Stellar Populations

The evolution of individual stars is well understood.
The light produced by a composite population of $\sim 10^{11}$ stars can get a bit complicated.

We measure light.
For dynamics, we need to know the mass.

For a single burst of star formation (SSP), much depends on the IMF (especially the composite mass-to-light ratio $\Upsilon_* = \frac{M_*}{L_*}$

IMF = Initial Mass Function
The number of stars that form as a fcn of mass

Initial attempt a power law due to Salpeter (1955)

$$\xi(M) = \frac{dN}{dM} = \xi_0 M^{-\Gamma} \qquad \Gamma = -2.35$$

"Salpeter slope"

# of stars $\quad N = \int \xi \, dM$ — integral performed over a finite range from the minimum to maximum stellar mass.

total mass $\quad M = \int M \xi \, dM$

total luminosity $\quad L = \int L \xi \, dM$ — L is a strong fcn of M; $L \sim M^{3.5}$ for main sequence stars. L goes way up during giant phase.

Most of the light is produced by massive stars while most of the mass is contained in low mass stars.
Nevertheless,

$$\Upsilon_* = \frac{M_*}{L} = \frac{\int M \xi \, dM}{\int L \xi \, dM} \sim 1 \frac{M_\odot}{L_\odot}$$

Υ_* varies with bandpass and age, but is almost always $0.5 < \Upsilon_* < 5 \frac{M_\odot}{L_\odot}$

Note that the Salpeter IMF blows up when integrated to a lower limit $M_\ell \to 0$. Usually truncate at $M_\ell \sim 0.1 M_\odot$ (brown dwarf limit)

Subsequent observations show that the power law is broken (as it must be : Kroupa IMF) so integral is finite.

Numbers of stars peaks somewhere around $M \simeq \frac{1}{3} - \frac{1}{2} M_\odot$

Thats just for a simple population in which all the stars form at once.

In spiral galaxies, of must also consider the star formation history (SFH)

The SFH can be viewed as the sum of many individual star forming events. In principle, each event might have its own unique IMF.

Fortunately, galaxies appear to be consistent with a single universal IMF (Kroupa ; Chabrier) which may simply result from averaging over many events.

Elaborate models can be made to estimate M_*/L.

These are good to a factor of ~ 2.

Hard to do much better (the IMF being the biggest uncertainty, esp. the low mass end.)

Typical values for spiral galaxies

Band		B	V	I	K	[3.6]	
Υ_*	=	1.5	1.4	1.2	0.6	0.5	$M_\odot / L_\odot$

The Υ_* in the near-infrared (K & [3.6]) is fairly stable and apparently universal. Fluctuations around the mean get larger as one goes to bluer bands.

In practice, build detailed models
that incorporate known spectra of stars

Major uncertainties
- IMF
- Star formation history

usually modeled as $SFR \propto e^{-t/\tau}$ *

E galaxies old : short τ : all SF over early on
S galaxies young : $\tau \to \infty$, roughly constant SFR

nagging minor uncertainties
- effect of Z-distribution
- contribution of poorly modeled late stages of stellar evolution (TP-AGB stars)

Nevertheless, get decent models like Bell & de Jong (2001)
Portinari et al (2004)
Schombert & McGaugh (2014)

* In additon to smooth, continuous star formation rates like

$$SFR \sim e^{-t/\tau}$$

one can also impose sporadic bursts of star formation

$$SFR \sim \delta(t - t_{burst})$$

to construct model SFH of arbitrary complexity.
Old ~~pops~~ pops fade, & massive stars fade fast, so most of
the details of early SFH get washed out.

HI Atomic gas

detected by spin-flip transition of H

$$\overset{\uparrow}{\oplus}\ \ \overset{\uparrow}{\ominus} \longrightarrow \uparrow\oplus\ \ \ominus\downarrow$$

transition frequency very low energy

$$\nu_{10} = \frac{8}{3}\, g_I \left(\frac{m_e}{m_p}\right) \alpha^2 \underbrace{(cR_M)} = 1420.4 \text{ MHz}$$

the <u>21cm</u> line

nuclear gamut factor
$g_I = 5.6$ for proton

fine structure constant
$\alpha = \frac{1}{137}$

Rydberg frequency

Emission coefficient

$$A_{ul} = \frac{64\pi^4}{3hc^3}\nu_{ul}^3 \left|\mu_{10}^*\right|^2$$

Bohr magneton
(dipole moment of e^-)

numerically

$$A_{10} = 2.85\times10^{-15}\ s^{-1}$$

$$\left|\mu_{10}^*\right| = \frac{\hbar}{2}\frac{e}{m_e c}$$

radiative half-life $\tau_{1/2} = \frac{1}{A_{10}} \approx 11\times10^6$ yr

$(3.5\times10^{14}$ s $= 11$ Myr$)$ $= \frac{1}{\tau_{1/2}}$

Very low critical density
$(\ll 1\ \text{cm}^{-3})$

so almost always in LTE through collisional excitation

Can also define "spin temperature"

$$\frac{N_1}{N_0} = \frac{g_1}{g_0} e^{-\frac{\nu h_{10}}{kT_S}}$$

$g_1 = 3$ upper states
$g_0 = 1$ ground state

Note $\frac{h\nu}{k} \ll 1$K very small, so $e^{-\frac{\nu h_{10}}{kT}} = 1$ if $T_S \approx T$ anywhere near equilibrium

so $\frac{N_1}{N_0} = \frac{3}{1}$ & $N_H = N_0 + N_1 = 4N_0$ good for counting atoms counting 21 cm photons → counting HI atoms

$$M_{HI} = \frac{16\pi m_H}{3 A_{ul}\, hc} D^2 \underbrace{\int F_\nu \, dv}_{\text{flux integral in Jy} \cdot \text{km/s}}$$

Numerically

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

$$M_{HI} = \left(2.34 \times 10^5\, M_\odot\right) D^2 \int F_\nu \, dv$$

D in Mpc (luminosity distance in cosmology) $(1+z) \times D_L$ because it's a line

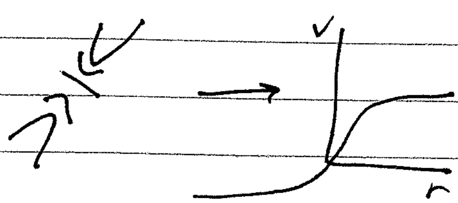
$$M_{\text{atomic gas}} = \frac{1}{X} M_{HI}$$

X: Hydrogen mass fraction

Can measure HI masses accurately to a few % IF care is taken.

HI emission ALSO gives velocity field from Doppler effect – important tracer of the gravitational potential

Fit velocity field with tilted ring model to obtain rotation curve



gravity
Modified inertia