4 Stars notes 2019/08/28 - Wed - Stars in Galaxy; EOS conventions; MESA

4.1 Our stellar environment

Stars in the galactic disk What are the properties of the galactic population? The number density of stars is $n_* \approx 0.05$ pc^{-3}, where pc$= 3 \times 10^{18}$ cm. Breaking this down by mass (roughly)

Mass($M_\odot$)	$\rho(M_\odot/1000pc^3)$
> 6	0.9
2-6	4.0
$0.08 < M < 2$	40
White dwarfs	20

more complete data on local densities in our galaxy (from Allen's astrophysical quantities):

19.9 MASS DENSITY IN THE SOLAR NEIGHBORHOOD [25–32]

Observed volume mass density

Interstellar matter (ISM)	0.04 ± 0.02	$\mathcal{M}_\odot$ pc^{-3}
Main Sequence Stars:		
$0.08 \le \mathcal{M}/\mathcal{M}_\odot < 1.0$	0.036	$\mathcal{M}_\odot$ pc^{-3}
$1.0 \le \mathcal{M}/\mathcal{M}_\odot < 100$	0.014	$\mathcal{M}_\odot$ pc^{-3}
Halo stars	0.0001	$\mathcal{M}_\odot$ pc^{-3}
Evolved stars:		
White dwarfs	0.005	$\mathcal{M}_\odot$ pc^{-3}
Dark extended halo, local density	0.01	$\mathcal{M}_\odot$ pc^{-3}
Total	0.10 ± 0.03	$\mathcal{M}_\odot$ pc^{-3}

Note that $0.01\mathcal{M}_\odot$ pc^{-3} is 0.3 Gev cm^{-3}.

Observed column mass densities, to $|z| = 1.1$ kpc

Neutral ISM	8	$\mathcal{M}_\odot$ pc^{-2}
Ionized ISM	2	$\mathcal{M}_\odot$ pc^{-2}
Molecular ISM	3	$\mathcal{M}_\odot$ pc^{-2}
ISM total	13 ± 3	$\mathcal{M}_\odot$ pc^{-2}
Stars:		
Disk main sequence	30	$\mathcal{M}_\odot$ pc^{-2}
Disk white dwarfs	3	$\mathcal{M}_\odot$ pc^{-2}
Thick disk	2	$\mathcal{M}_\odot$ pc^{-2}
Halo subdwarfs	< 1	$\mathcal{M}_\odot$ pc^{-2}
Stellar total	35 ± 5	$\mathcal{M}_\odot$ pc^{-2}
Observed total	48 ± 8	$\mathcal{M}_\odot$ pc^{-2}
Extended dark halo		
$\lvert z \rvert < 1.1$ kpc	23	$\mathcal{M}_\odot$ pc^{-2}
Total	71 ± 6	$\mathcal{M}_\odot$ pc^{-2}

K dwarfs ($z \lesssim 160$ pc) $\rho_0 = 0.10 \pm 0.03\mathcal{M}_\odot$ pc^{-3}.

All determinations are consistent with each other and with zero local unidentified matter at the $\sim 1.5\,\sigma$ level.

Dynamical analysis of the column mass density, $\mathcal{M}_\odot$ pc^{-2}

K dwarfs ($300 \lesssim z \lesssim 2000$ pc)

$\sum_{\rm tot}(z \le 1.1\ {\rm kpc}) = 71 \pm 6\mathcal{M}_\odot$ pc^{-2},

$\sum_{\rm disk} = 48 \pm 9\mathcal{M}_\odot$ pc^{-2},

$\sum_{\rm dark\ halo} = 23\mathcal{M}_\odot$ pc^{-2},

Unidentified disk dark matter $= 0 \pm 12\mathcal{M}_\odot$ pc^{-2}.

Our view of the galaxy
the stars in the bulge are quite different from the stars in the disk.
Properties of the disk componont (Pop I)

- In the disk, all in nearly circular orbits
- Many Young stars (i.e. recently formed)
- are metal rich (in some sense like the sun) to get a sense of what metal rich means: ratios: $O/H \sim 10^{-3}$, $C/H \simeq 4 \times 10^{-4}$ and $Fe/H \simeq 4 \times 10^{-6}$. All these metals together add up to about 1% by mass.

Properties of the spheroidal (bulge+halo) component (Population II)

- kinematics: small circular orbital motion, i.e. mostly radial orbits.
- Metal Poor (10^{-2} of sun)
- old population (no evidence for star formation). Remnant of something that happened long ago.
- Globular clusters ($\simeq 10^6 M_\odot$) these orbit the galaxy also in a spherical (but bigger) area.

More in Binney an Merrifield on these topics.

4.2 Hydrostatic Balance prep: EOS conventions

Lets investigate atmospheres where $g = \frac{GM}{R^2}$ is constant. Hydrostatic balance is known to be good because, for instance, the sun doesn't change shape on the hydrostatic timescale of about an hour. Taking gravity to be down and then hydrostatic balance is

$$\frac{dP}{dz} = -\rho g$$

where ρ is the matter density (in gram/cubic cm). In stars the matter is generally fully ionized. The pressure has two compnents, from the ions and from the electrons, when both are ideal gasses:

$$P = P_{\rm ion} + P_e = \sum_i n_i kT + n_e kT$$

and then

$$n_i = \frac{X_i \rho}{A m_p}$$

where X_i is defined to be the mass fraction of a species of nucleus. Then the ion pressure is

$$P_{ion} = \frac{kT\rho}{m_p} \sum \frac{X_i}{A_i}$$

so define μ_i such that

$$P_{ion} = \frac{\rho k T}{m_p} \frac{1}{\mu_i}$$

The electron pressure is

$$P_e = n_e k T = \sum Z_i n_i k T = \sum \frac{Z_i X_i}{A_i m_p} \rho k T$$

putting in for n_i

$$P_e = \frac{\rho k T}{m_p} \sum \frac{Z_i X_i}{A_i} = \frac{k T \rho}{m_p} \frac{1}{\mu_e}$$

So that with these terms defined the total pressure is

$$P = P_i + P_e = \frac{\rho k T}{m_p} \left(\frac{1}{\mu_i} + \frac{1}{\mu_e} \right) = \frac{\rho k T}{m_p} \frac{1}{\mu}$$

which defines the mean molecular weight μ.

What is μ for interesting stuff?
metals don't matter.
For the cosmic mix, $X_H = 0.7$ and $X_{He} = 0.3$ we get $\mu = 0.64$. this is for the sun and other main sequence stars.
Since fusion of H→He changes μ (increases) during stellar evalution, the T required to exert the same pressure will change.

4.3 Getting started installing MESA

See links on website