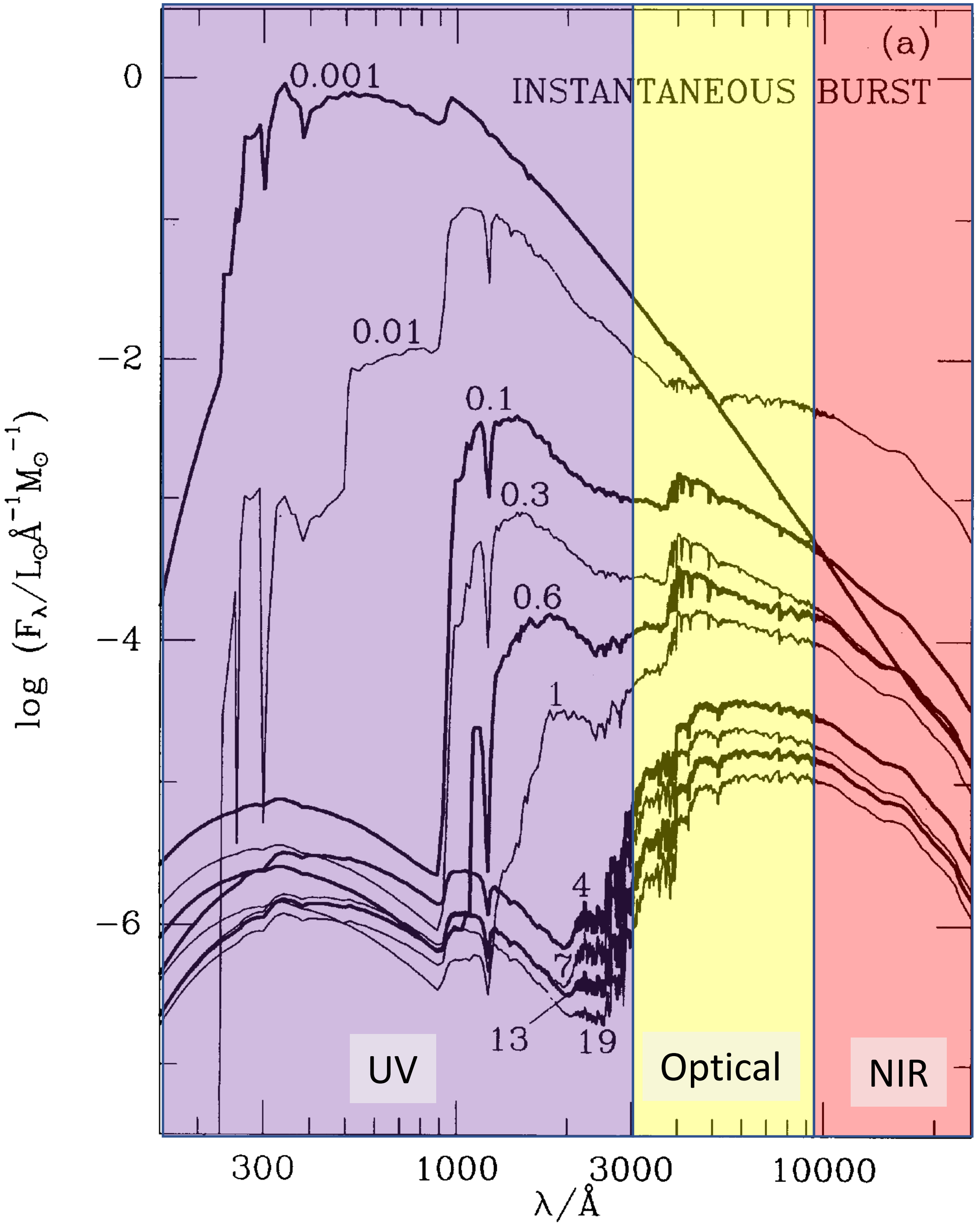
Ages marked in Gyr



UV light decreases very fast, since all the massive young blue O and B stars that provide that light are dying out quickly.

At later times, the (weak) UV light comes from evolved horizontal branch stars.

Optical and NIR light drop more slowly as lower mass stars begin to die out over longer time scales.

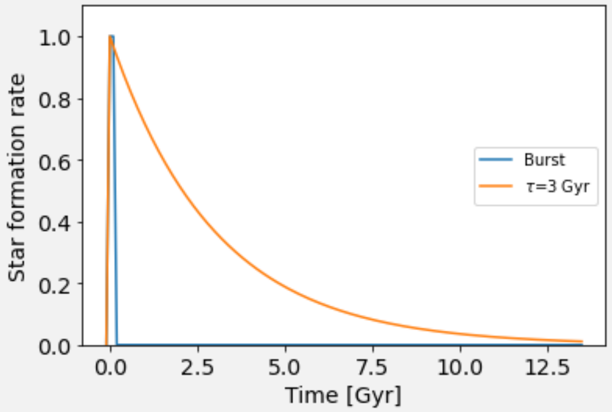


Bruzual & Charlot 1993

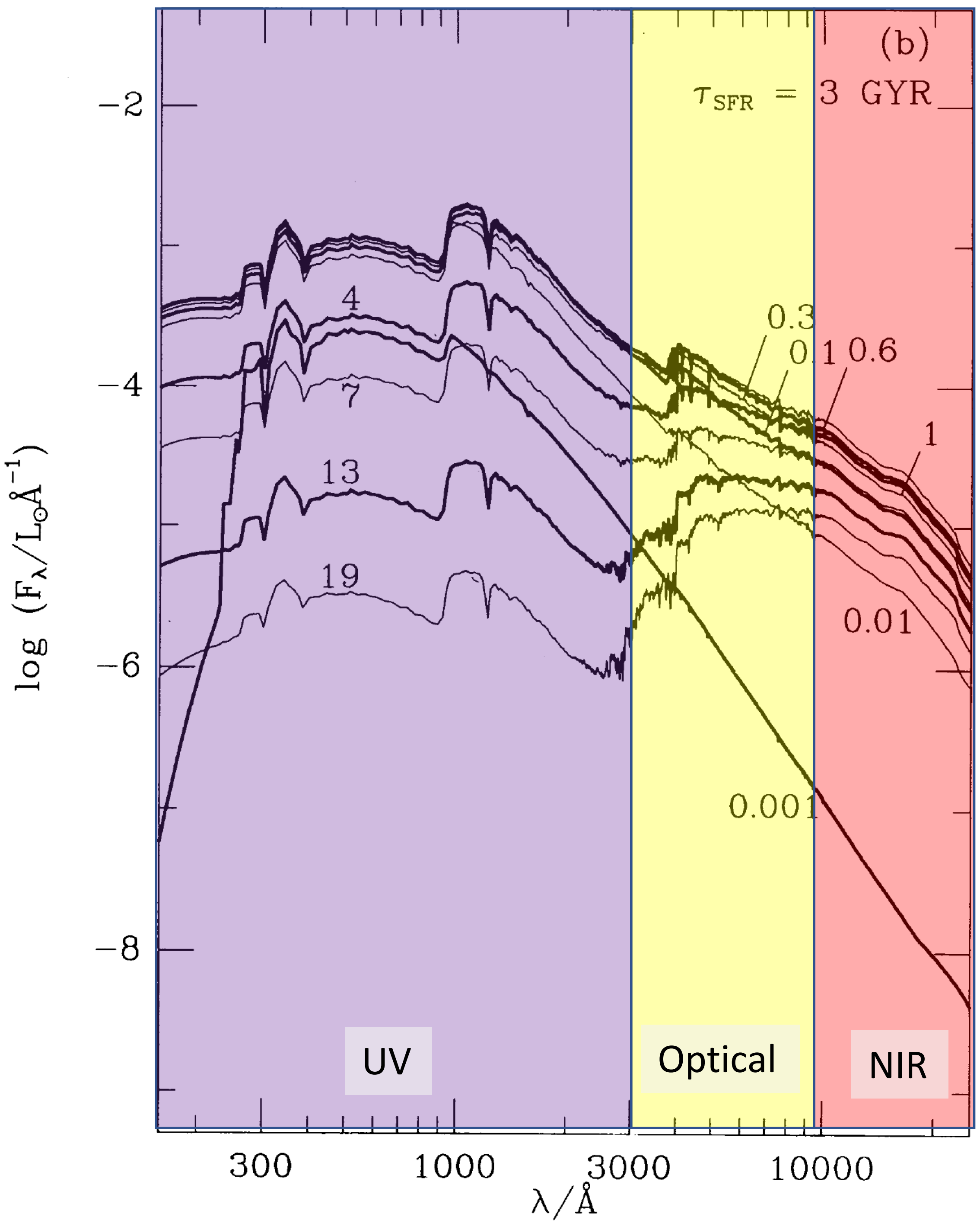
Spectral Evolution of different stellar populations

SFR(t): $e^{-t/\tau}$, τ=3 Gyr

Ages marked in Gyr



UV light does not drop so quickly because you continue to make stars (although at a slower rate), including O and B stars that can produce UV light.

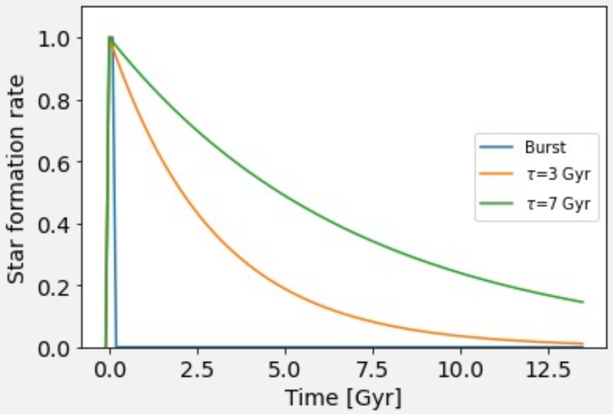


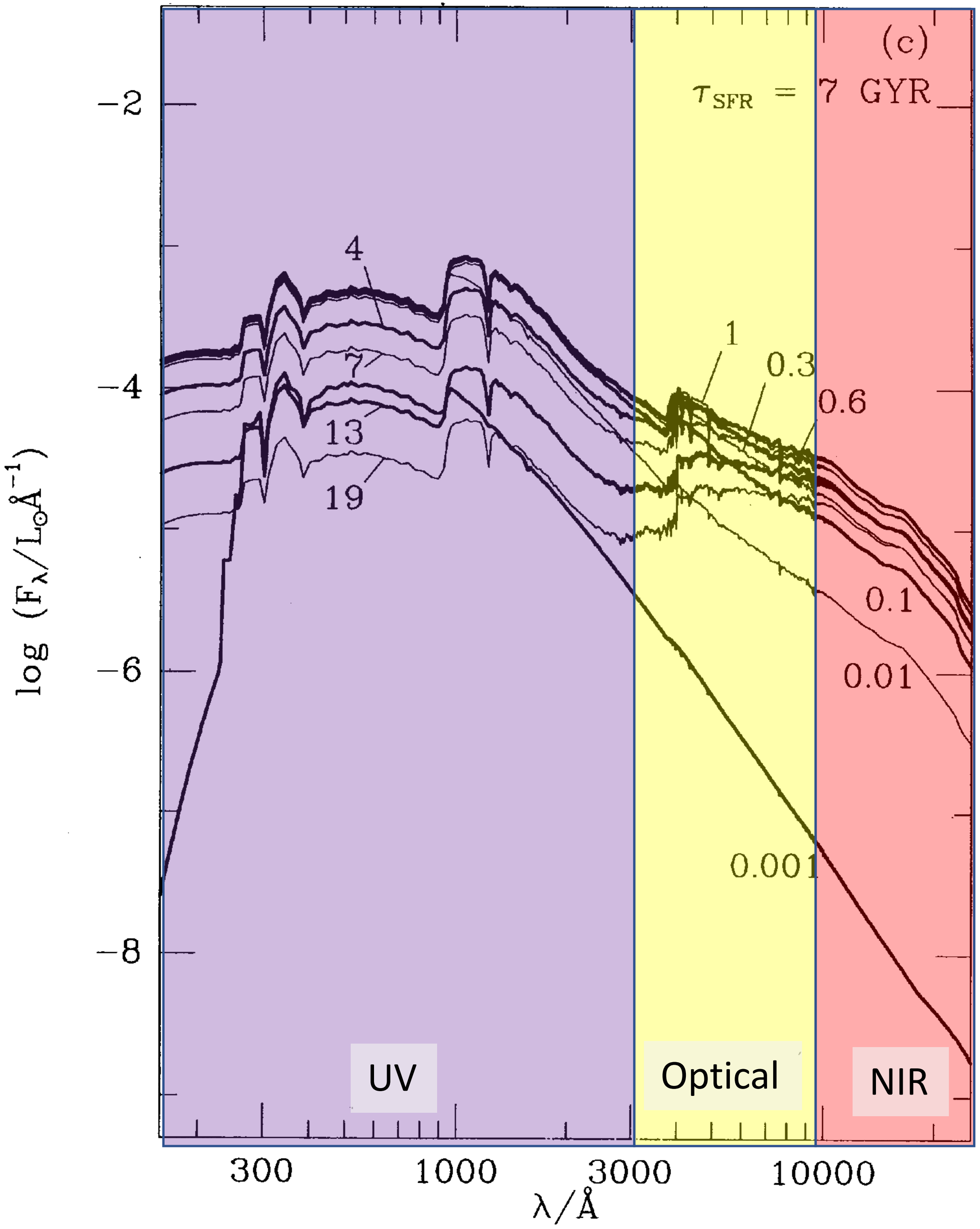
Bruzual & Charlot 1993

Spectral Evolution of different stellar populations

SFR(t): $e^{-t/\tau}$, τ=7 Gyr

Ages marked in Gyr



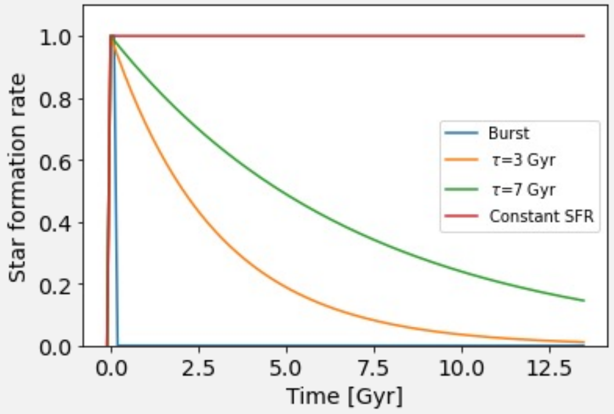


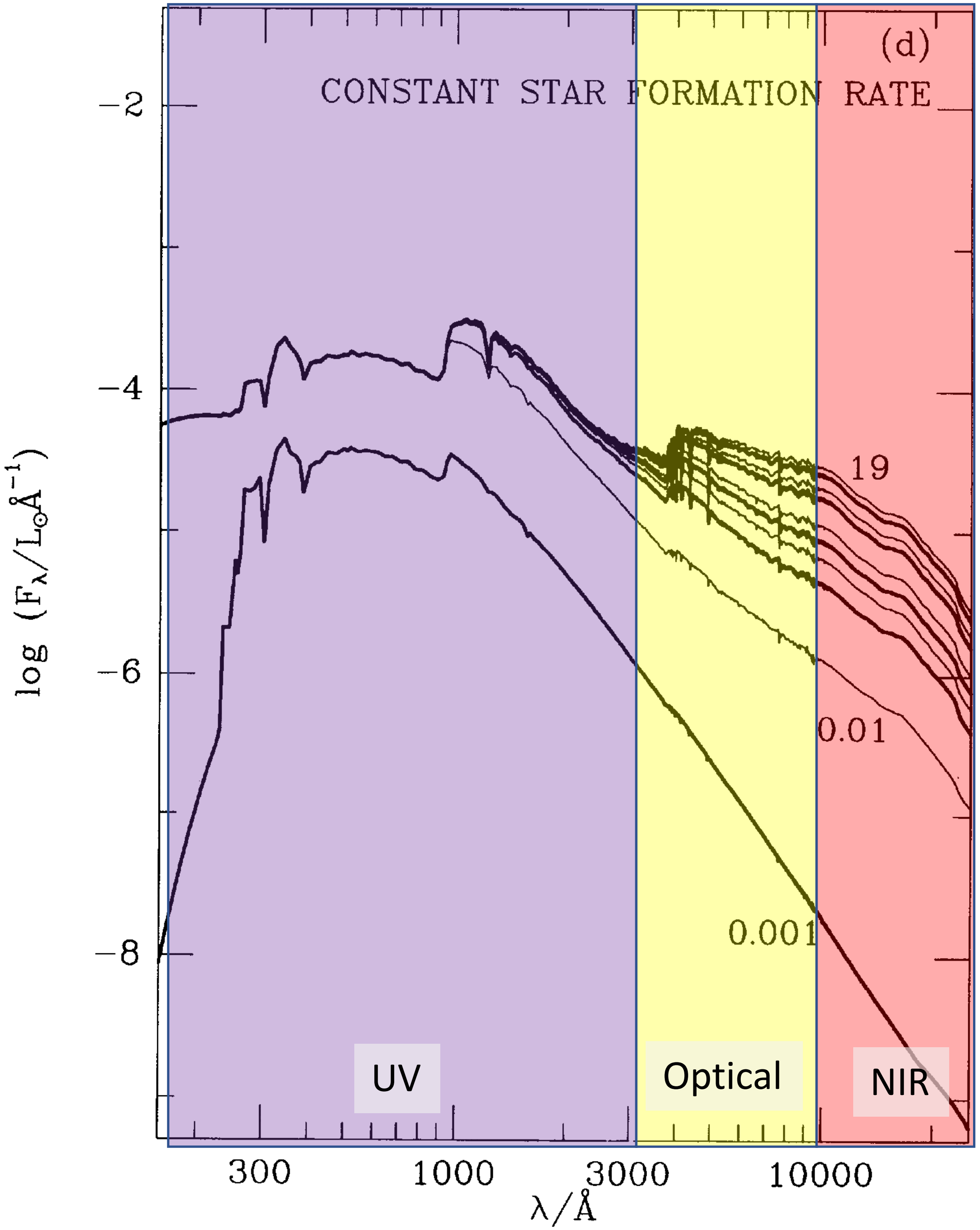
Bruzual & Charlot 1993

Spectral Evolution of different stellar populations

SFR(t): constant over time

Ages marked in Gyr





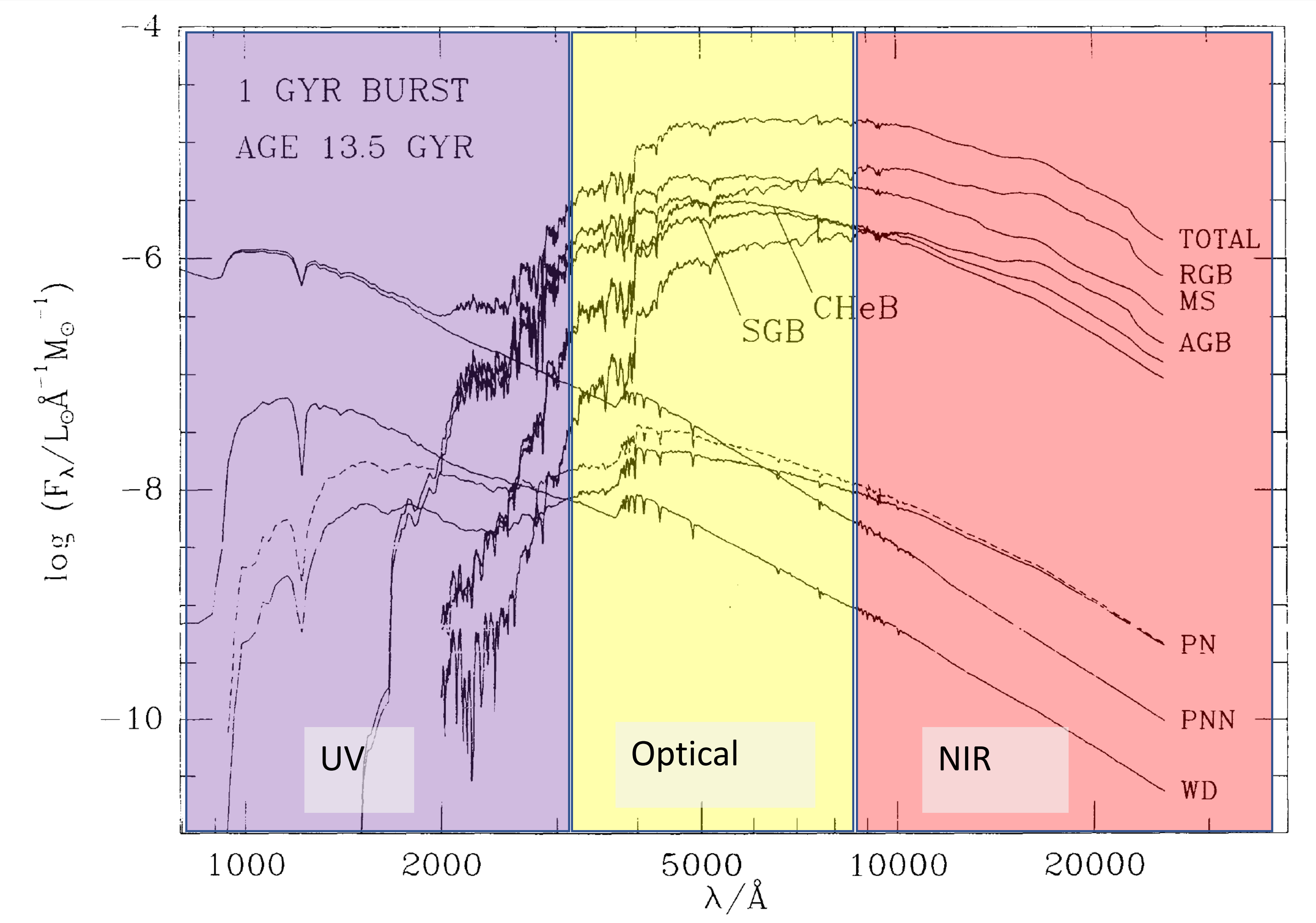
Bruzual & Charlot 1993

Contribution from different evolutionary stages

Old, single burst population

In optical and infrared, light is dominated by RGB stars, MS stars, and horizontal branch stars (CHeB).

In UV, much less light, and it is dominated by horizontal branch stars (CHeB) and planetary nebula nuclei (PNN).



Bruzual & Charlot 1993

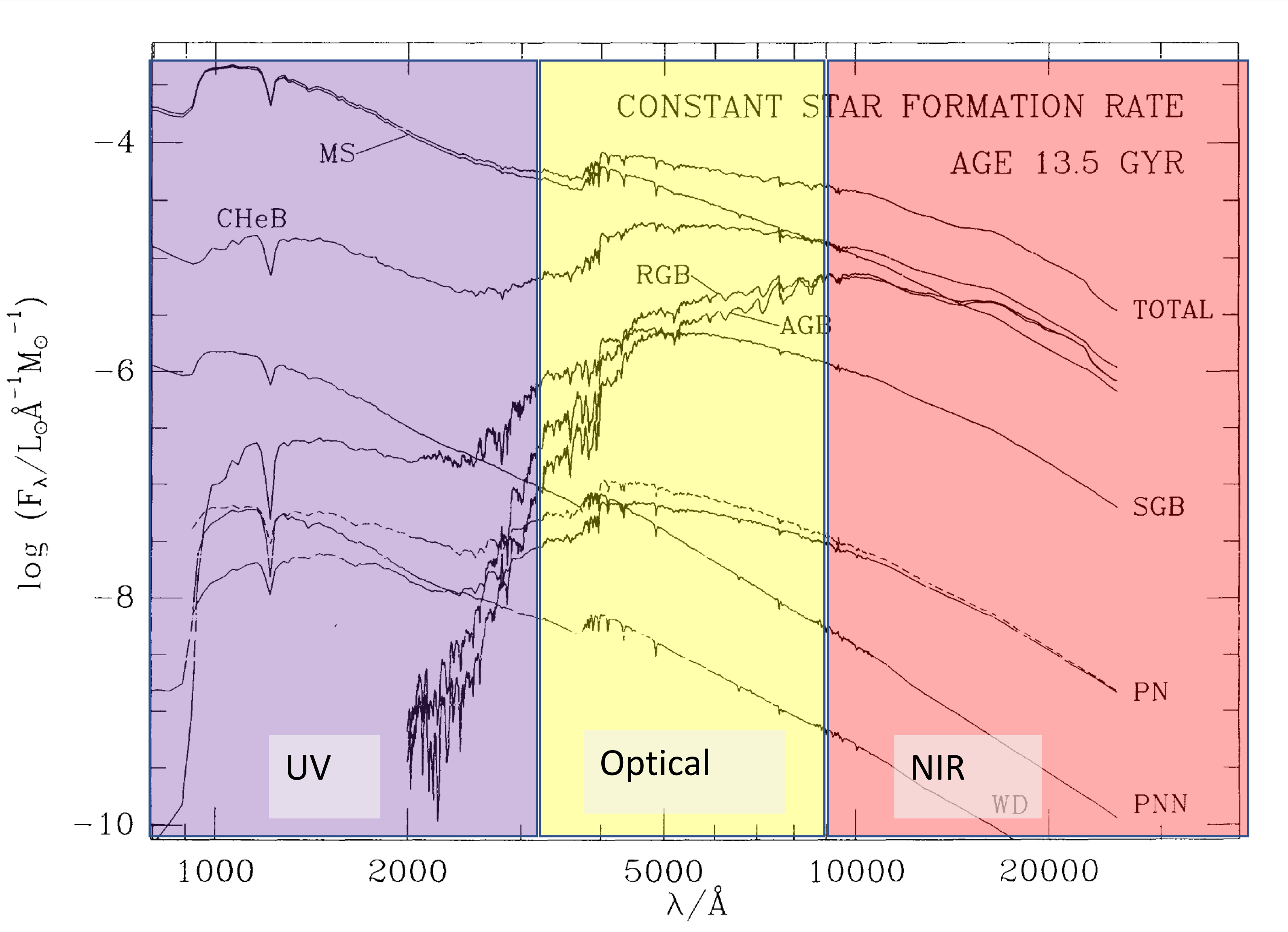
Contribution from different evolutionary stages

Constant star-forming population

In optical, light is dominated by MS stars, except at the reddest colors.

In the IR, evolved stars contribute much of the light.

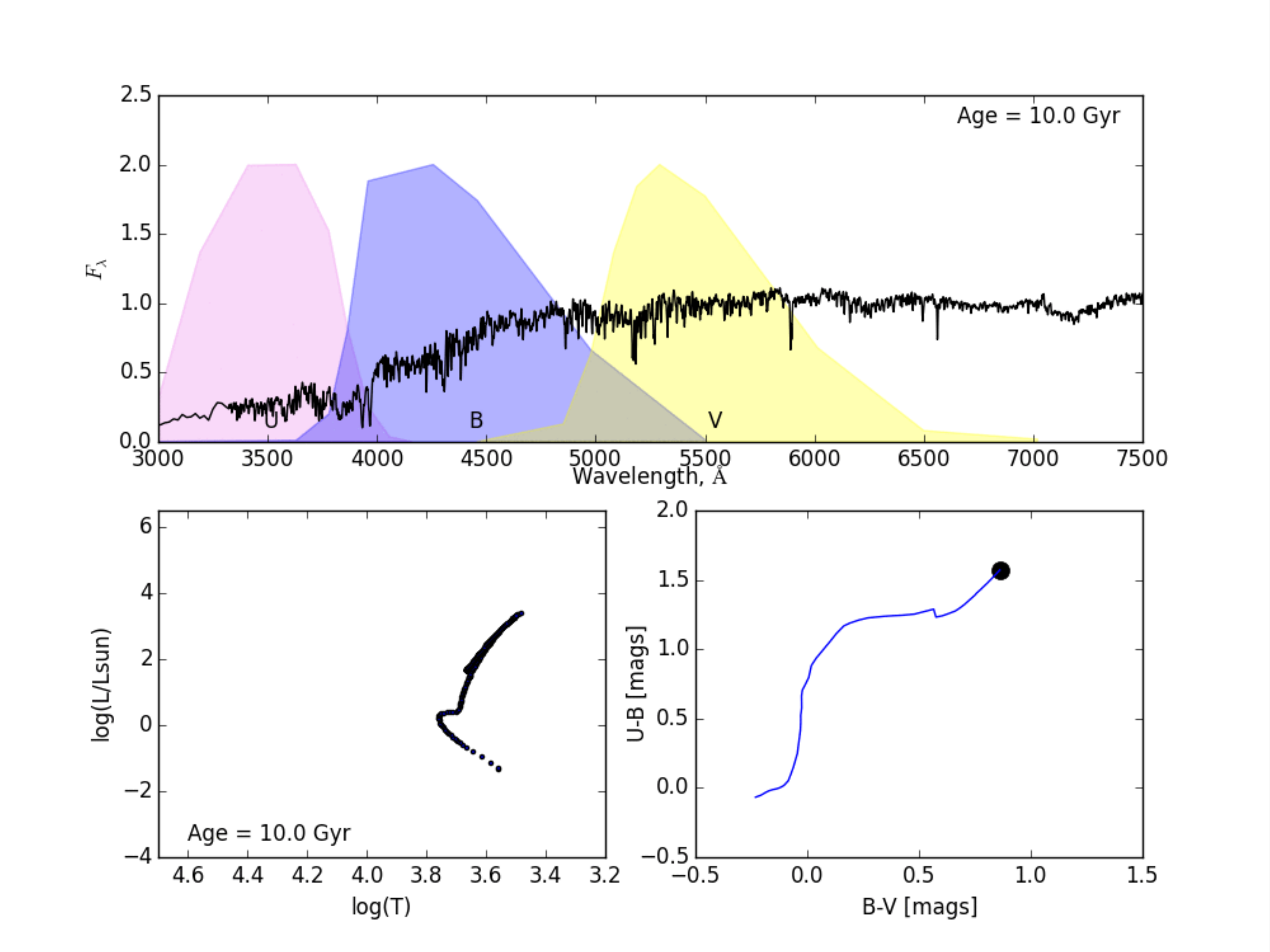
Very bright in the UV, from massive young stars on the upper main sequence.



Bruzual & Charlot 1993

Observables: Colors

Imaging and photometry is “quick and easy”: Can study the colors, color gradients, etc of galaxies.



Evolution of a single burst population

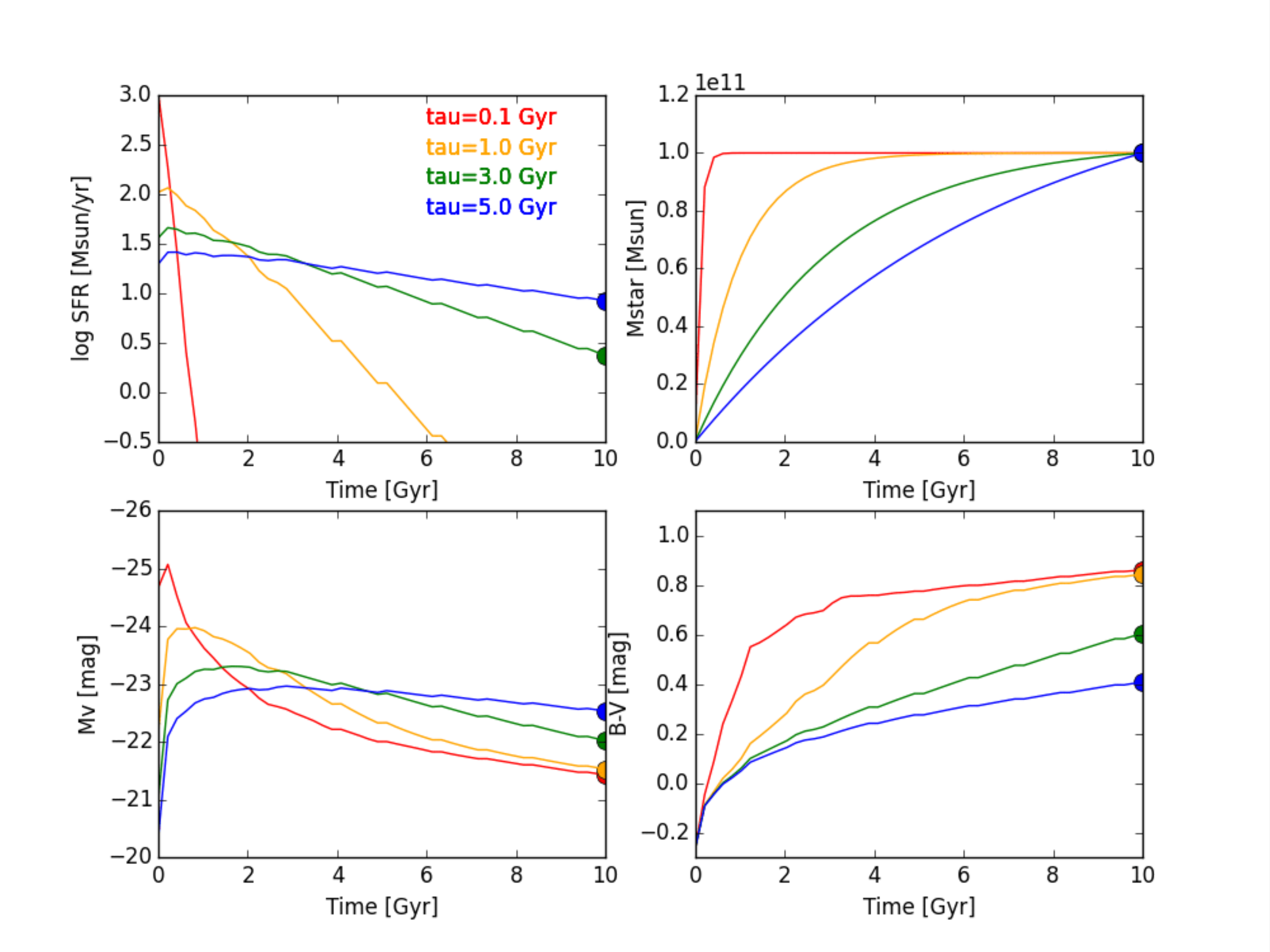
Top: Integrated light spectrum
Bottom left: evolving CMD
Bottom right: evolving integrated colors.

Remember: when looking at colors, smaller or more negative numbers means bluer colors.

(see the course website for a link to the animated figure…)

Observables: Colors

Imaging and photometry is "quick and easy": Can study the colors, color gradients, etc of galaxies.



Evolution of a different star forming histories

$$SFR(t) = Ce^{-t/\tau}$$

Small tau: fast burst
Large tau: slowly declining SFR

Fast bursts: As massive stars quickly die out, they fade rapidly and turn red.

Slowly changing SFR: Constantly replenishing stars of all types through new star formation. Fade slowly or not at all, don't get as red.

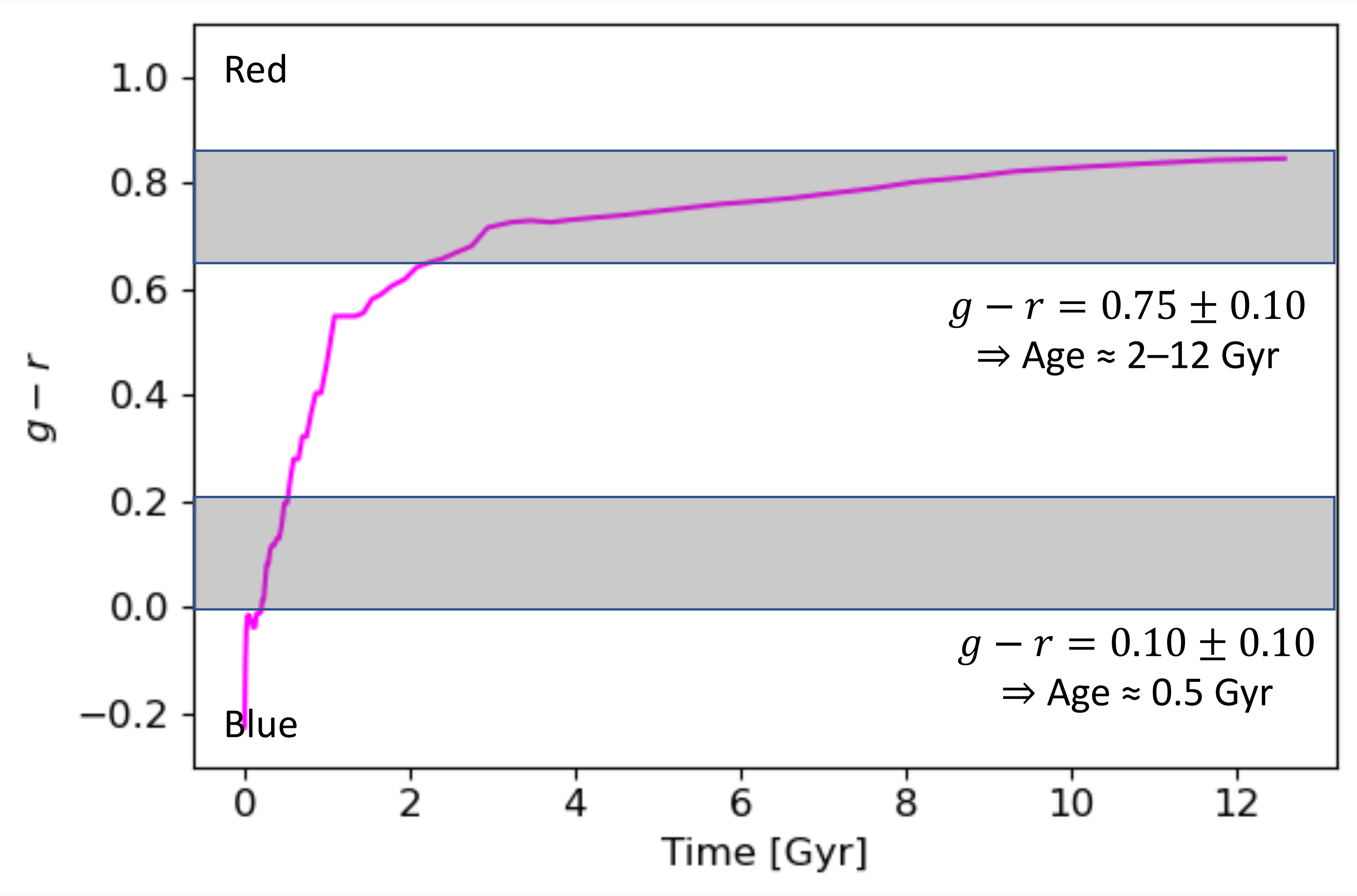
(see the course website for a link to the animated figure…)

Colors, ages, and metallicity

Colors evolve rapidly for young populations (<2 Gyr), but then the color evolution is much weaker. This means constraining ages gets much more difficult for old populations.

Uncertainty in color can lead to a big uncertainty in age.

Color evolution for a single burst stellar population with solar metallicity.



Banana analogy
courtesy of Mia de los Reyes (Caltech)

Colors, ages, and metallicity

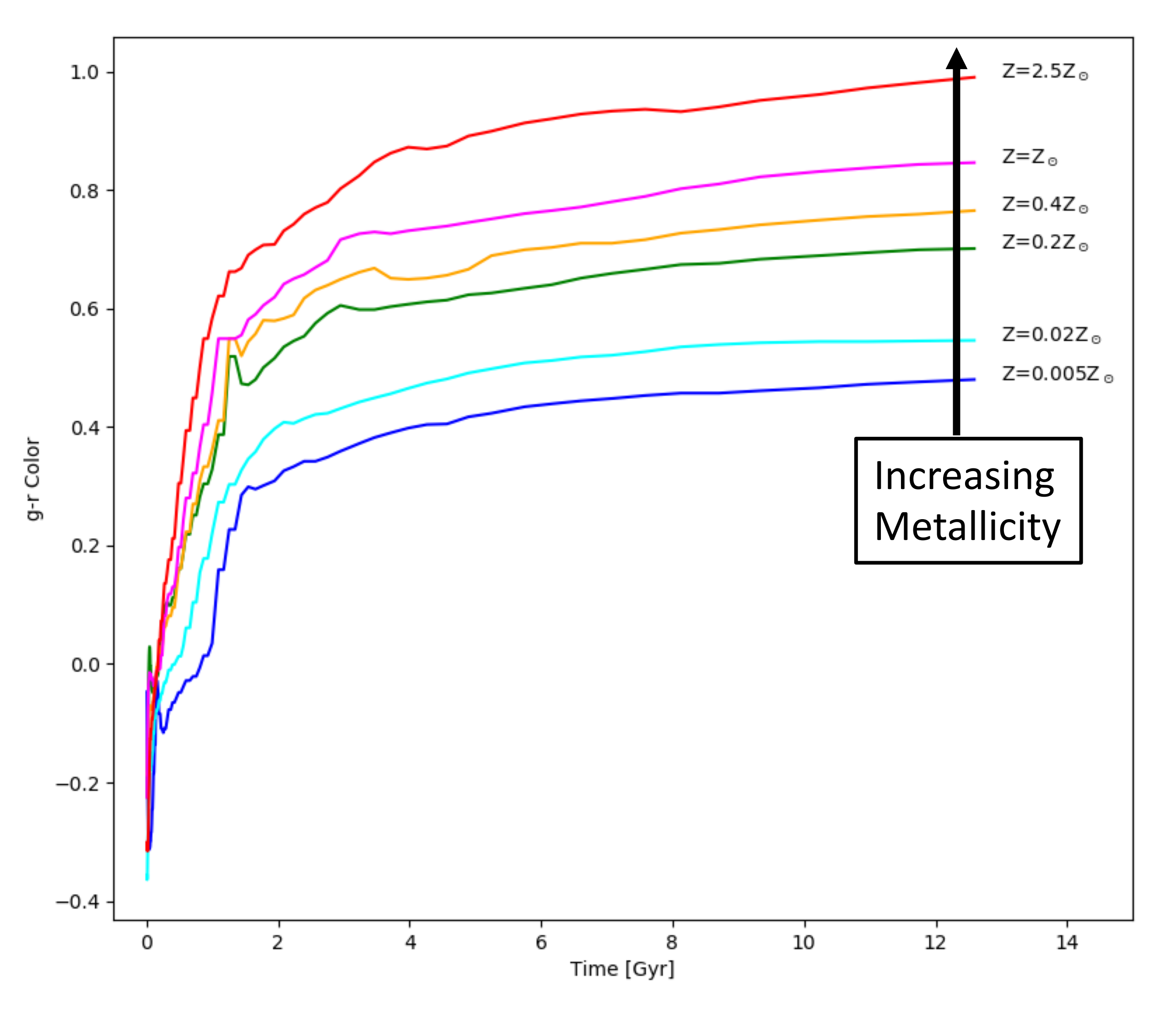
Colors evolve rapidly for young populations (<2 Gyr), but then the color evolution is much weaker. This means constraining ages gets much more difficult for old populations.

Uncertainty in color can lead to a big uncertainty in age.

They also suffer from the notorious "**age-metallicity degeneracy**". Since higher metallicity makes stars redder, if you see a blue population is it young, or is it metal poor?

Multiple colors (imaging in many filters) helps break this degeneracy since the evolution is different at different wavelengths.

….but we haven't even mentioned dust!



Observables: Spectra

Spectroscopy is "expensive": need big telescopes, multiobject spectrographs, etc. But delivers lots of information:

Overall shape ("continuum") tells you color.

Absorption lines gives you specific information about stellar ages and metallicities.

Emission lines (gas ionized by young stars) tells you information about the star formation rate and metallicity.

Kong+03

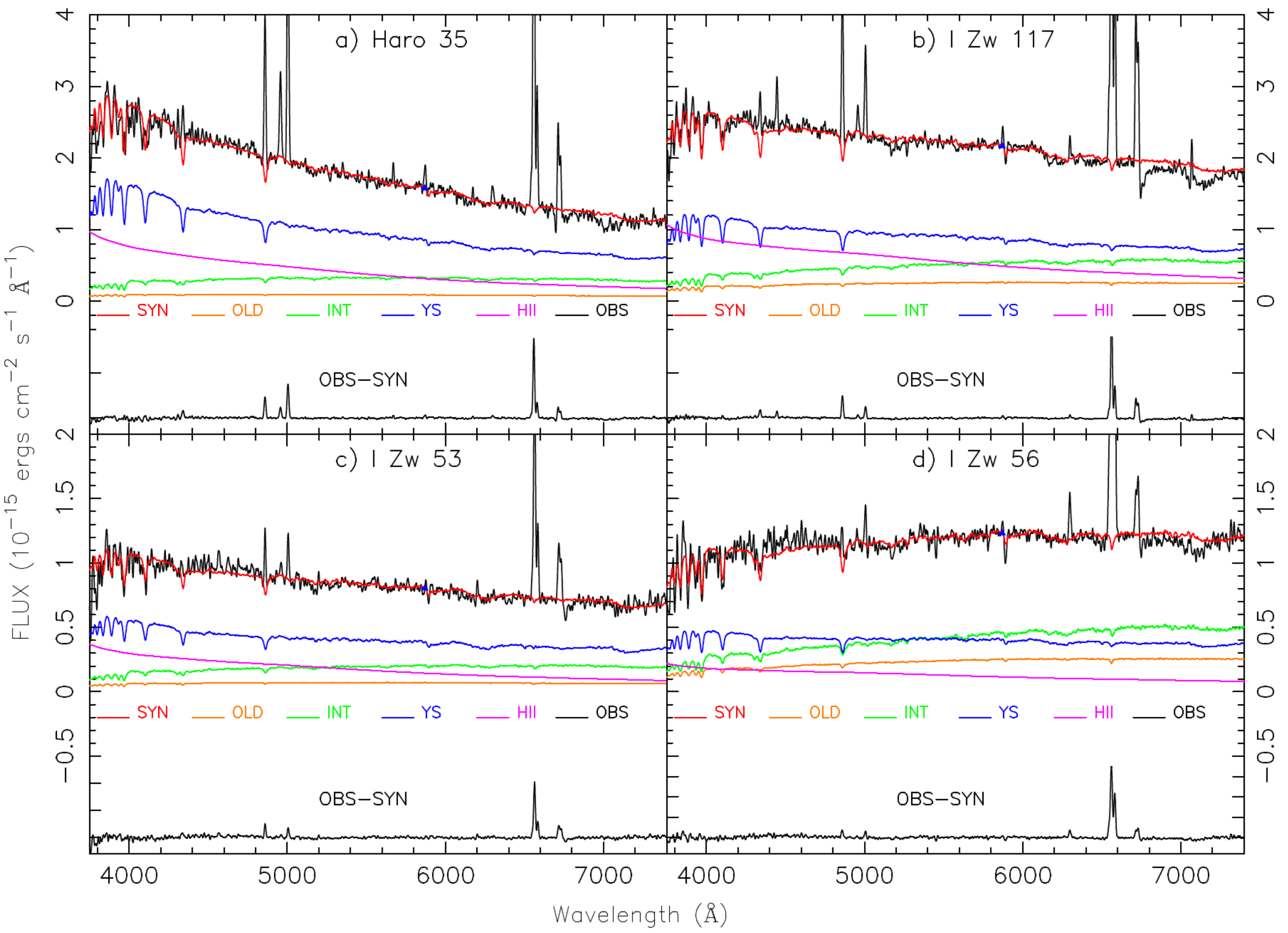
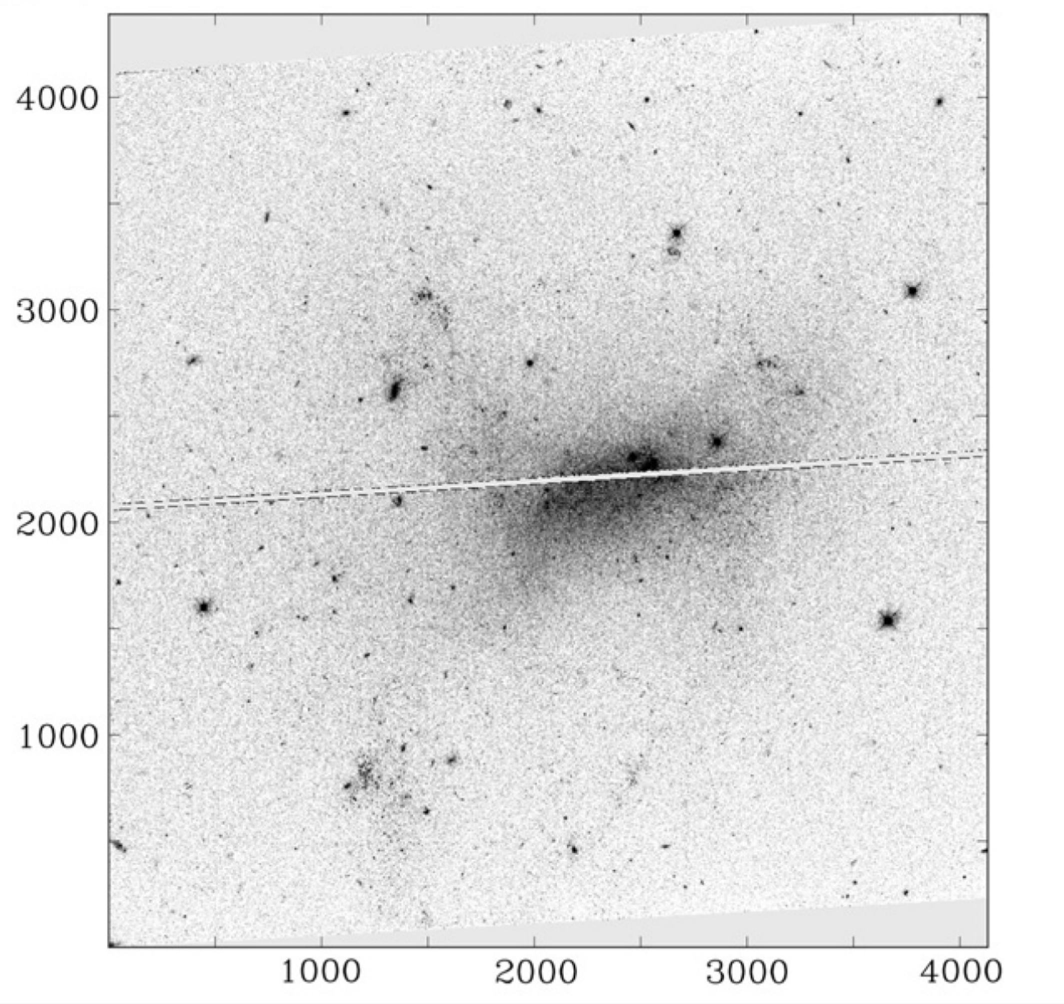


Fig. 3.— Comparison of synthetic spectra (red-solid lines) to the observed spectra of four BCGs (corrected for Galactic reddening; black-solid lines): Haro 35, I Zw 117, I Zw 53, and I Zw 56. The contributions to the synthetic spectra by old stars (OLD, 10^{10}yr), intermediate-age stars (INT, 10^9, 5×10^9yr), young stars (YS, 10^7 – 5×10^9yr), and newly-born stars (H II) are also shown. The emission line spectrum appears in the OBS–SYN difference, at the bottom of each panel.

Observables: Color Magnitude Diagrams

For nearby galaxies where we resolve individual stars, we can actually synthesize CMDs as well.



Observed CMD

Modeled CMD
(stars color-coded by age)

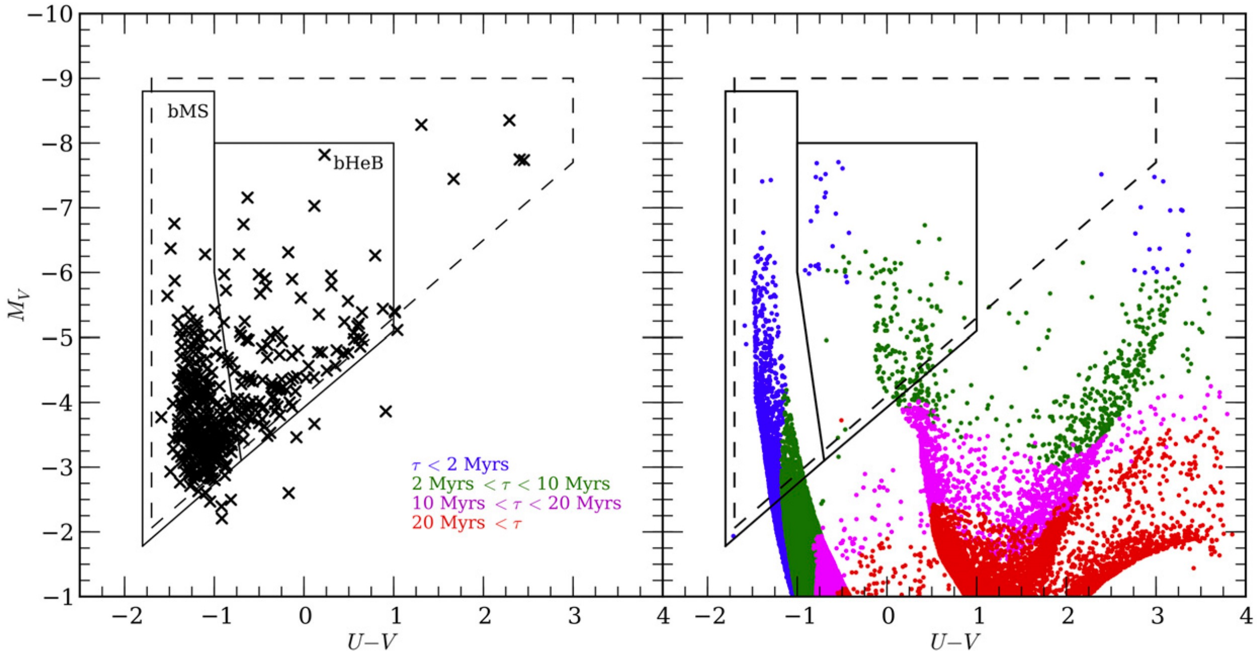


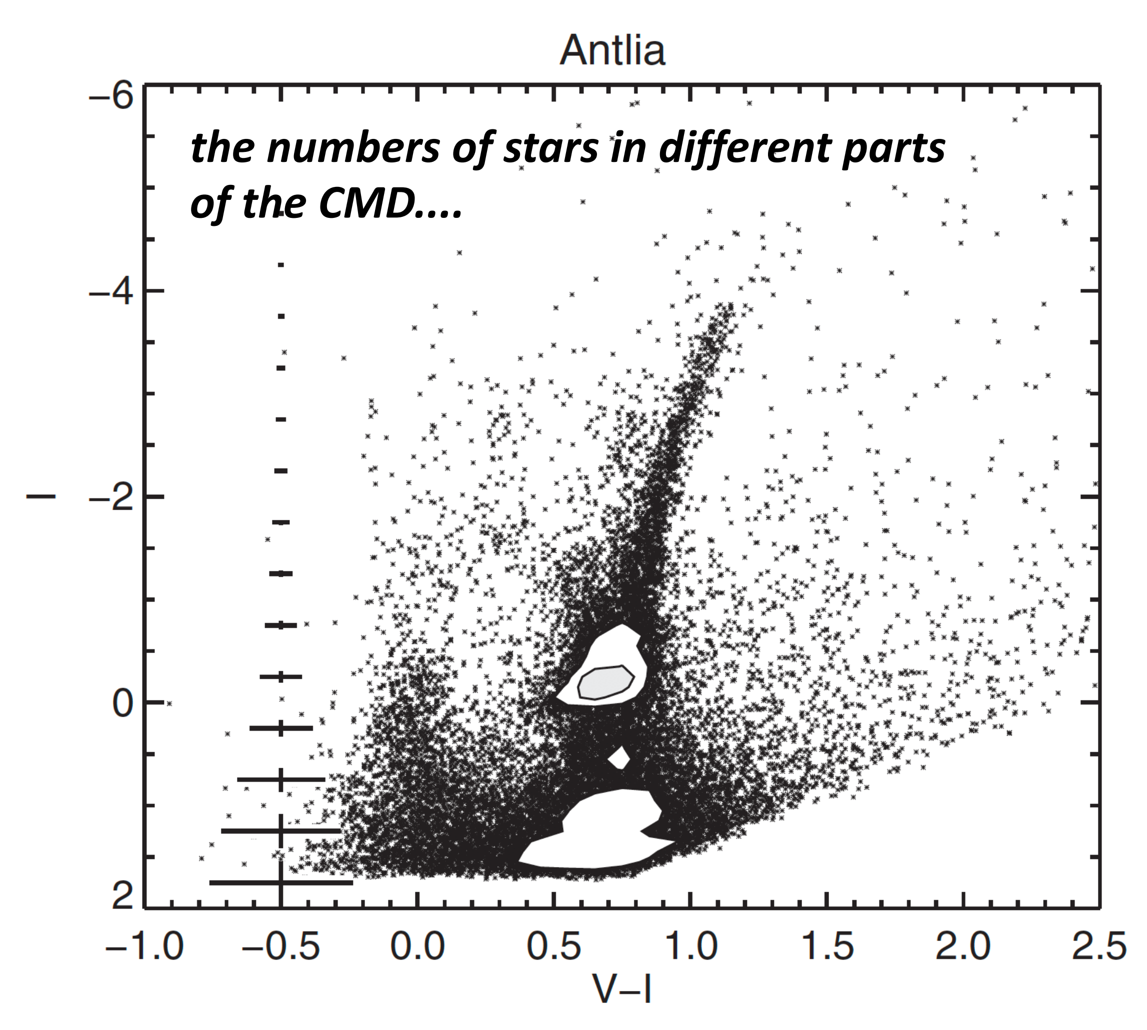
Figure 21. $U - V$ CMD for F415-3 compared with an IAC-STAR simulation of enhanced recent star formation ([Fe/H] = −0.4). The completeness, bMS, and bHeB regions are marked. The bMS and bHeB branches (measuring 2 and 10 Myr stars, respectively) are clearer in the $U - V$ plane than $V - I$, and the ratio of the bMS and bHeB stars will measure recent star formation on timescales of 2–10 Myr.

Schombert & McGaugh 2015

Observables: Color Magnitude Diagrams

For nearby galaxies where we resolve individual stars, we can actually synthesize CMDs as well.

Antlia Dwarf Galaxy
McQuinn+10



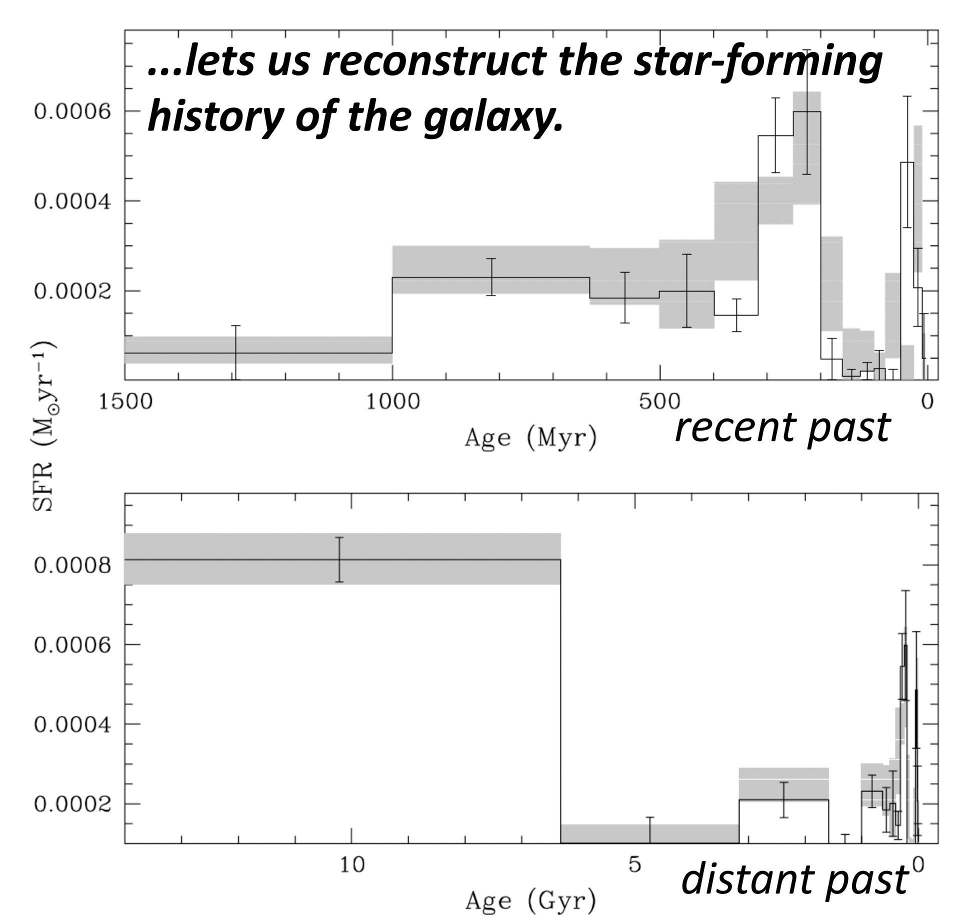
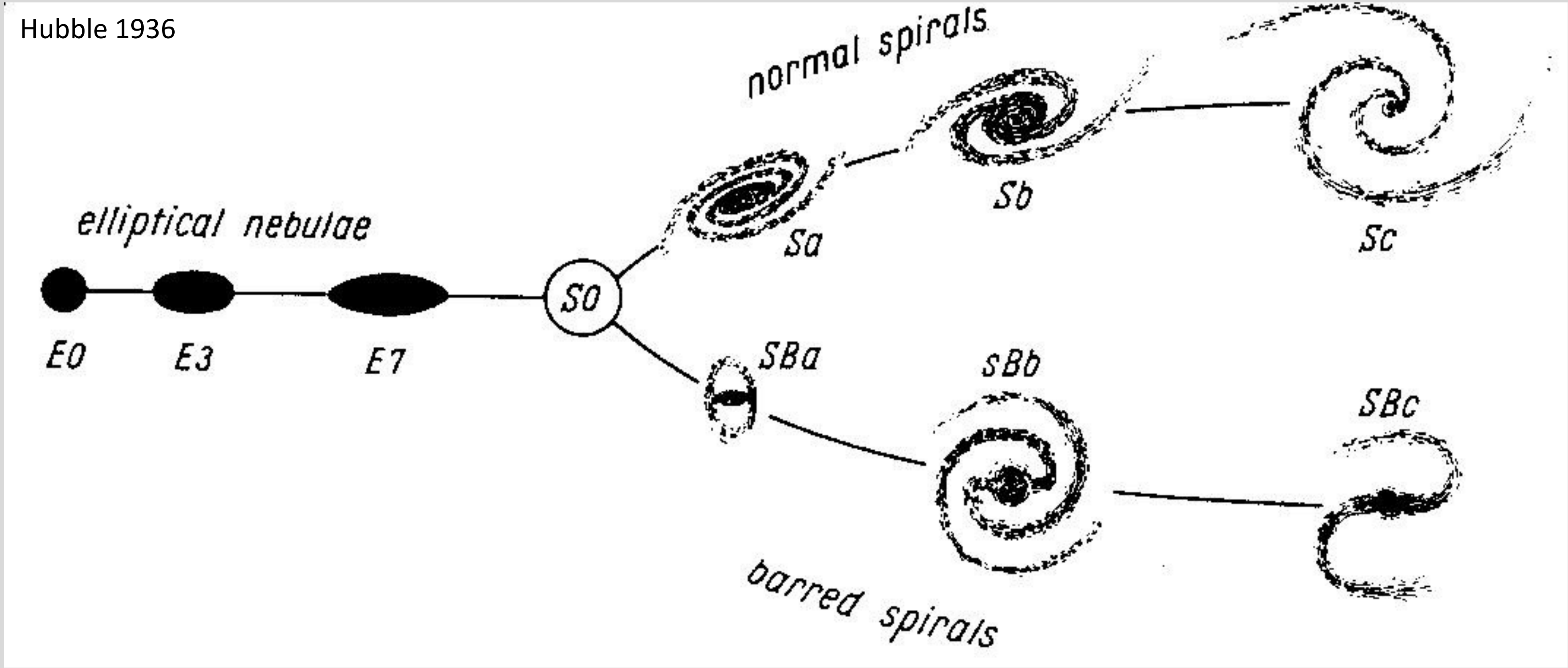


Figure 5. Best SFH fit with metallicity constrained to increase in time for the Antlia dwarf galaxy is plotted as a solid line with the best SFH fit with unconstrained metallicity evolution overplotted in shaded gray. The solutions are in excellent agreement in both the ancient and recent time bins.

Galaxies: Types and Properties

Hubble Sequence (“The Tuning Fork”): The most basic of classification schemes: visual morphology.



Ellipticals: EN

$$N = 10\left(1 - \frac{b}{a}\right)$$

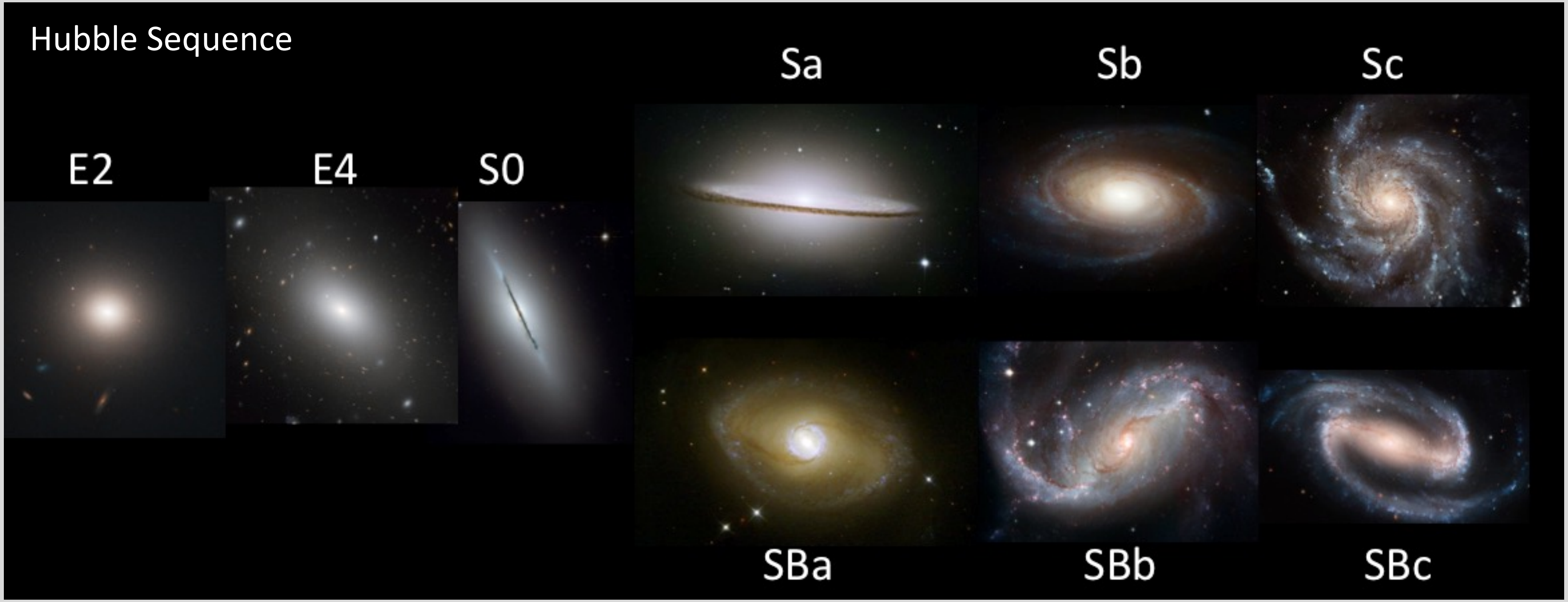
S0 (“Lenticulars”)
intermediate type,
disky but smooth

Spirals: Sa,Sb,Sc
tightness of spiral
prominence of bulge

Barred Spirals: SBa, SBb, SBc
presence of central bar
otherwise like Spiral

Galaxies: Types and Properties

Hubble Sequence (“The Tuning Fork”): The most basic of classification schemes: visual morphology.



Extensions
(de Vaucouleur)

Sd
(diffuse spiral)

Sm
(irregular spiral)

Irr
(very irregular)

Ellipticals: EN

$$N = 10\left(1 - \frac{b}{a}\right)$$

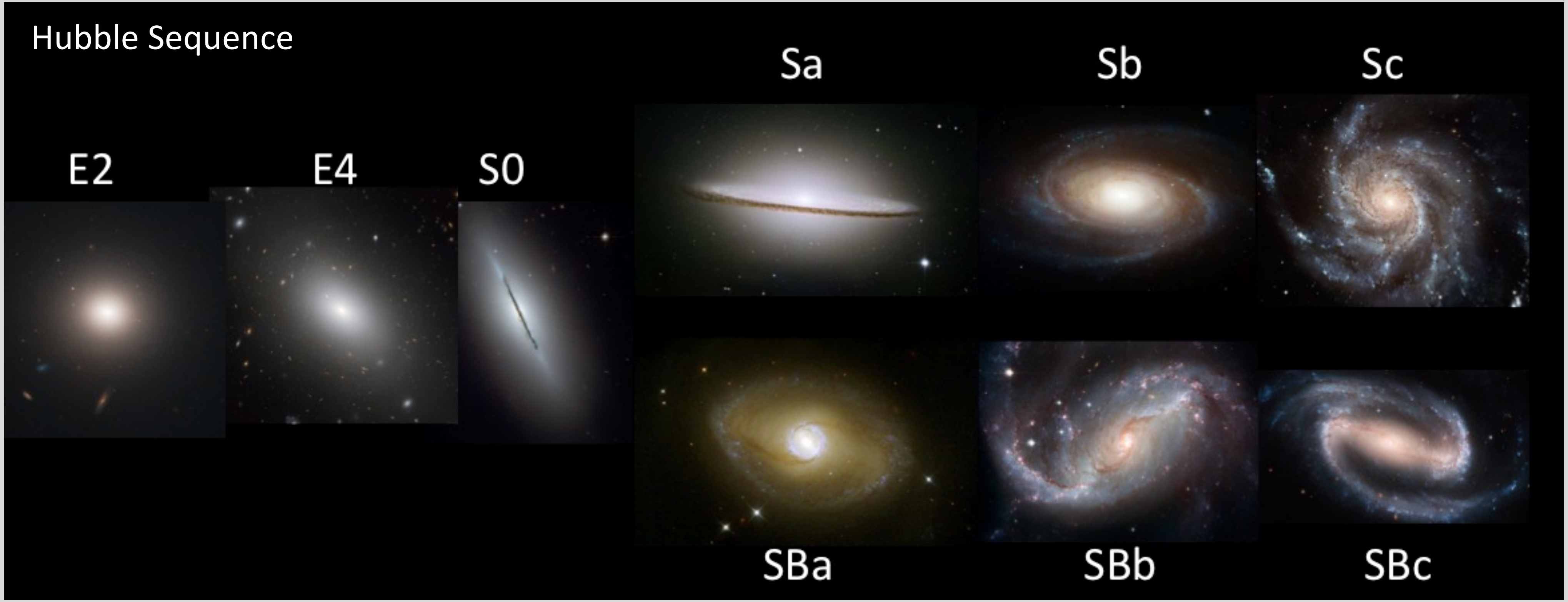
S0 (“Lenticulars”)
transitional type
disky but smooth

Spirals: Sa,Sb,Sc
tightness of spiral
prominence of bulge

Barred Spirals: SBa, SBb, SBc
presence of central bar
otherwise like Spiral

Galaxies: Types and Properties

Hubble Sequence ("The Tuning Fork"): The most basic of classification schemes: visual morphology.



Extensions
(de Vaucouleur)

Sd
(diffuse spiral)

Sm
(irregular spiral)

Irr
(very irregular)

"Early" → "Late"

"T-type":

-5	-2	0	2	3	5	8-10

Galaxies: Types and Properties

Many, many other classification schemes exist:

Morphology, colors, bulge:disk ratio, spectral properties, structural properties, star forming properties, luminosity classes, kinematic properties, etc, etc.

Classifications for MESSIER 101

1 of 2 (1 - 100 of 132)

Domain	Published Classification	Refcode	NED Homogenized Classificati
Luminosity Class	Sc(s) I	1981RSA...C...0000S	LC I
Galaxy Morphology	SAB(rs)cd	1991RC3.9.C...0000d	SAB(rs)cd
Galaxy Morphology	Sc(s)	1981RSA...C...0000S	S(s)c
Galaxy Morphology	WR	1999A&AS..136...35S	Wolf-Rayet Galaxy
Galaxy Morphology	Sc	1973UGC...C...0000N	Sc
Galaxy Morphology	spiral with one heavy arm	1966ApJS...14....1A	spiral with one heavy arm
Galaxy Morphology	AC 09	1987ApJ...314....3E	Arm Class 09
Galaxy Morphology	2	1975SoByu..47...43A	flat central luminosity profile
Galaxy Morphology	multi-armed spiral	1994CAG1..B...0000S	multi-armed spiral
Galaxy Morphology	arms branch into multiple	1994CAG1..B...0000S	arms branch into multiple fragmer
Galaxy Morphology	Type 1 XUV disk	2007ApJS..173..538T	Type 1 XUV disk
Galaxy Morphology	lopsided galaxy	1980MNRAS.193..313B	lopsided galaxy

Galaxies: Types and Properties

Many, many other classification schemes exist:

Morphology, colors, bulge:disk ratio, spectral properties, structural properties, star forming properties, luminosity classes, kinematic properties, etc, etc.

Classifications for MESSIER 087

1 of 1 (1 - 96 of 96)

Domain	Published Classification	Refcode	NED Homogenized Classificati
Hierarchy	GM	1975SSS.....9..557d	Group member
Galaxy Morphology	cD pec	1991RC3.9.C...0000d	cD0-1 pec
Galaxy Morphology	E0	1981RSA...C...0000S	E0
Galaxy Morphology	E	1973UGC...C...0000N	E
Galaxy Morphology	galaxy with jet	1966ApJS...14....1A	jet
Galaxy Morphology	E	2002MNRAS.333..423T	E
Galaxy Morphology	3	1975SoByu..47...43A	no nucleus
Galaxy Morphology	3	1975SoByu..47...43A	continuous brightening towards c
Galaxy Morphology	jet	1994CAG1..B...0000S	jet
Galaxy Morphology	Jet	1988AJ.....95..422E	jet
Galaxy Morphology	smooth nebulosity	1964RC1...C...0000d	smooth nebulosity
Galaxy Morphology	extremely bright center	1964RC1...C...0000d	extremely bright center
Galaxy Morphology	blue jet	1964RC1...C...0000d	blue jet

Galaxies: Types and Properties

Many, many other classification schemes exist:

Morphology, colors, bulge:disk ratio, spectral properties, structural properties, star forming properties, luminosity classes, kinematic properties, etc, etc.

Classifications for MESSIER 082

1 of 1 (1 - 40 of 40)

Domain	Published Classification	Refcode	NED Homogenized Classificati
Kinematics	HI line width	1961BAN....15..307V	HI line width
Galaxy Morphology	I0 edge-on	1991RC3.9.C...0000d	I0 edge-on
Galaxy Morphology	Amorphous	1981RSA...C...0000S	Amorphous
Galaxy Morphology	IRR	1973UGC...C...0000N	Irr
Galaxy Morphology	2s	1975SoByu..47...43A	structured nuclear region
Galaxy Morphology	high-surface-brightness d	1994CAG1..B...0000S	high-surface-brightness disk
Galaxy Morphology	dusty	1994CAG1..B...0000S	dusty
Galaxy Morphology	amorphous	1994CAG1..B...0000S	amorphous
Galaxy Morphology	Sm	1979AISAO..11....3K	Sm
Galaxy Morphology	nb/d	2011ApJ...733L..47F	no bulge
Radio Morphology	I	1983MNRAS.204..151L	FR I
Radio Morphology	C I	1974MNRAS.167P..31F	FR I C

Trends along the Hubble Sequence

Later-type galaxies *tend to be*

- lower in luminosity
- more gas rich
- bluer in color

than early-type galaxies.

(caveat: this is for bright galaxies; dwarf galaxies behave differently...)

data catalogs: RC3, UGC

open symbols ⇒ mean
filled symbols ⇒ median
errorbars ⇒ 25-75% range

Roberts & Haynes 94 ARAA