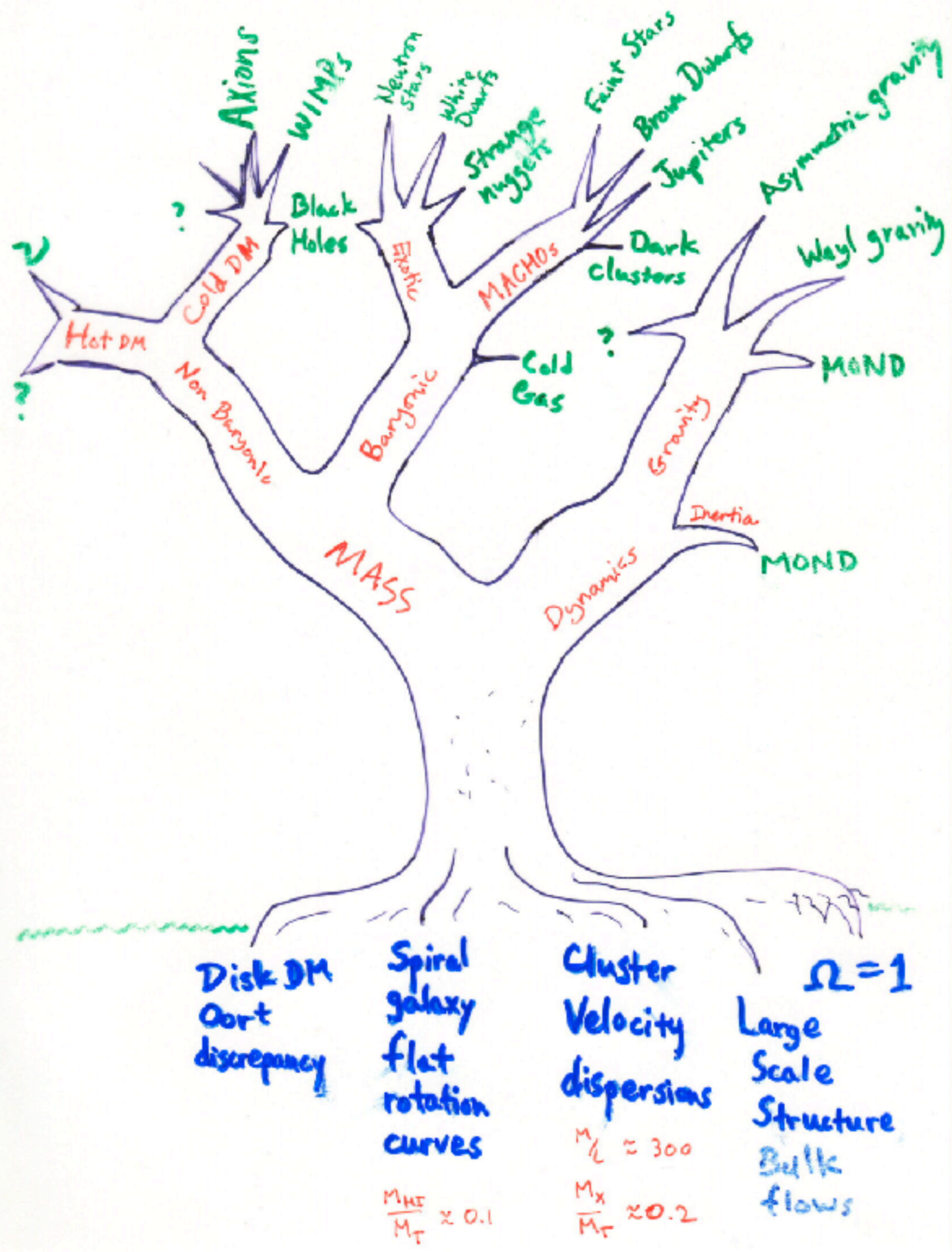
Dark Matter

ASTR 333/433
Spring 2016
T R 4:00-5:15pm
Sears 552

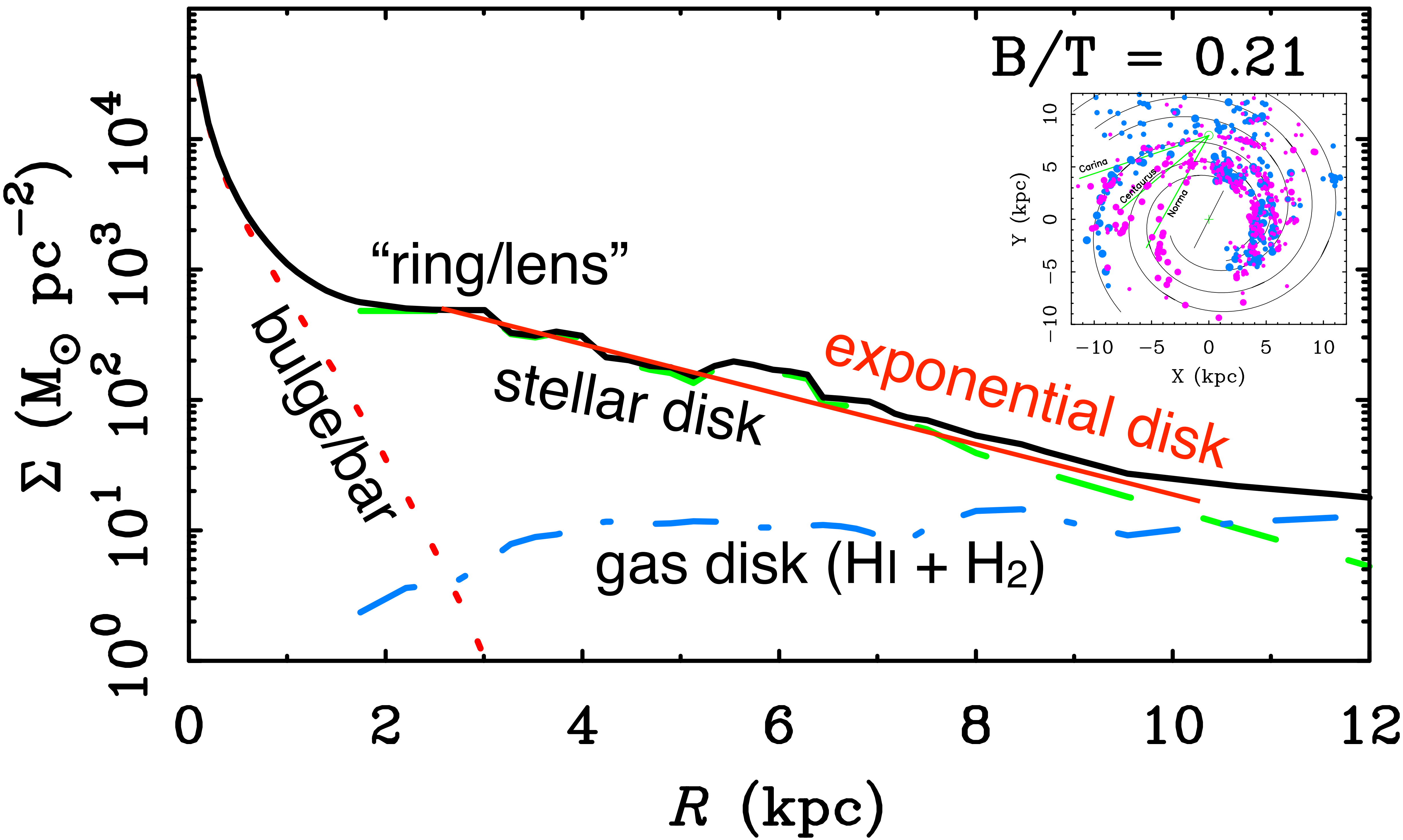
TODAY

Galaxy Structure
- Mass components
  - Exponential Disks
  - $r^{1/4}$ Bulges
  - Stellar Populations
- Interstellar medium
  - Atomic gas (HI)
  - Molecular gas (H2)
  - Ionized gas (HII)
  - Dust

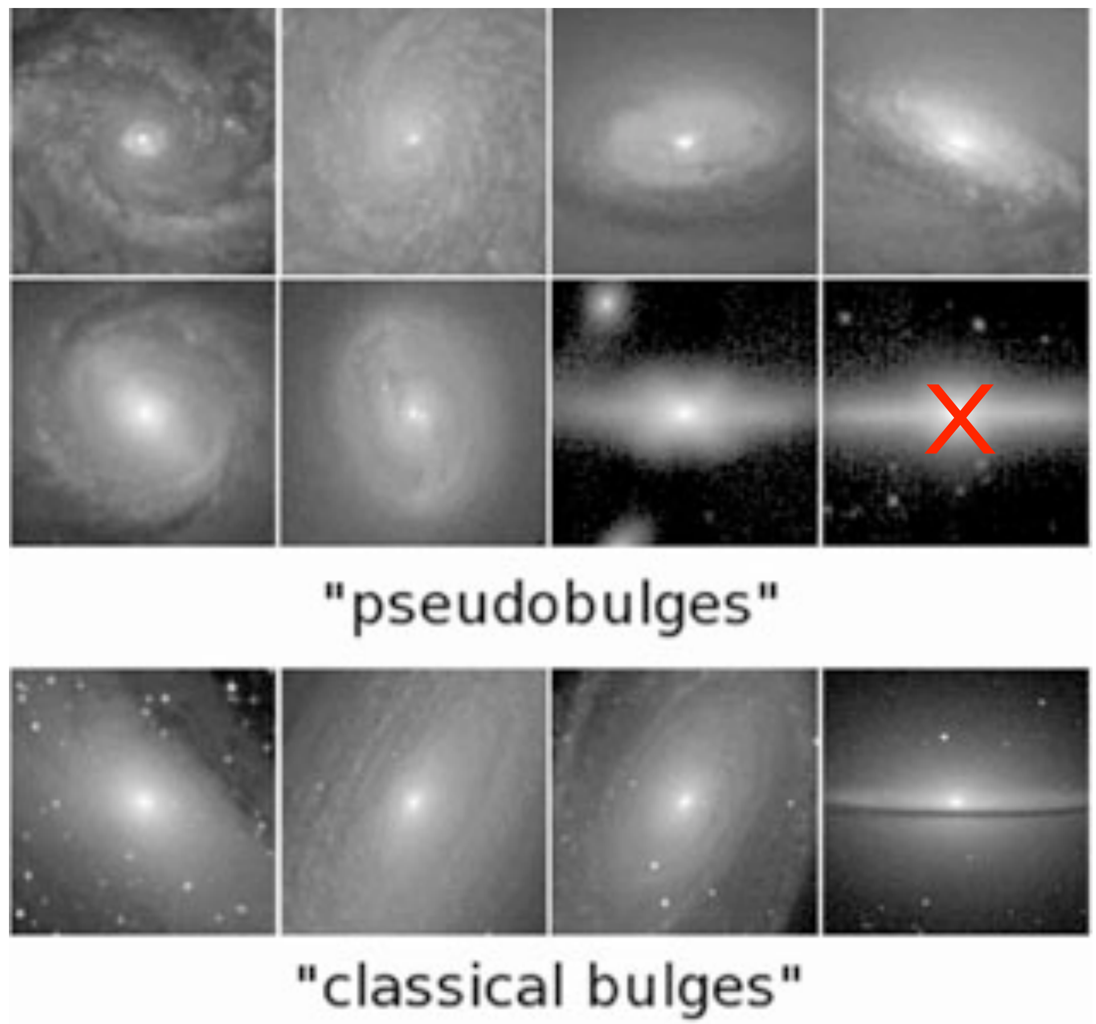
Homework 1
DUE 8 February



Milky Way model illustrating baryonic mass components



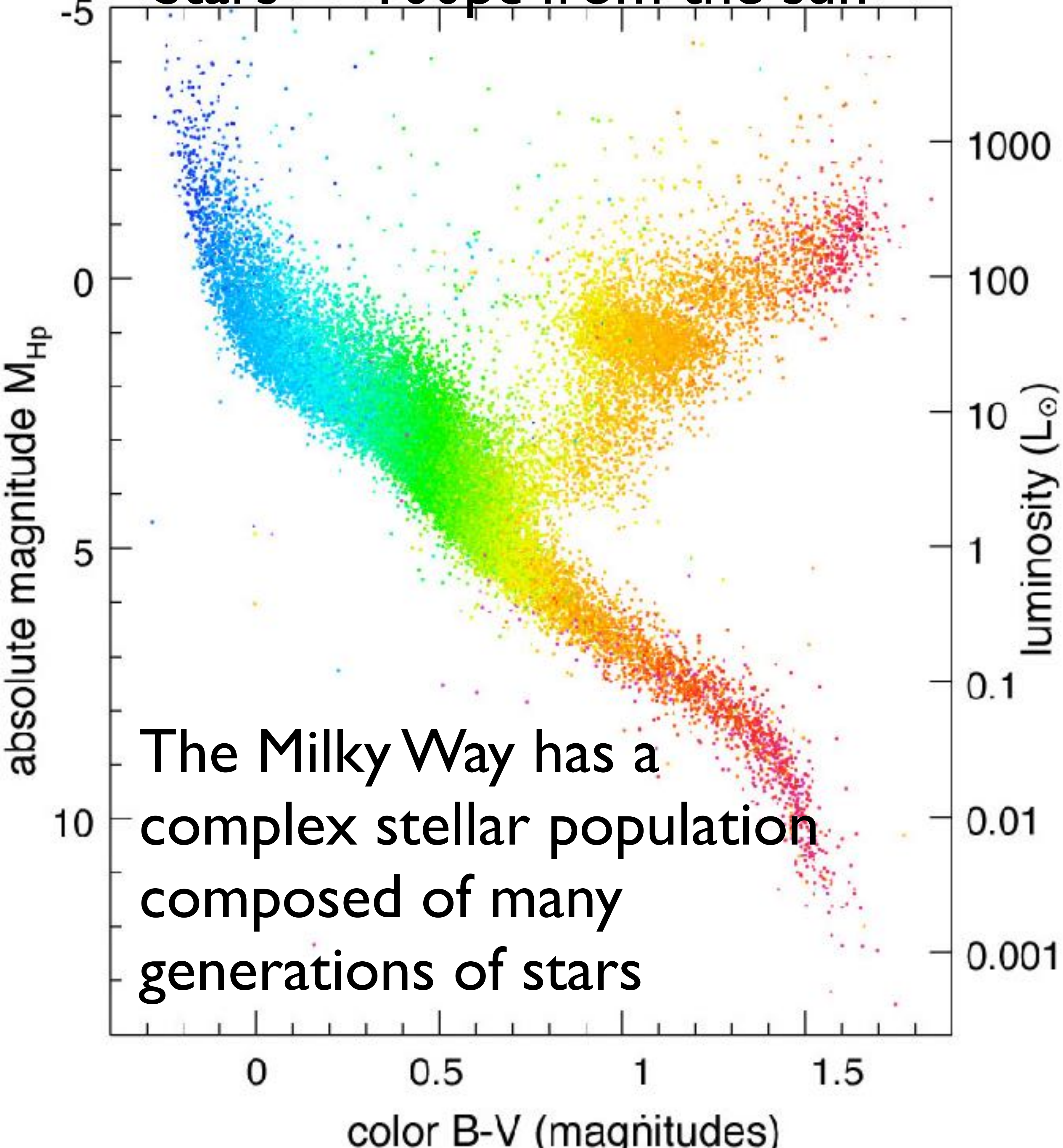
Pseudo-bulges have various Sersic indices, often closer to n=1 (exponential) than to n=4 (de Voucoulers profile)



X/peanut shape characteristic of bars seen edge-on

Classical bulges tend to have Sersic indices closer to n=4 (de Voucoulers profile)

Stars < 100pc from the sun



The Milky Way has a complex stellar population composed of many generations of stars

Typical Stellar composition

- Hydrogen mass fraction $X = 0.74$
- Helium mass fraction $Y = 0.25$
- Heavier elements ("metals"): $Z \approx 0.01$

Abundances of H & He set during Big Bang.
Heavier elements made in previous generations of stars.
Z often called "metallicity" and sometimes referenced to the iron abundance, [Fe/H].

open cluster

Stellar populations

- Simple Single Population (SSP)
  - stars of all masses born at the same time
  - e.g., a star cluster

- Complex stellar population
  - Convolution of many star forming events
  - need to know
    - IMF (initial mass function)
    - Birthrate (star formation rate history)

globular cluster

Galaxy spectra composed of complex stellar populations

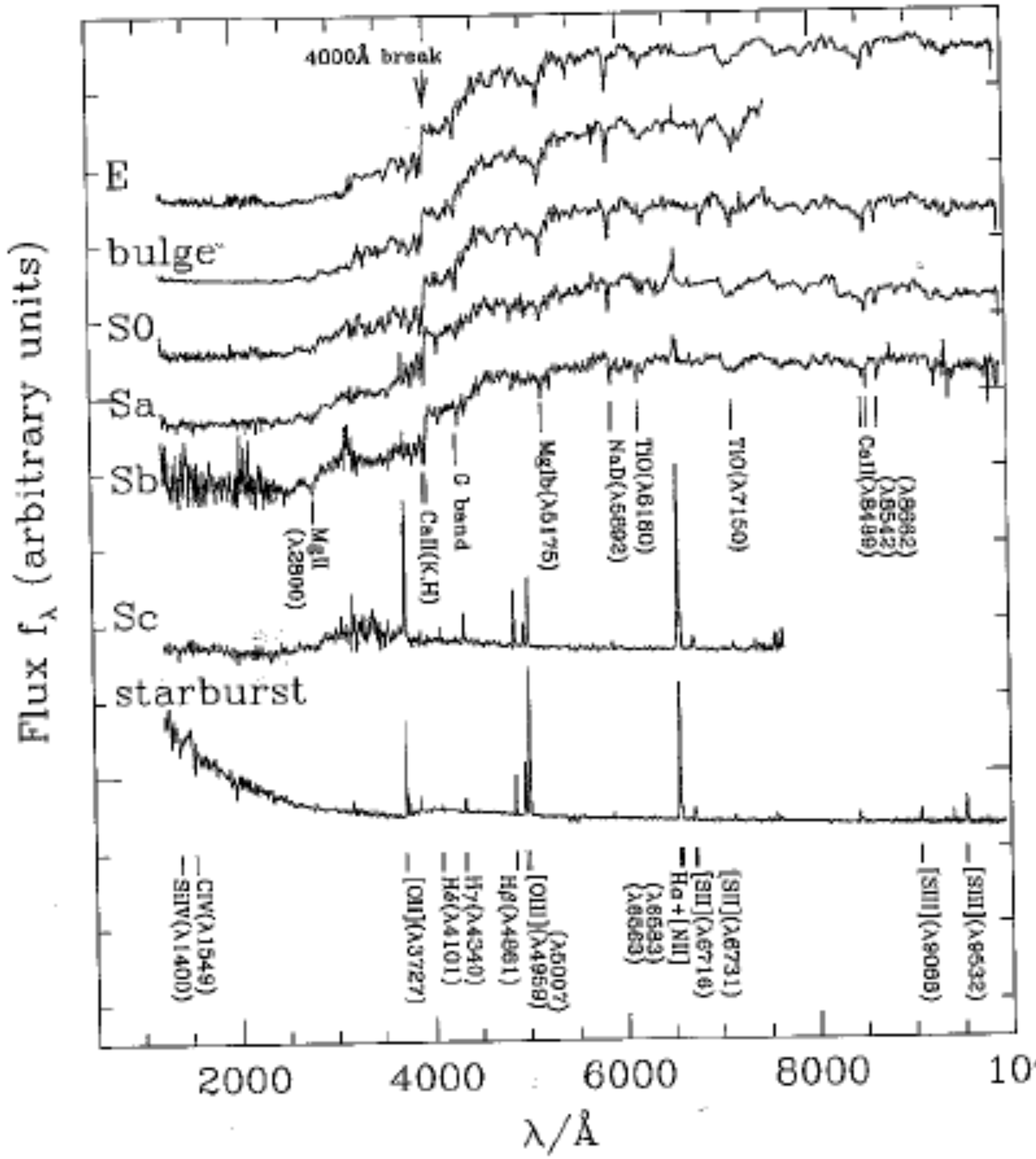
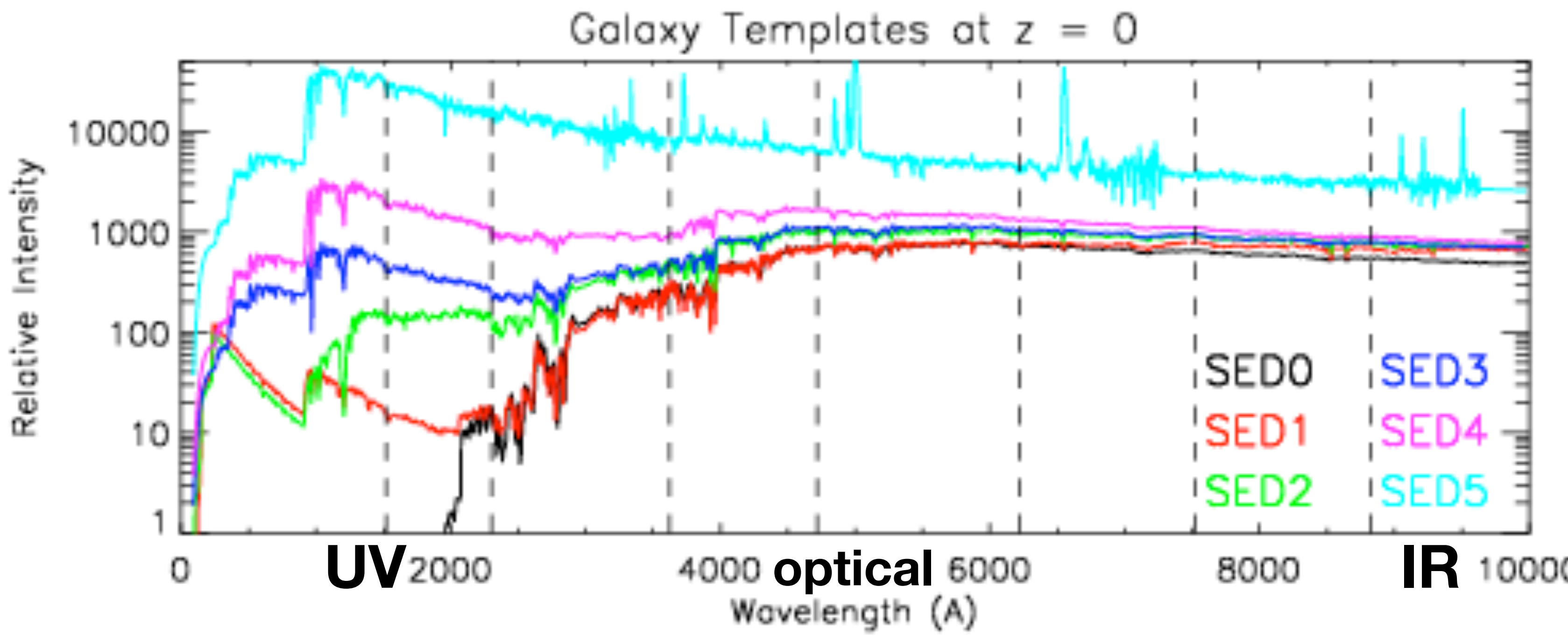
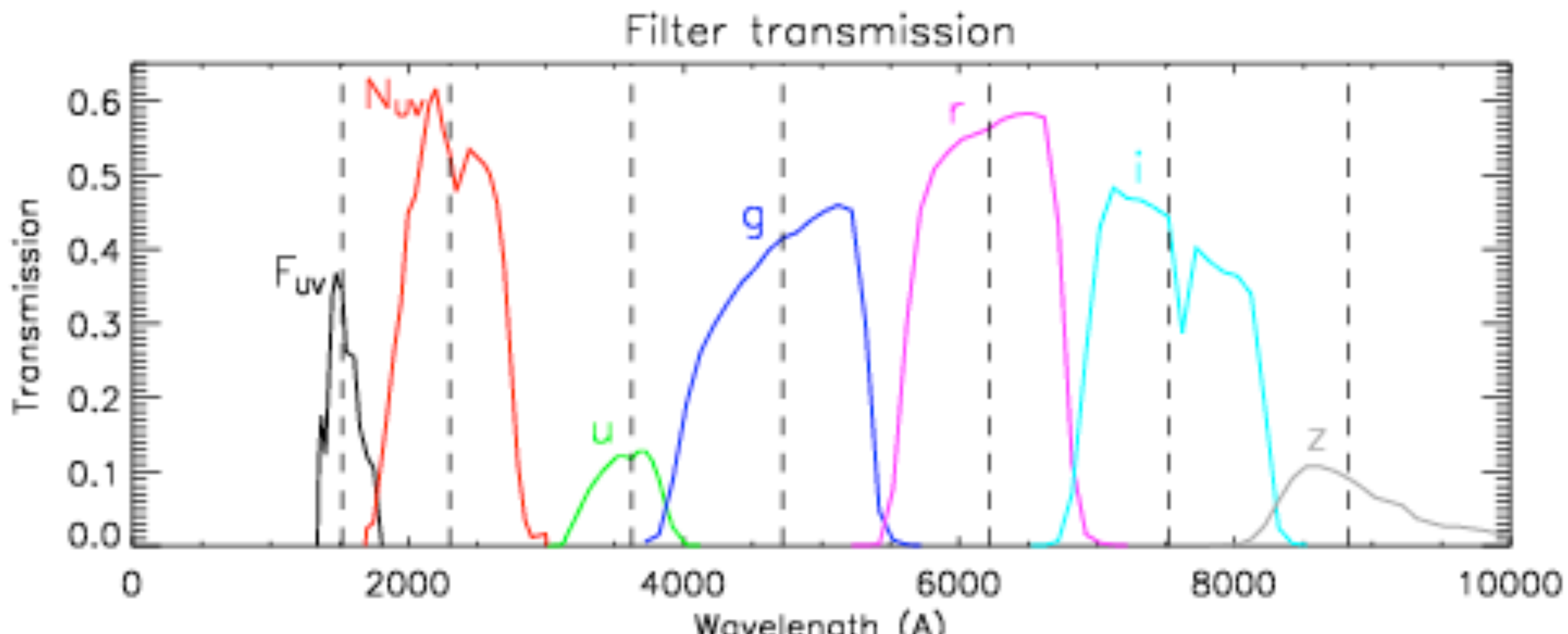


Fig. 2.12. Spectra of different types of galaxies from the ultraviolet to the near-infrared. From ellipticals to late-type spirals, the blue continuum and emission lines become systematically stronger. For early-type galaxies, which lack hot, young stars, most of the light emerges at the longest wavelengths, where one sees absorption lines characteristic of cool K stars. In the blue, the spectrum of early-type galaxies show strong H and K absorption lines of calcium and the G band, characteristic of solar type stars. Such galaxies emit little light at wavelengths shorter than 4000 Å and have no emission lines. In contrast, late-type galaxies and starbursts emit most of their light in the blue and near-ultraviolet. This light is produced by hot young stars, which also heat and ionize the interstellar medium giving rise to strong emission lines. [Based on data kindly provided by S. Charlot]

The effect of age variations

Galaxy Spectra

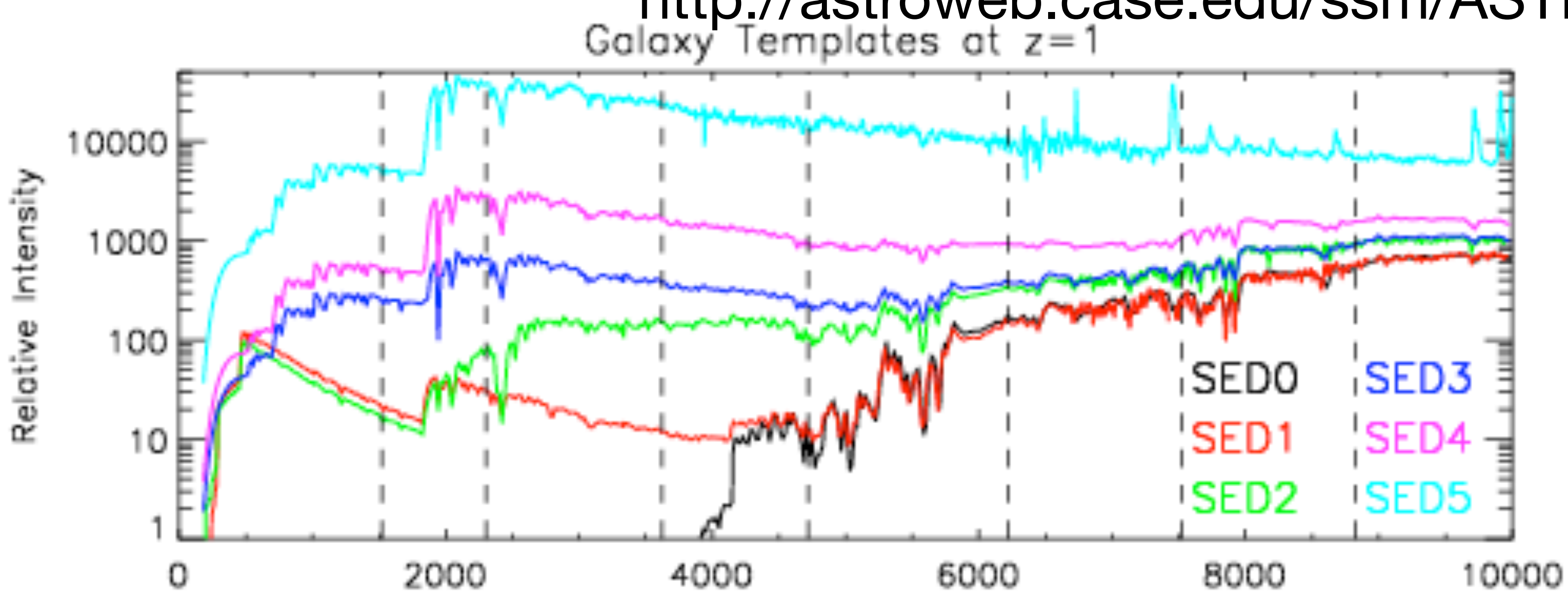




ugriz -
Gunn filters
Sloan (SDSS)

http://astroweb.case.edu/ssm/ASTR620/mags.html

The effect of redshift



Stars by mass, light, and number

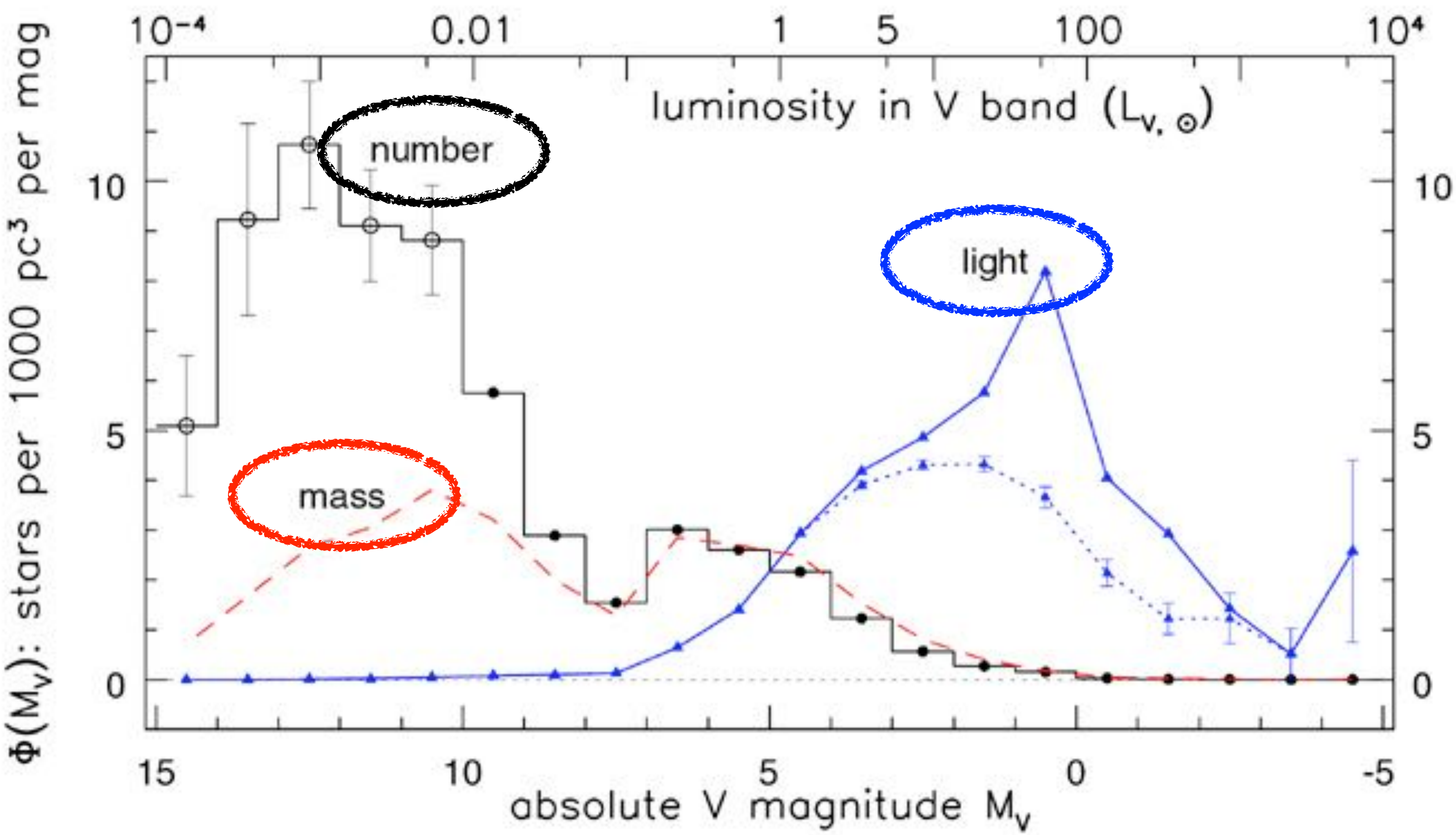


Fig 2.3 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Low mass stars exist in the greatest numbers and contain most of the mass.
High mass stars produce most of the light.

IMF vs PDF

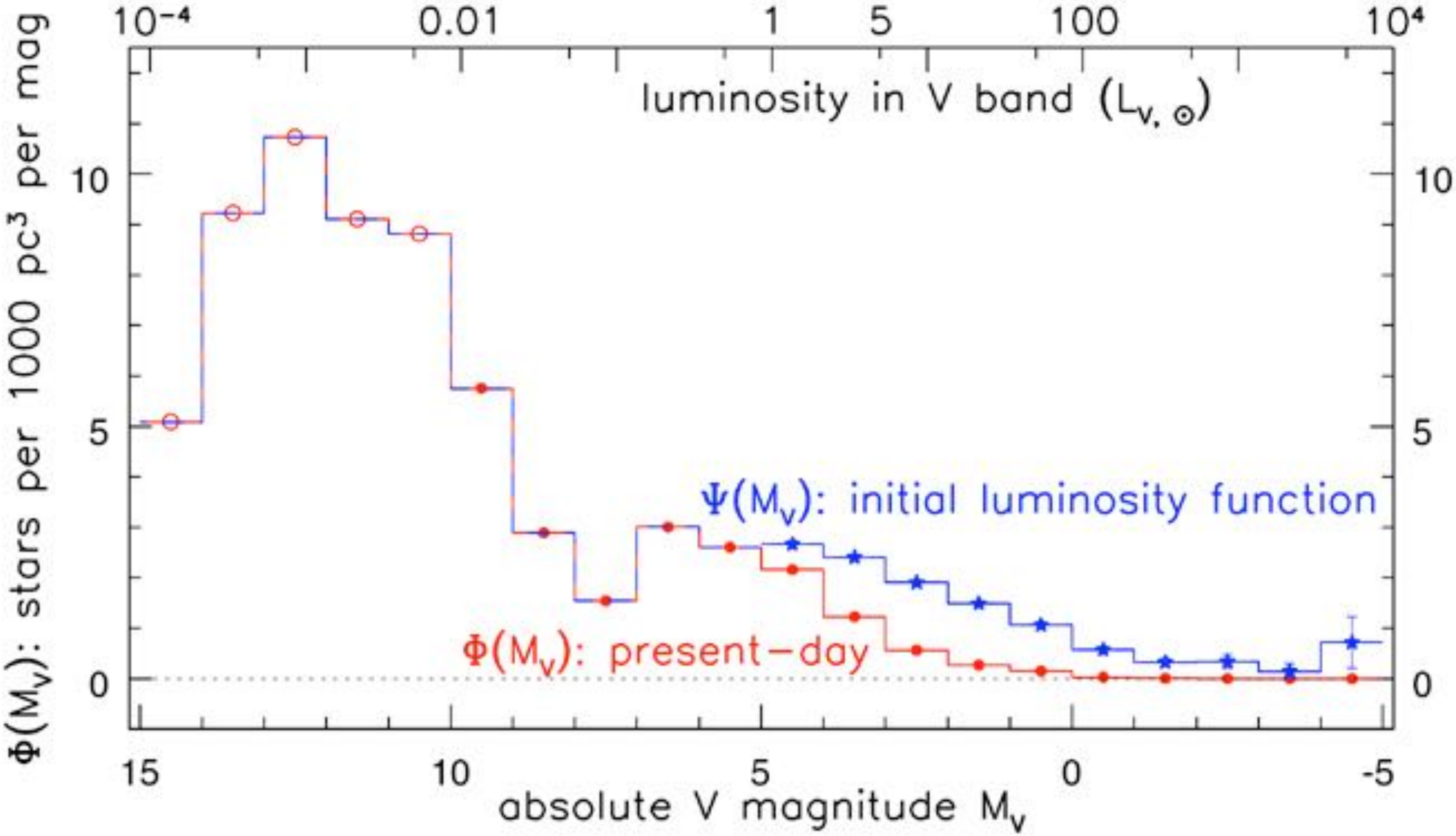


Fig 2.4 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Pleiades:

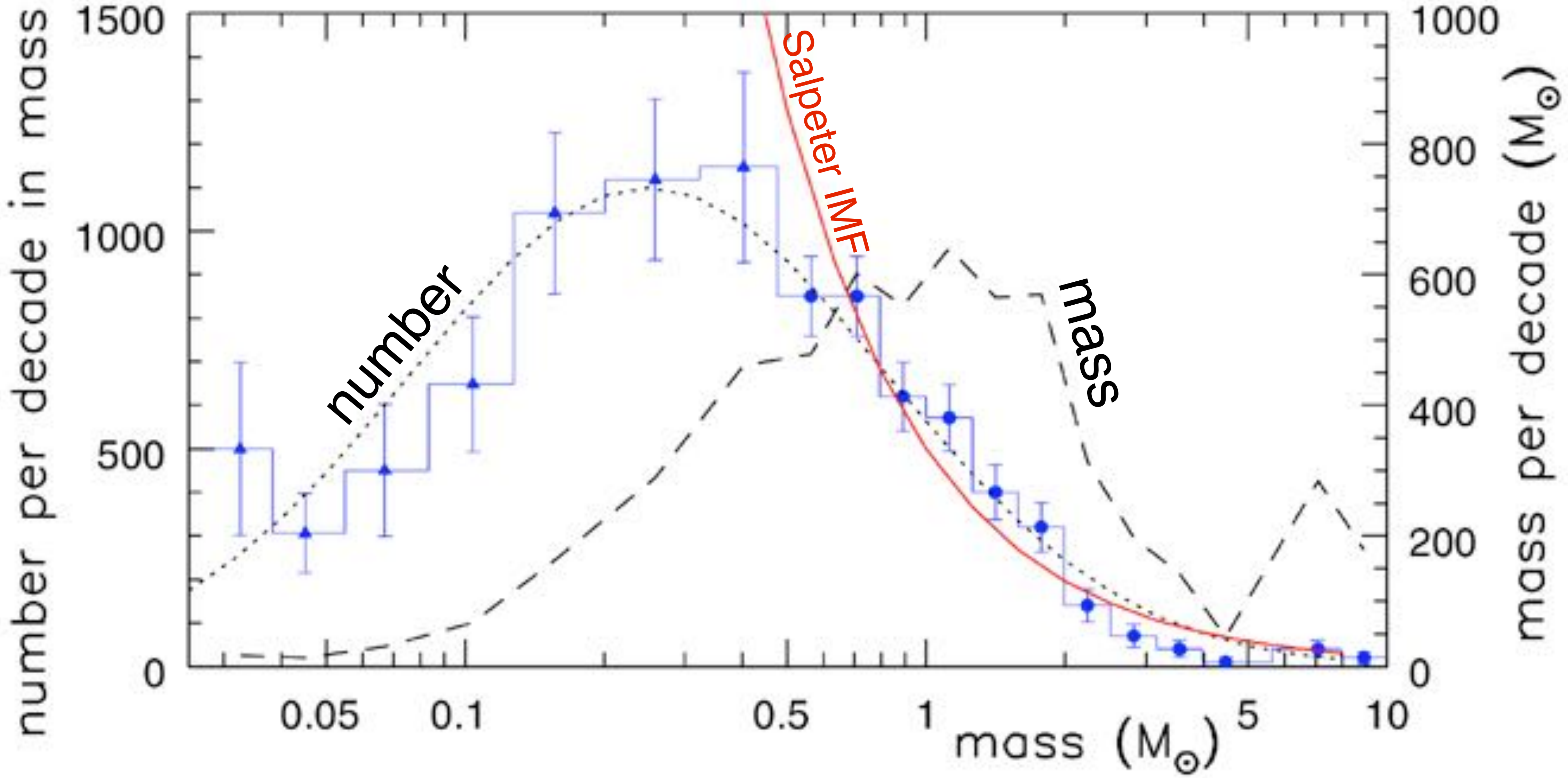
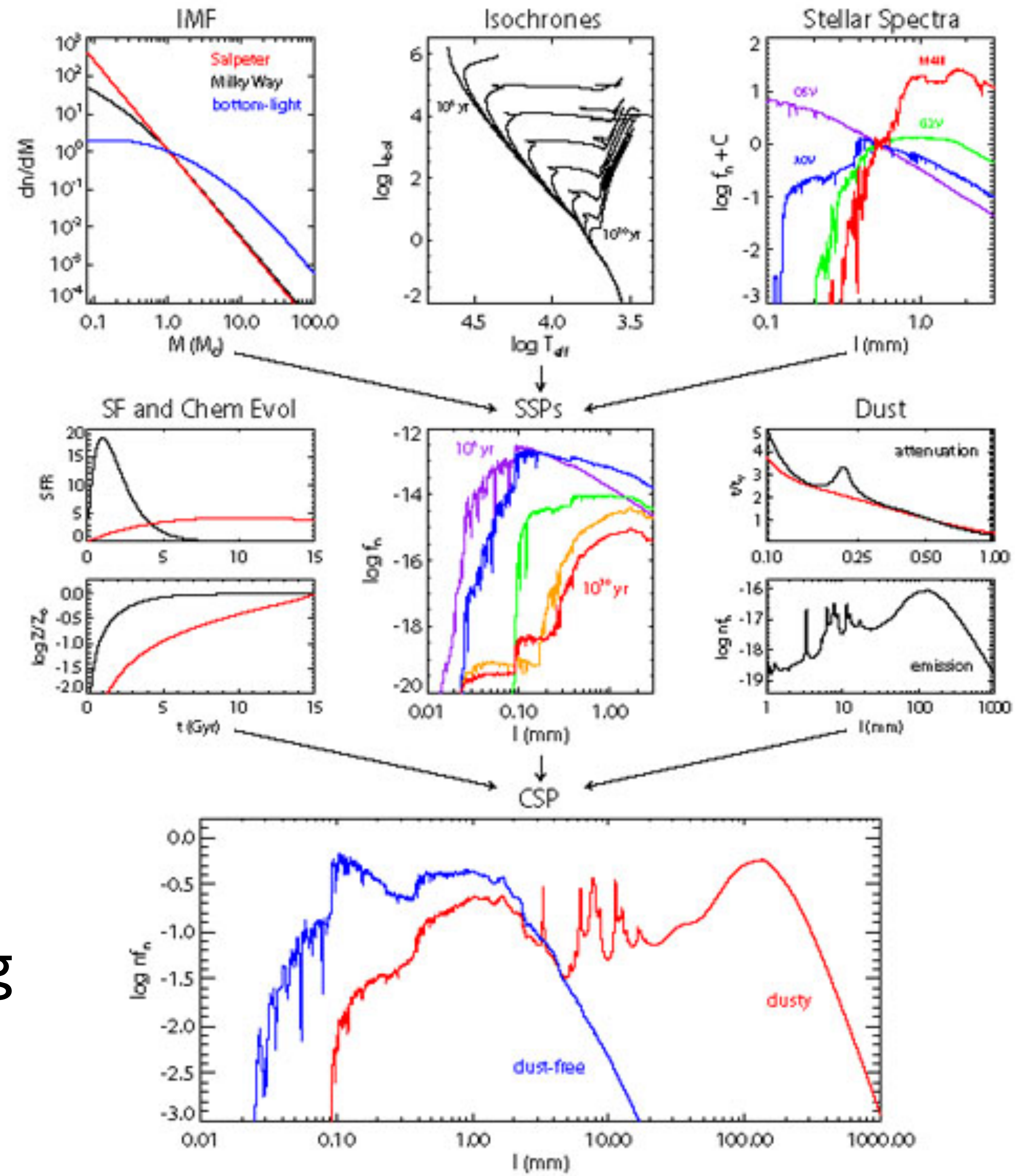
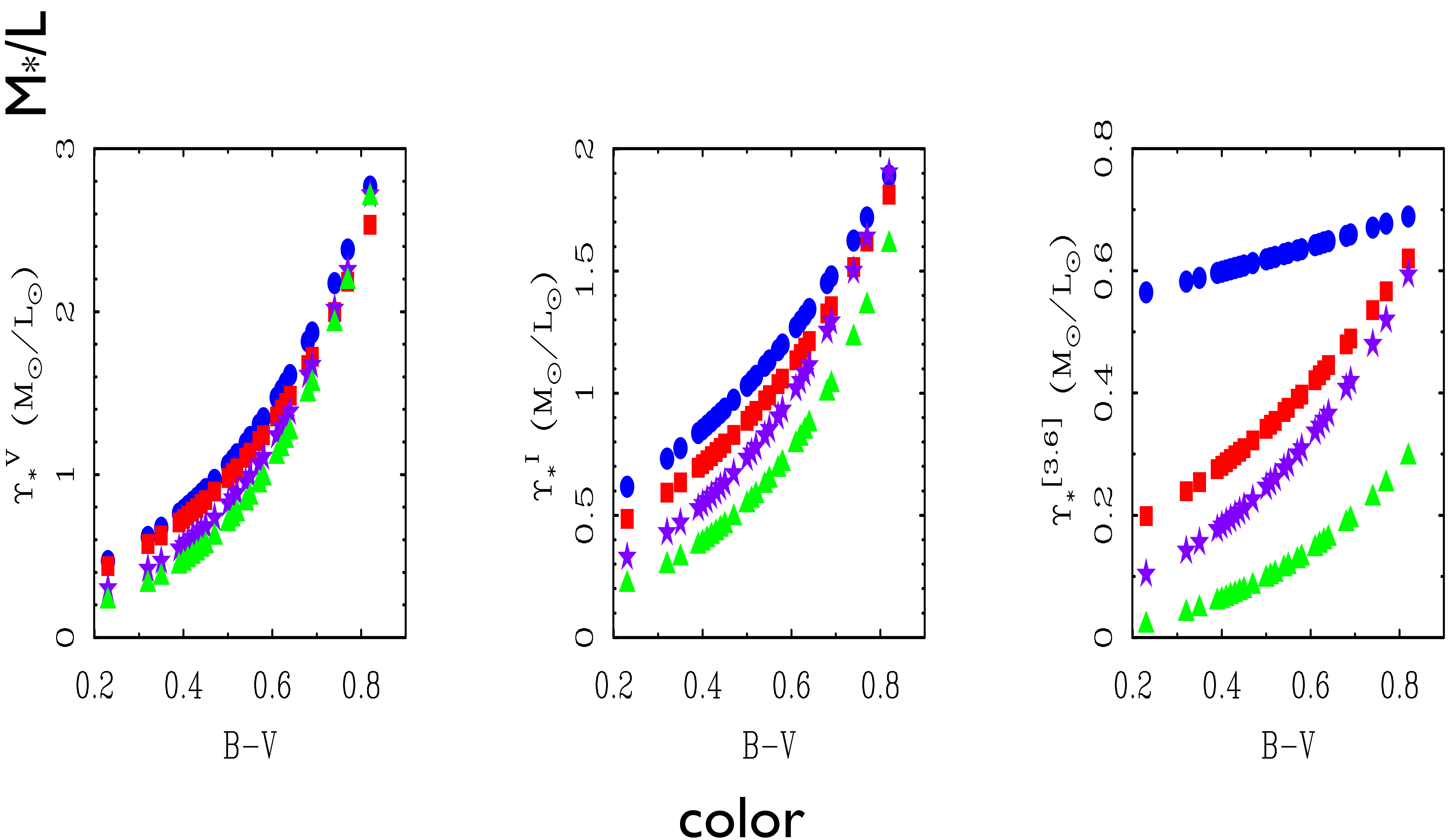


Fig 2.5 (E. Moreau) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007



Stellar population synthesis modeling technique

stellar population models



Typically, redder colors mean higher mass-to-light ratios

Table 5
Self-Consistent Population Synthesis Mass-to-Light Ratios

Model	a_V	b_V	α_I	β_I	$\alpha_{[3.6]}$	$\beta_{[3.6]}$	$\Upsilon^V_{0.6}$	$\Upsilon^I_{0.6}$	$\Upsilon^{[3.6]}_{0.6}$
Bell et al. (2003)	−0.628	1.305	−0.259	0.565	−0.313	−0.043	1.43	1.20	0.46
Portinari et al. (2004)	−0.654	1.290	−0.302	0.644	−0.575	0.394	1.32	1.22	0.46
Zibetti et al. (2009)	−1.075	1.837	−0.446	0.915	−1.115	1.172	1.07	1.27	0.39
Into & Portinari (2013)	−0.900	1.627	−0.394	0.820	−0.841	0.771	1.19	1.25	0.42

Note. — Stellar mass-to-light ratios in the V, I, and K-bands given by the formula $\log \Upsilon^j_* = \alpha_j + \beta_j(B-V)$. For each model, the V-band is identical to that in Table 3, but the I and [3.6] bands have been revised to attain self-consistency with the V-band (see text). For reference, the mass-to-light ratio at $B-V = 0.6$ is also given.

$$\log\left(\frac{M_*}{L_i}\right) = a_i + b_i(B-V)$$

Older populations (like in Elliptical galaxies) can have larger mass-to-light ratios, but usually $\left(\frac{M_*}{L}\right) < 5\ \frac{\mathrm{M}_\odot}{\mathrm{L}_\odot}$

ISM

The stuff between the stars

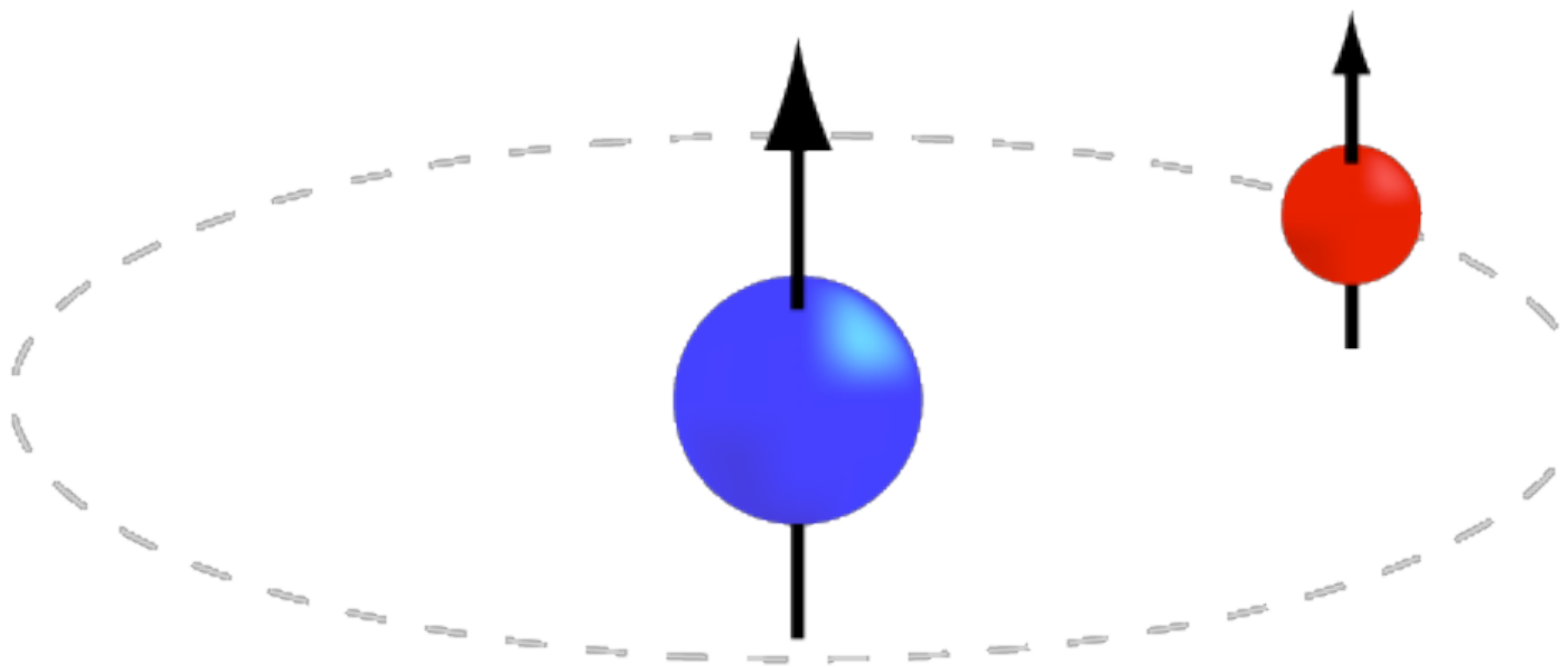
Atomic gas (H I)
Molecular gas (H_2)
Ionized gas (H II)
Dust

Explanatory links at NRAO

H I: http://www.cv.nrao.edu/course/astr534/HILine.html

H_2: http://www.cv.nrao.edu/course/astr534/MolecularSpectra.html

HI: atomic hydrogen in the interstellar medium



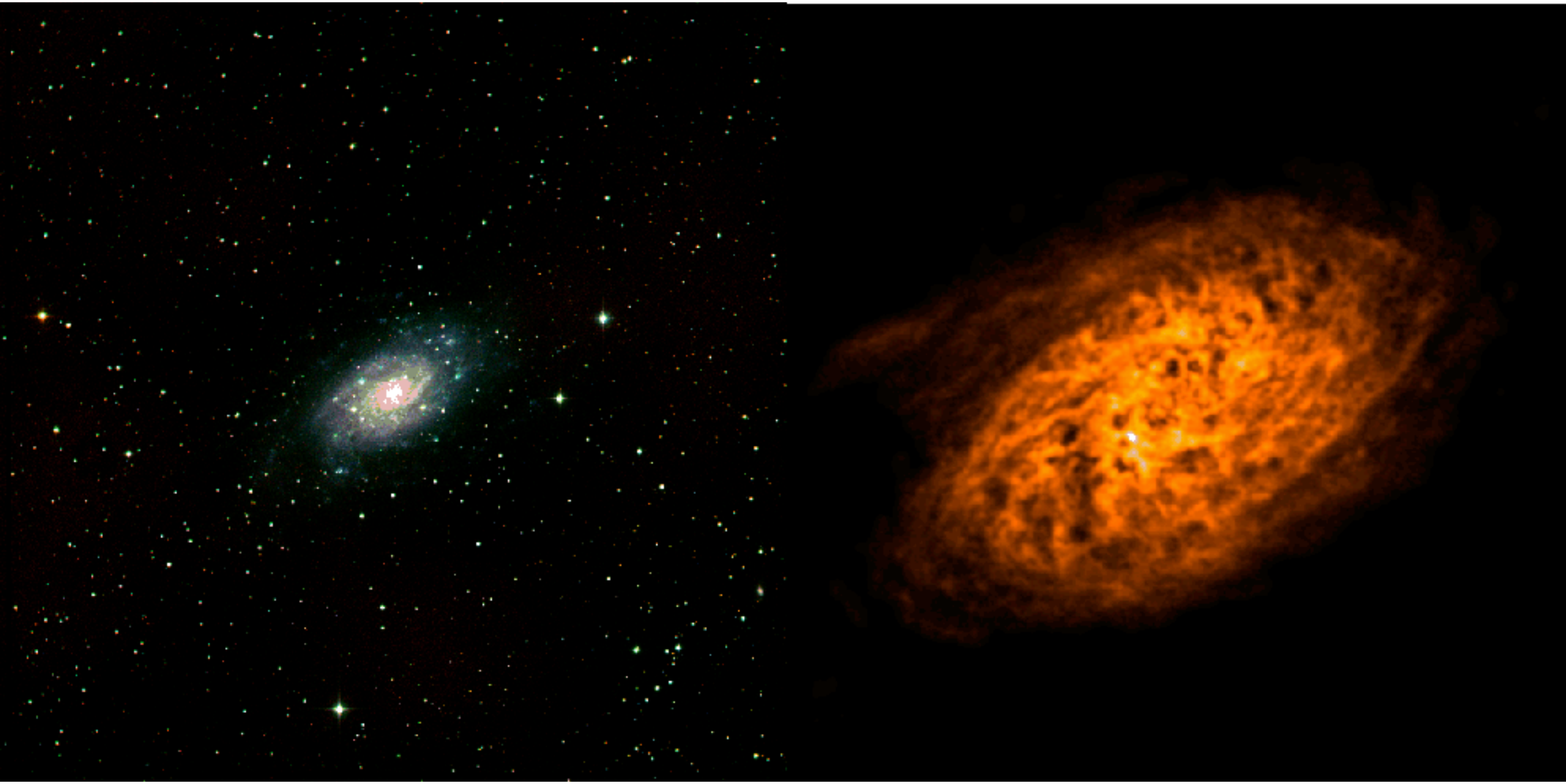
21 cm emission from hyperfine transition: parallel to anti-parallel spins

$$\nu = \frac{8}{3} g_I \frac{m_e}{m_p} \alpha^2 R_m c = 1420.405751 \text{ MHz}$$

Radio line!

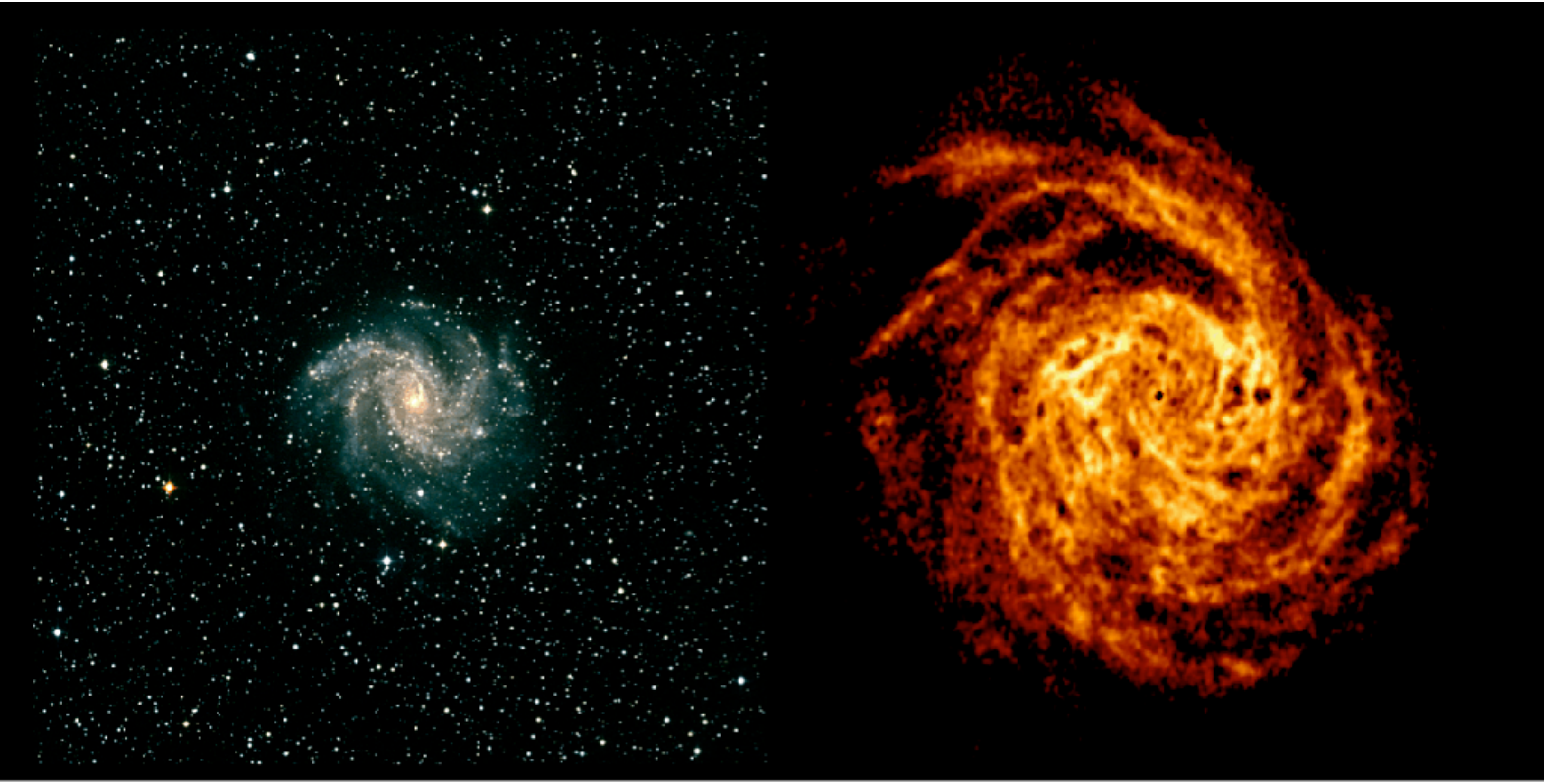
NGC 2403

Stars | HI gas



Fraternali, Oosterloo, Sancisi, & van Moorsel 2001, ApJ, 562, L47

NGC 6946

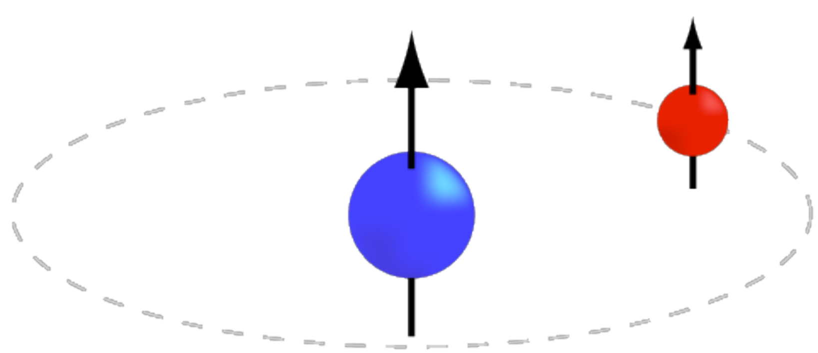


Boomsma 2005

emission coefficient

$$A_{UL} = \frac{64\pi^4}{3hc^3}\nu^3|\mu^*|^2$$

Bohr magneton



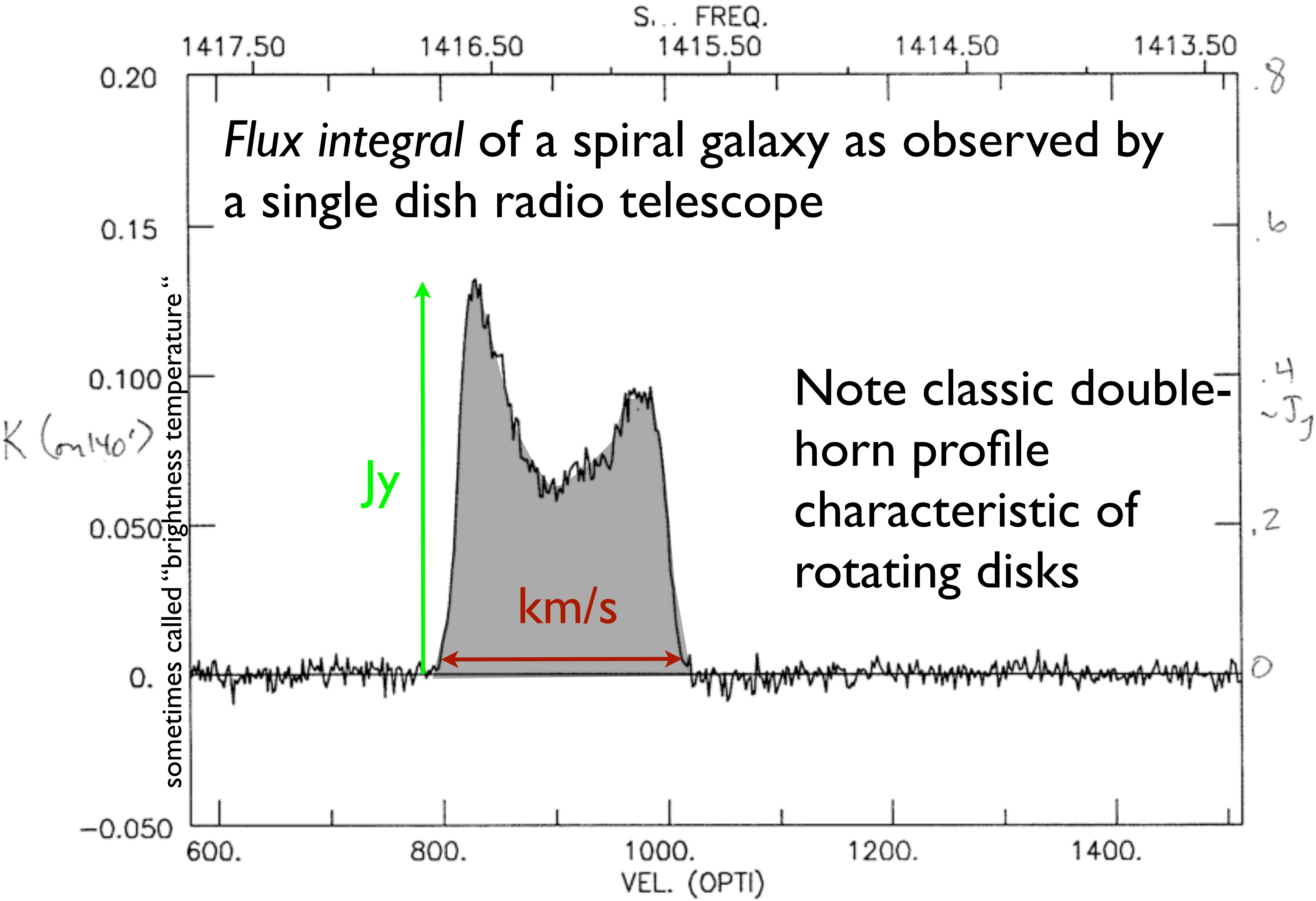
The radiative half-life of this transition is 11 Myr. This is readily maintained in equilibrium even in a cool (~100 K), diffuse ISM (< 1 atom/cc)

Counting 21 cm photons is equivalent to counting hydrogen atoms - a direct relation to mass!

$$M_{HI} = 2.36 \times 10^5 D^2 F_{HI}$$

Gives mass in solar masses for *D* in Mpc and measured F_{HI}, the flux integral in Jy-km/s

$1\ \mathrm{Jy} = 10^{-26}\ \mathrm{W\,m^{-2}\,Hz^{-1}}$



Flux integral of a spiral galaxy as observed by a single dish radio telescope
Note classic double-horn profile characteristic of rotating disks
Jy
km/s
sometimes called "brightness temperature"
S... FREQ.
1417.50
1416.50
1415.50
1414.50
1413.50
0.20
0.15
0.100
0.050
0.
−0.050
600.
800.
1000.
1200.
1400.
VEL. (OPTI)
.8
.6
.4
~Jy
.2
0