AY 20 Fall 2010

Structure & Morphology of the Milky Way

Reading: Carroll & Ostlie, Chapter 24.1, 24.2

3 populations of stars in our Galaxy

Initially Pop I and Pop II only; kinematically different

- Pop I star velocities relative to Sun much lower than Pop II velocities
- Pop I stars mainly in disk of galaxy; Pop II well away from plane

Later, metallicity differences noted:

- Pop I metal rich, Z up to 0.03 ; Pop II metal poor, Z > 0

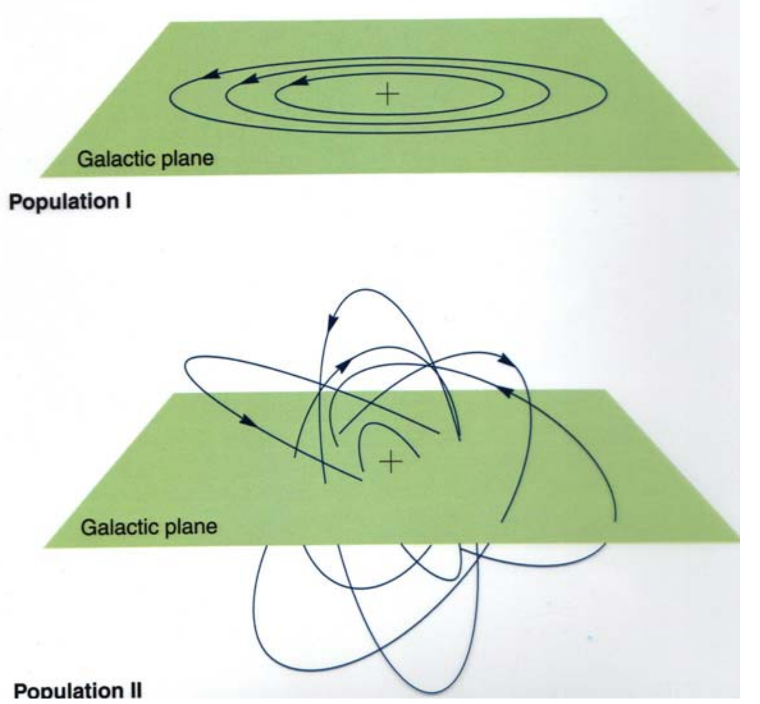
Theorists postulate Pop III:

- PopIII: first stars after Big Bang; no metals Z=0

Open clusters	Globular clusters
loosely bound	gravitationally bound
$T_{evap} \sim 10^8$ yrs	$T_{evap} \sim 10^{11}$ yrs
younger	typically old
metal rich	metal poor
Pop I	Pop II

(galactic clusters)

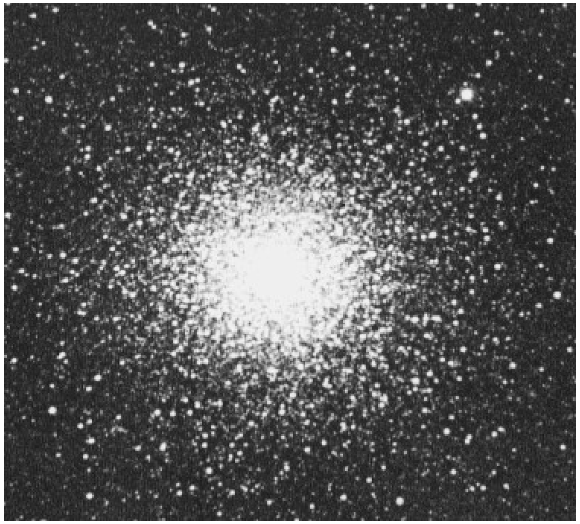
Orbits of disk stars and halo stars

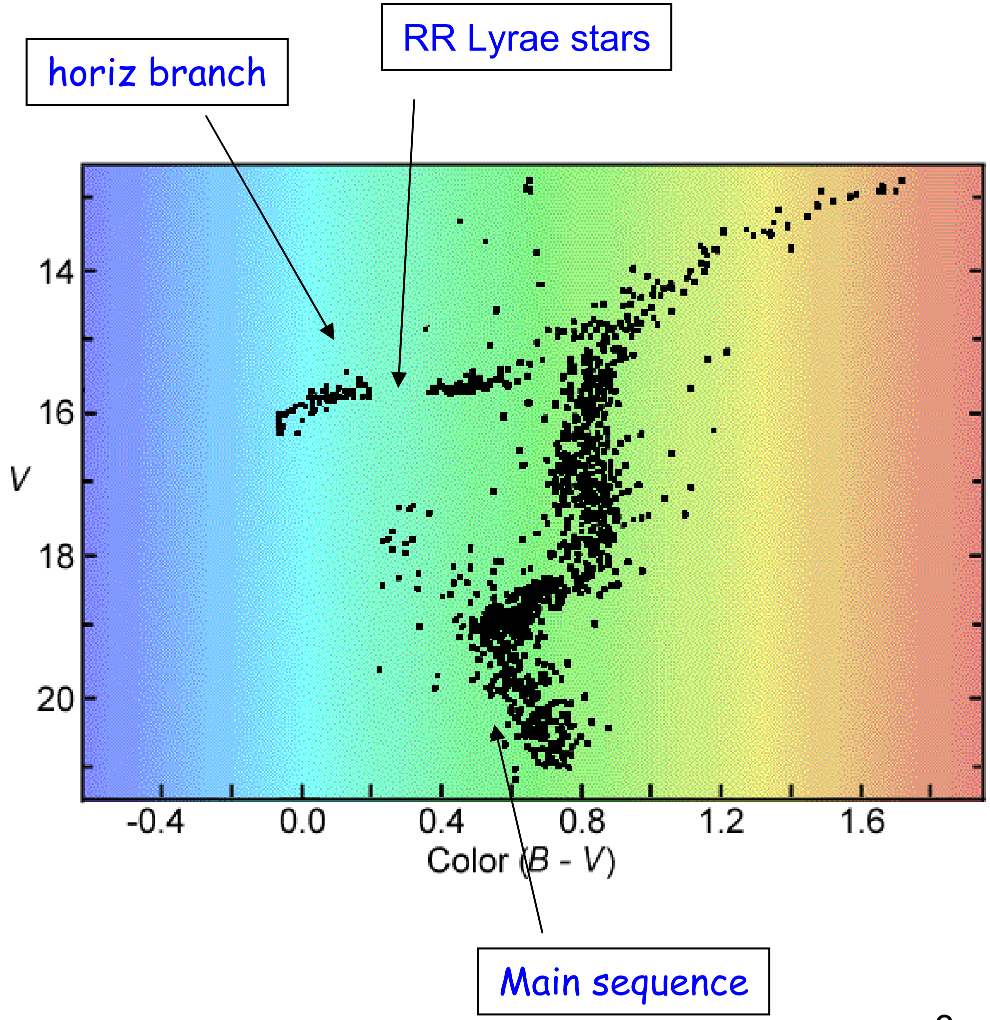


Distance scales from:
main sequence fitting
RR Lyrae variables*
Cepheid variables

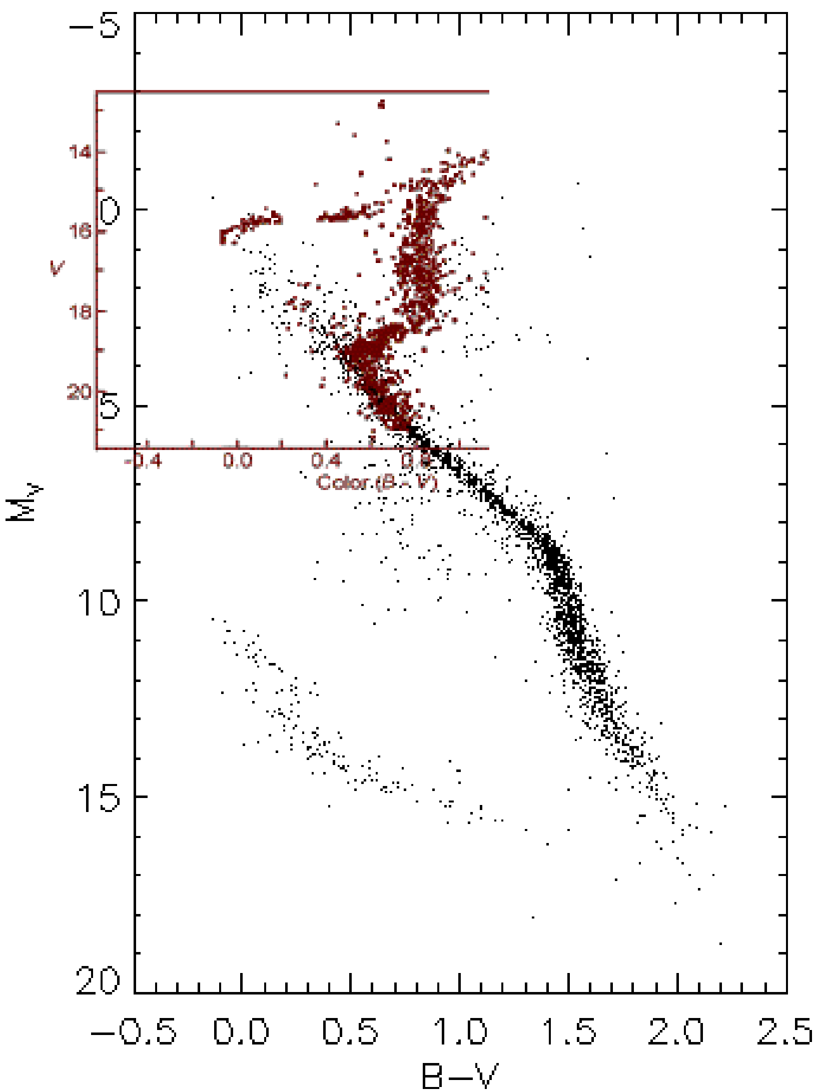
*RR Lyrae stars fainter: use for smaller distance scales than Cepheids

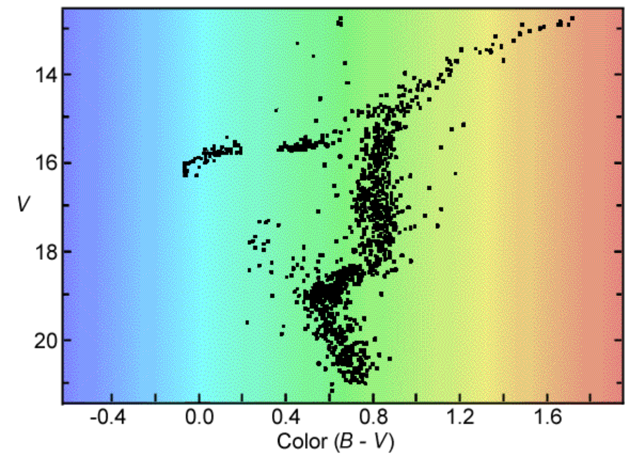
Last class: globular cluster M3 – all RR Lyrae stars on horizontal branch ∴with same $M_V = 0.6 \pm 0.3 \rightarrow d \sim 11kpc$





M3 in Canes Venatici - ~ 0.5 x 10^6 stars; many variables
(RA 13h 44m Dec 28°11^{h})





Age = 2.6 x 10^9 yrs (Sandage)

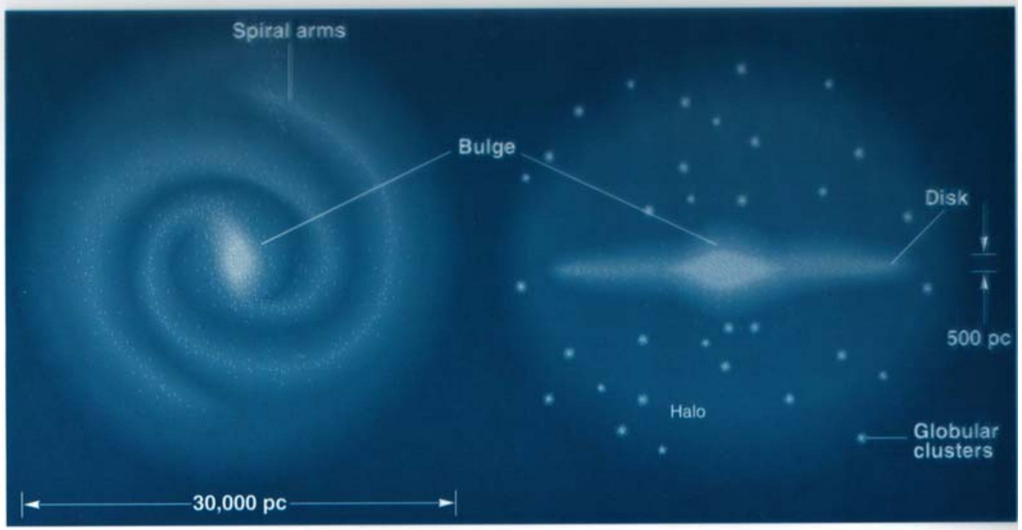
Vertical shift ~ 19 - 3.5 = 15.5 (15.4)

= mv –Mv = 5logd – 5

∴ logd = (15.4 + 5)/5 = 20.4/5 = 4.1

∴ d = 12kpc

Our Galaxy: The Milky Way



Milky Way from band of stars inclined at 60° to celestial equator

Implies galaxy must be a disk

Most stars lie in disk (including Sun)

At the center of the galaxy is a bulge (nuclear bulge)

Halo: a roughly spherical distribution including oldest stars in galaxy – 146 globular clusters 10 – 15 x 10^9 yrs + diffuse, hot, ionized gas

Spiral system containing > 4 x 10^{11} stars

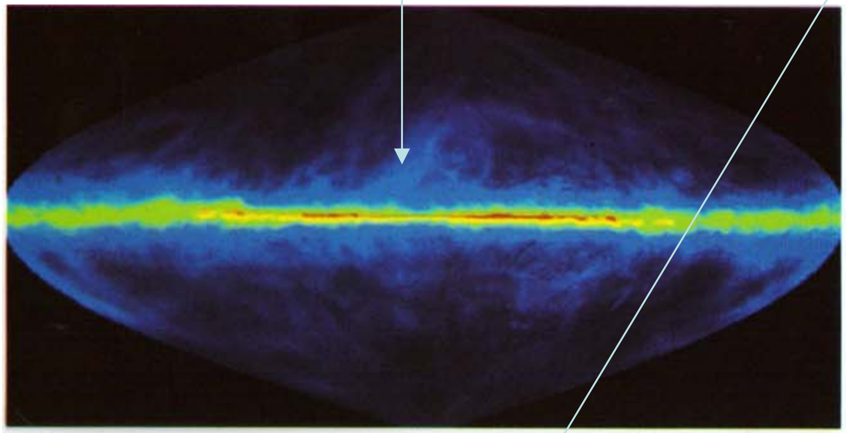
Milky Way Galaxy from southern hemisphere

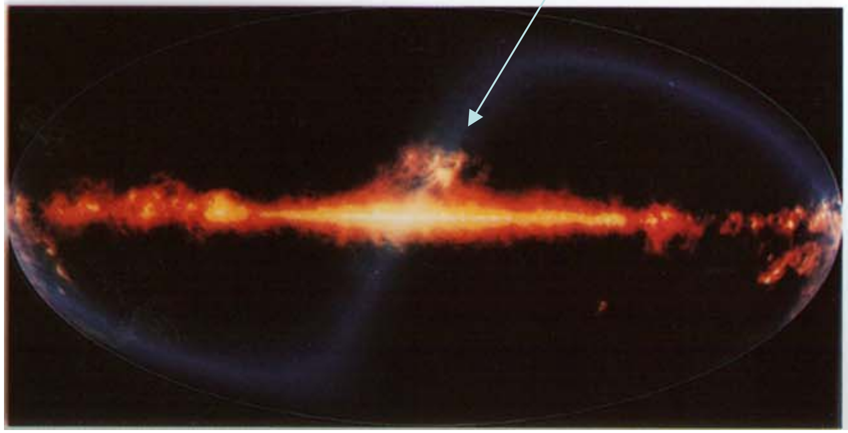
Coalsack, Southern Cross, Jewel Box Cluster

Galactic Center +bulge

Milky Way

Cold Gas (CO/H_2) Warm dust Cool stars





Efforts to determine shape of galaxy began 18th century

Studies based on star counts → "Kapteyn universe" ~1922.

Actually counted "bins" of stars in specific regions. Remarkably careful analysis but assumed (wrongly):

- all stars have same Av
- number density of stars in space is constant
- no extinction (∴no accounting of variation of extinction w. direct^{n})
- could see to edge of distribution

→ flattened spheroidal system, density decreases with increasing distance from center; Sun close to center

in plane of galaxy, number density of stars falls by factor of 2 at 800 pc

- perpendicular to plane falls off by 50% at 150 pc
- number densities at 1% by 8500 pc from center in plane and by 1700 pc perpendicular to plane
- Sun at 650 pc from center, 38 pc north of plane

Also ~1920, Shapley used RR Lyrae and WW Virginis stars to measure distances to globular clusters

Noted many clusters in halo; concentrated toward a center in Sagittarius

Calculated distance of "center": 15 kpc from Sun

Other clusters at distances up to 70 kpc from Sun

→ diameter of Galaxy ~ 100 kpc

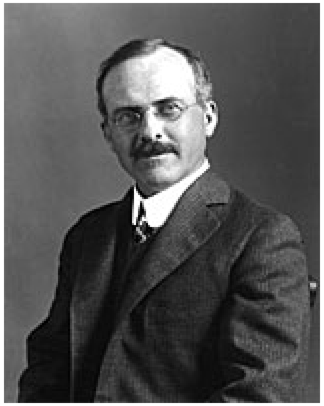
∴ Kapteyn universe too small; Shapley's too big

Kapteyn regions in plane, heavily affected by extinction

Shapley's clusters mostly out of plane, relatively unaffected by extinction but period-luminosity relation for variables in error

For Shapley, MW large enough to 'contain' Andromeda galaxy → NO "island universes" ≡ no external galaxies

1920 – Great Shapley-Curtis Debate



Kapteyn's method not based on getting d for each star

Used integrated star counts

count stars brighter than limiting magnitude m_V in selected regions

Alternate method: differential star counts

count number of stars in specified magnitude range in selected regions

Described in more detail p 878 C& O

Briefly number of stars with magnitudes between M and M+ dM, in a conical volume of space subtended by solid angle Ω and extending to distance d from observer at r= 0 to r=d, is $N_M(M, S, \Omega, d)dM$, where S is e.g.spectral type

$$N_M(M,S,\Omega,d)dM = \left[\int_0^d n_M(M,S,\Omega,r)\Omega r^2 dr\right] dM$$

integrated star count

n_M is number density of stars in cone of side r

Since $m_V = M_V + 5\log d - 5 + A_v$ (adopting $\lambda = V$)

$d = 10^{(m - M - A + 5)/5} = d' \, 10^{-A/5}$; true dist $d > d'$

For stars with same M_V, m_V varies due to d

$\therefore$ replace d by m $\rightarrow N_M(M, S, \Omega, m)\, dM$ (m is limiting magnitude)

$N_M(M, S, \Omega, m)\, dM$ = total number of stars with absolute magnitudes between M and dM that appear brighter than limiting magnitude m

If m is increased slightly, limiting distance increases

$\rightarrow$ larger conical volume and more stars included

Increase in number of stars is $\left[\frac{dN_M(M,S,\Omega,m)}{dm}dm\right]dM$

Defines differential star count: (number of stars with absolute magnitudes between M and M+dM, found in a solid angle Ω, with apparent magnitudes be

$$A_M(M,S,\Omega,m)dMdm \equiv \frac{dN_M(M,S,\Omega,m)}{dm}dMdm$$

Nowadays: CCDs $\rightarrow N_M, A_M$
+ $n_M(S)$ near Sun
+ computer modeling

Models of MW structure from star counts, distance indicators, abundance analyses, comparison with other galaxies – many uncertainties

MW about ~ 50 kpc in diameter, Sun ~in plane of disk at 8 kpc from GC

i.e. galactocentric distance R_0 = 8 kpc (8.5 kpc?)

GC = Sgr A*: α (2000) = $17^h45^m40.0^s$, δ = -29°00′28.1′′

Different components often distinct kinematically as well as morphologically

- galactic clusters, young stars, lower velocities, trace disk
- globular clusters, older, higher velocities, trace halo and bulge
- OB stars (associations) trace spiral structure
- HII regions trace spiral structure
- HI (21 cm line) traces spiral structure
- H_2 (carbon monoxide CO) traces disk
- Dust thermal emission traces disk

Similar structure seen other galaxies –NGC 891

O STARS IN THE MILKY WAY

200 O STARS < 150 IN ASSOC. / 50 FIELD

1450 B0-B2 STARS < 810 IN ASSOC. / 640 FIELD

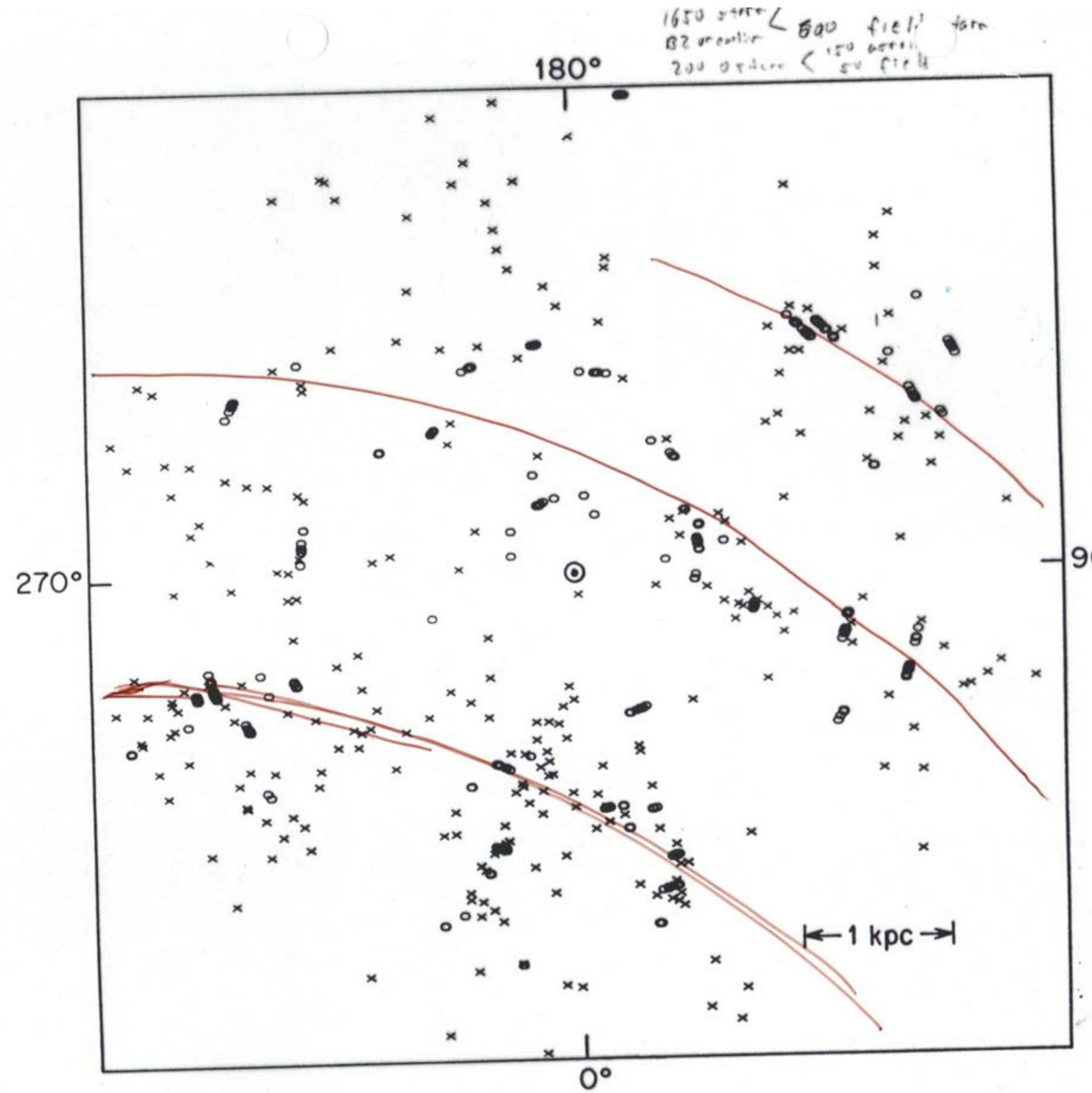


FIG. 2.—O star distribution in the galactic plane of all stars within 3 kpc of the Sun. Open circles = association membe stars

SPIRAL STRUCTURE FROM HII REGIONS' DISTRIBUTION

- ALSO GAS & DUST SIGNPOSTS

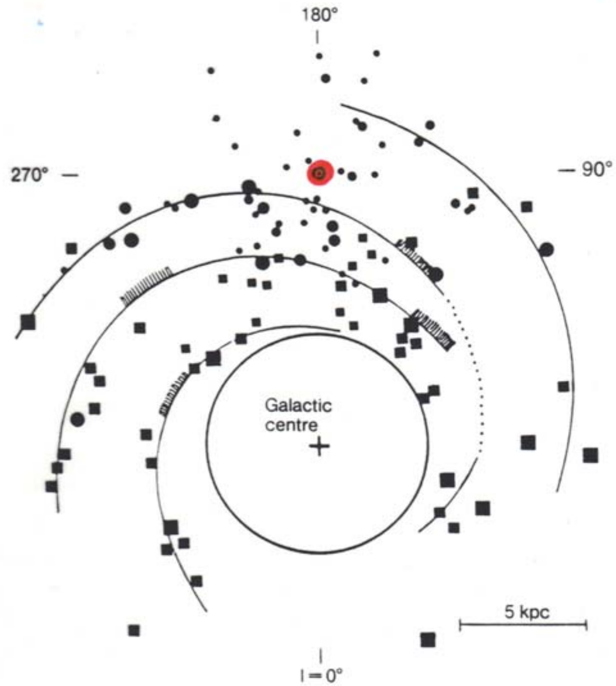


Fig. 18.20 regions ac… and radio … spiral arms

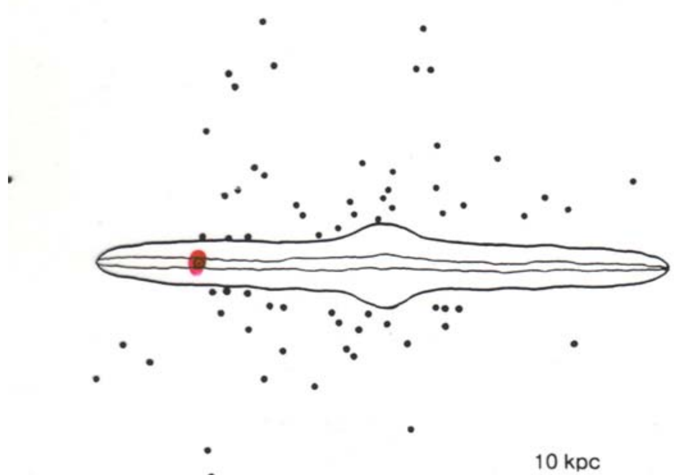
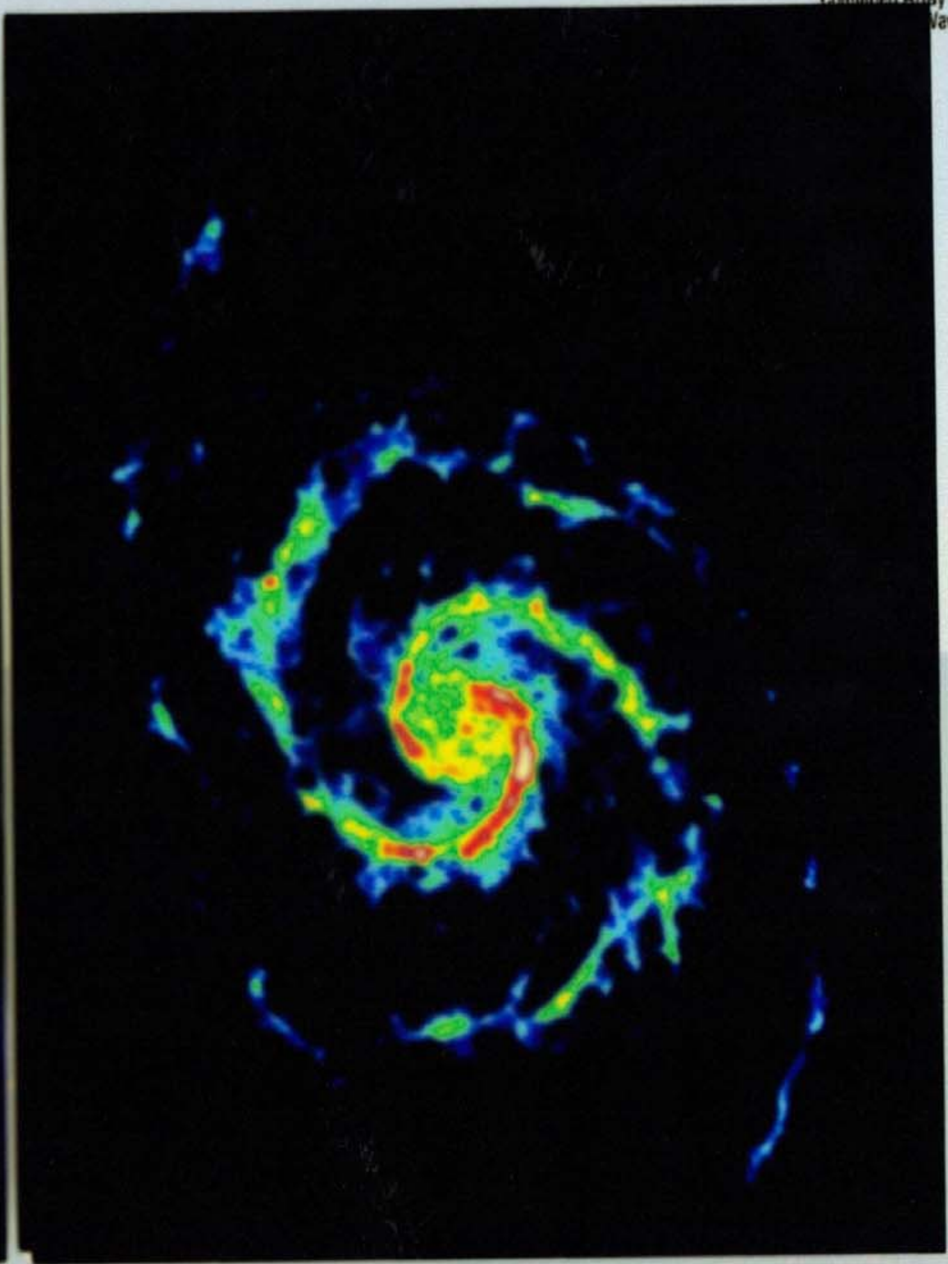
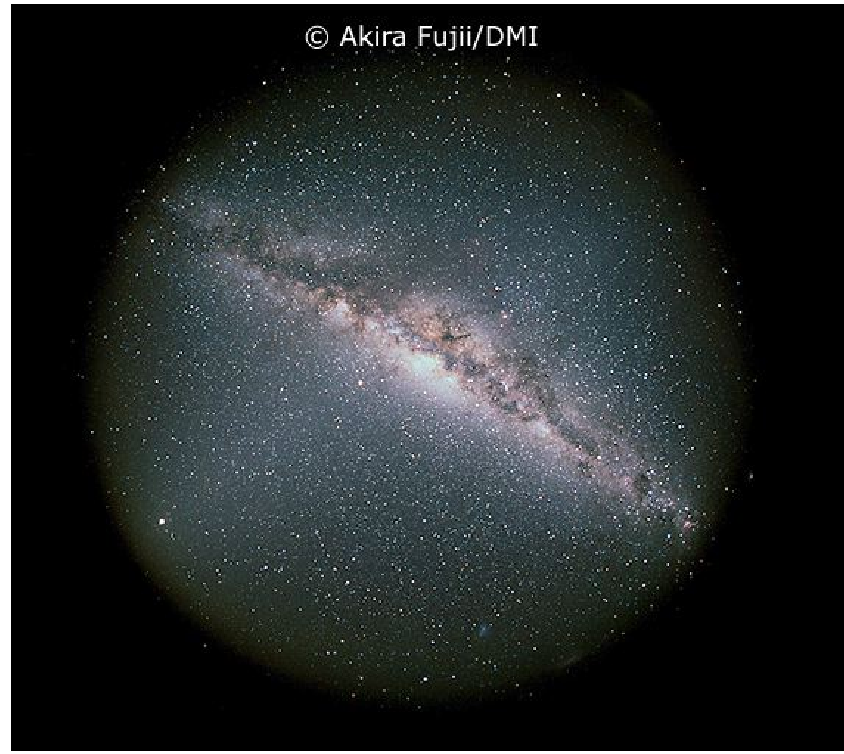


Fig. 18.12. The distribution of globula clusters



NGC 891 Milky Way analog

http://imgsrc.hubblesite.org/hu/db/images/hs-199



Milky Way Galaxy

Thin and Thick disks

"thickness" $\equiv$ vertical scale height

1 scale height = distance over which number density decreases by e⁻

In solar neighborhood, measure distribution of K giants

Young thin disk: age < 10^8 yrs; z < 100 pc; radius ~ 25 kpc

Old thin disk: age < 10^9 yrs; z ~ 350 pc; radius ~ 25 kpc

Thick disk: age < 10^9 yrs; z ~ 1 kpc; radius ~ 25 kpc

Scale height for gas ~ 90 pc (800 pc in outer galaxy)

Star counts + kinematics $\rightarrow M_{thin\ disk} = 6\times10^{10} M_\odot + 0.5\times10^6 M_\odot$

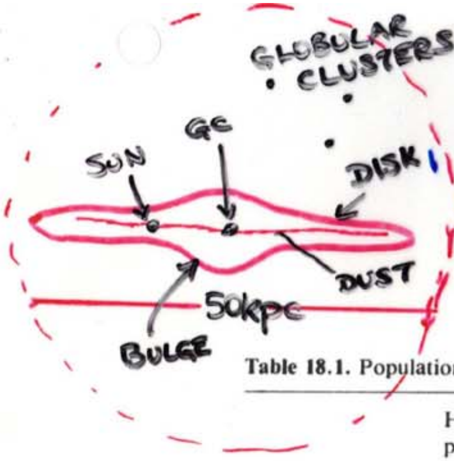
stars gas & dust

and $L_B = 1.8 \times 10^{10} L_\odot$ $\therefore$ mass to light ratio = $3(M_\odot/L_\odot)$

mass-luminosity relat^n for m-s sequence stars $L/L_\odot = (M/M_\odot)$

$\therefore$ $\langle M\rangle = 3^{(1/1-\alpha)} M_\odot$ in Galaxy: for α =4, $\langle M\rangle \sim 0.7\ M_\odot$ in disk

$\rightarrow$ Many dwarf M stars



SHAPE' OF EACH POPULATION DEPENDS ON ORBITAL CHARACHTERISTICS

Table 18.1. Populations of the Milky Way

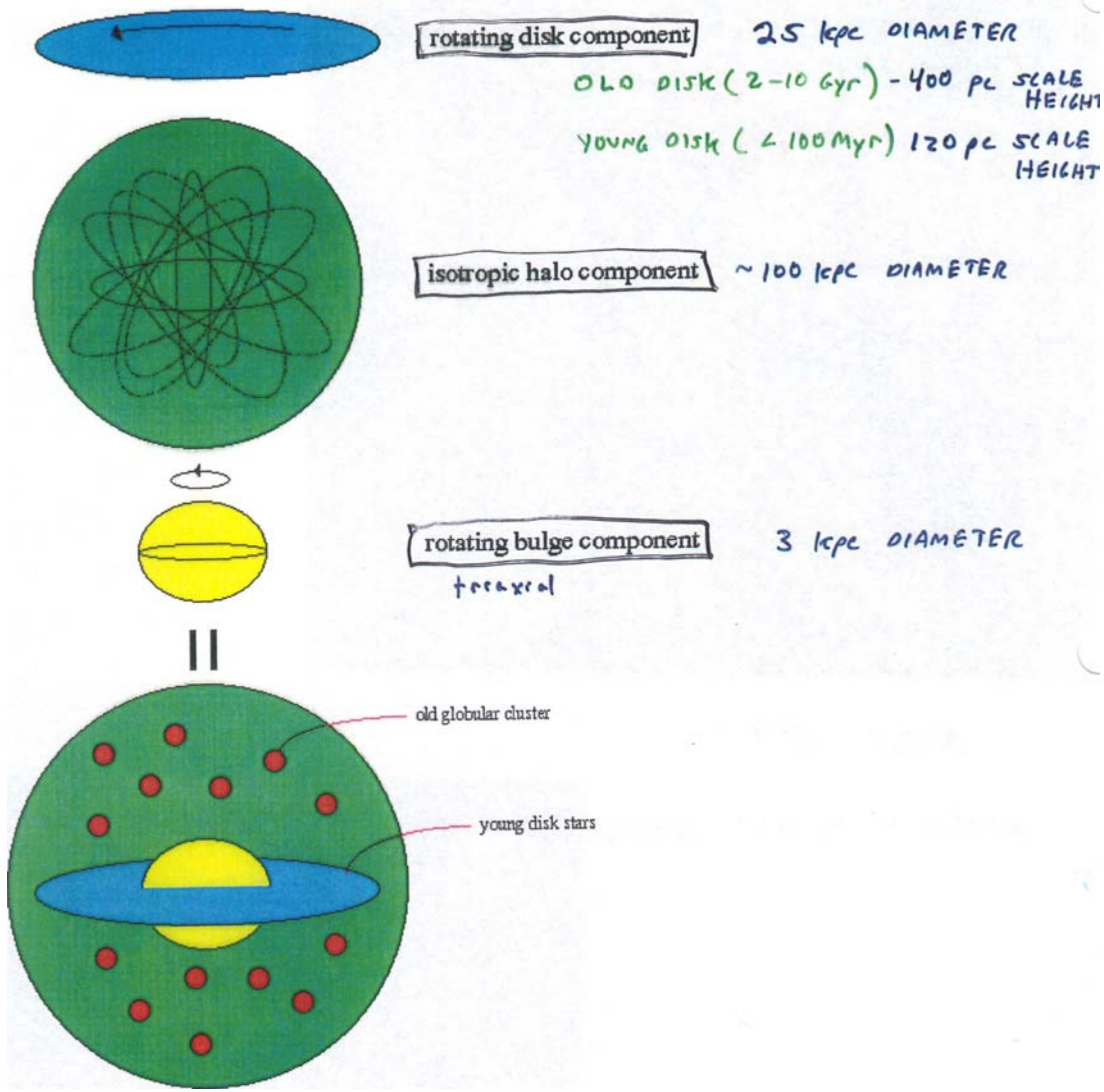
	Halo population II	Intermediate population II	Disc population	Old population I	Young population I
Typical objects	Subdwarfs, globular clusters, RR Lyr ($P>0.4$d)	Long period variables	Planetary nebulae, novae, bright red giants	A stars, Me dwarfs, classical cepheids	Gas, dust, supergiants, T Tau stars
Average age [10^9 y]	17 – 12	15 – 10	12 – 2	2 – 0.1	0.1
Distance from galactic plane [pc]	2000	700	400	160	120
Vertical velocity [km/s]	75	25	18	10	8
Metal abundance	0.001	0.005	0.01 – 0.02	0.02	0.03 – 0.04

$V_{circ} \gg V_{random}$ IN DISK, STARS, GAS, DUST IN ~ CIRCULAR ORBITS ABOUT GC

BULGE: CIRCULAR SPEEDS SMALL, RANDOM MOTIONS → 'SPHERE'

$V_{random} \gg V_{circ}$ HALO: LARGE RANDOM VELOCITIES [LESS BOUND]

SUN AT ~8 kpc, 30 pc ABOVE PLANE


rotating disk component
25 kpc DIAMETER
OLD DISK (2-10 Gyr) - 400 pc SCALE HEIGHT
YOUNG DISK (< 100 Myr) 120 pc SCALE HEIGHT
isotropic halo component
~100 kpc DIAMETER
rotating bulge component
triaxial
3 kpc DIAMETER
old globular cluster
young disk stars